

**Bodies of Information:**

**Reinventing Bodies and Practice in Medical Education**

Rachel Prentice  
A.B., Comparative Literature, Columbia University  
New York, New York, 1987

Submitted to the Program in Science, Technology, and Society in Partial Fulfillment of  
the requirements for the Degree of

Doctor of Philosophy  
In this History and Social Studies of Science and Technology  
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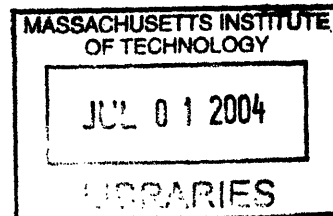
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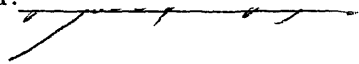
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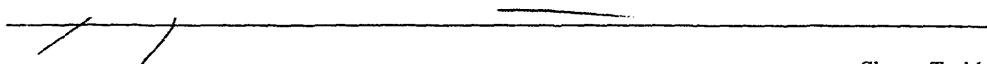
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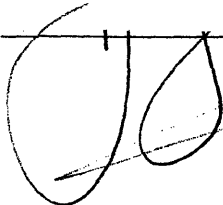
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**Bodies of Information:  
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By

Rachel Prentice

Submitted to the Department of Science, Technology and Society in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Science, Technology and Society

**ABSTRACT**

This dissertation recounts the development of graphic models of human bodies and virtual reality simulators for teaching anatomy and surgery to medical students, residents, and physicians. It considers how researchers from disciplinary cultures in medicine, engineering, and computer programming come together to build these technologies, bringing with them values and assumptions about bodies from each of their disciplines, values and assumptions that must be negotiated and that often are made material and embedded in these new technologies. It discusses how the technological objects being created privilege the body as a dynamic and interactive system, in contrast to the description and taxonomic body of traditional anatomy and medicine. It describes the ways that these technologies create new sensory means of knowing bodies. And it discusses the larger cultural values that these technologies reify or challenge.

The methodology of this dissertation is ethnography. I consider in-depth one laboratory at a major medical school, as well as other laboratories and researchers in the field of virtual medicine. I study actors in the emerging field of virtual medicine as they work in laboratories, at conferences, and in collaborations with one another. I consider the social formations that are developing with this new discipline. Methods include participant-observation of laboratory activities, teaching, surgery, and conferences and extensive, in-depth interviewing of actors in the field.

I draw on the literatures in the anthropology of science, technology, and medicine, the sociology of science, technology, and medicine, and the history of science and technology to argue that “bodies of information” are part of a bio-engineering revolution that is making human bodies more easily viewed and manipulated. Science studies theorists have revealed the constructed, situated, and contingent nature of technoscientific communities and the objects they work with. They also have discussed how technoscientific objects help create their subjects and vice versa. This dissertation considers these phenomena within the arena of virtual medicine to intervene in debates about the body, about simulation, and about scientific cultures.

Thesis supervisor: Sherry Turkle

Title: Professor of the Social Studies of Science and Technology

## **Biographical note**

Rachel Prentice obtained a Bachelor of Arts (A.B.) degree in Comparative Literature (with extensive coursework in biology) from Columbia College, Columbia University, New York, New York, in 1987. She was awarded a Hugh Hampton Young Fellowship (MIT) in 2003. She was a Jacob K. Javits Fellow (U.S. Department of Education) from 1998 to 2002. And she was awarded the Ida Green Fellowship for female graduate students (MIT) in 1997. She has received the Siegel Prize for best paper on an STS topic for “Calculating Women, Calculating Machines: The Rise of Scientific and Technical Computation in England, 1920-1945” (1998). Her publications include “The Anatomy of a Surgical Simulation: The mutual articulation of bodies in and through the machine” (*Social Studies of Science*, forthcoming) and *Your Child in the Hospital: A practical guide of parents* (O’Reilly, 1997). She has worked as a newspaper reporter for ten years and has authored thousands of newspaper and magazine articles. At MIT, she has taught an undergraduate seminar, “From Surgery to Simulation,” a course on medical technologies, and she has been a teaching assistant for “Drugs, Politics, and Culture.”

## Acknowledgments

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The Stanford University Medical Media and Information Technologies laboratory was my home from November 2001 through August 2002. Without the wisdom, patient teaching, and enthusiasm of all laboratory members, this dissertation would not exist in this form. The group at SUMMIT not only shared their lives with me, but also provided an extraordinarily rich and diverse model of researcher collaboration. My work and my life are profoundly enriched for knowing and working with this extraordinary group of people. I also thank researchers in other laboratories at the University of Washington and elsewhere who shared their work in the field of virtual reality in medicine with me. My encounters with these researchers were often brief, but highly informative.

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**Introduction:**  
**Medicine, information technology and embodied practice**

On a hot August day in Palo Alto, sun streams into a small room filled with computers, making the air hot and close. Three visitors to a laboratory that builds simulations, applications, and computer archives for medical education play with demonstrations of computer programs. An Australian psychiatrist has come to the laboratory in Stanford's University's School of Medicine to inspect new technologies for teaching medical students. His university has abandoned a traditional anatomy teaching program that included memorization of body parts and cadaver dissection in favor of increases in clinical problem solving and demonstrations with pre-dissected materials, models made from polymerized tissues, and computer applications.<sup>1</sup> He tries an application that asks him to probe a virtual body part he cannot see. He holds a pen-like stylus suspended on a robot arm. Feedback built into the simulation signals the stylus, which behaves as though it touches the body part, allowing the psychiatrist to experience the feel of exploring its boundaries, its geometry, and its hardness, even though the body exists only in virtual space. He cannot identify the body part. A gynecologist, who is demonstrating the program, reaches for the mouse and, a few clicks later, reveals a shape on the screen that resembles a craggy mountain peak. "That's an engineer's idea of a breast," he jokes. The conical object looks vaguely like a woman's breast, but is the color

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<sup>1</sup> The process of turning tissue into polymerized models is called "plastination." Plastination was invented by a physician from the former East Germany named Gunther Von Hagens and involves the replacement of human fat and water with polymers. The process leaves tissues hard and semi-permanent, but almost unchanged in appearance. Von Hagens has created anatomical "sculptures," including such displays as a flayed rider on a flayed horse, which have been controversially displayed in Europe and Japan (Grice 2001 40). Efforts to show plastinated bodies—even with a more clinical focus—to public viewers in the United States have failed due to controversy (Roach 2000; Donnelly 2001).



of dirty snow, and has facets rather than contours. The breast is part of a game called “I feel it,” designed to enable users to experience the physical sensations of probing a solid object when they probe a virtual object. The psychiatrist replies, “It’s not like any breast I ever felt.”

This moment came during my first visit to the Stanford laboratory in 2001, while I was starting dissertation fieldwork in laboratories where physicians, engineers, and computer scientists build computer simulations and related technologies for teaching anatomy and surgery. These technologies include graphic models of bodies, simulators that incorporate these graphic models, and some underlying computational structures. The virtual breast story touches on four themes of this dissertation: First, a group of engineers and programmers built the breast model as a demonstration for use in a laboratory where engineers, programmers, and physicians build virtual bodies. The senior physician mocks the engineer’s representation of the breast, as though physicians know breasts and engineers do not. The comment plays on stereotypes of engineers as male nerds, who know machines, contrasting them to doctors, who know bodies.<sup>2</sup> These stereotypes suggest that physicians and engineers have different ideas about machines and bodies that come into play when they build these teaching technologies. This dissertation focuses on how researchers from different epistemic cultures (Knorr Cetina) collaborate to invent virtual bodies and to build computer technologies for working with them. I explore how virtual bodies reflect the values of the epistemic cultures that build them. The interdisciplinary nature of these groups, which are composed primarily of

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<sup>2</sup> Although the joke does not specify the biological sex of the engineer in question, it relies on the way engineering is gendered as masculine (or sometimes emasculated).

engineers, computer scientists, and physicians, make this an exceptionally rich location for studying the values and assumptions about bodies that technology researchers build into their creations. New social formations are developing around the construction of virtual bodies.

Second, the virtual breast is a new creation in cyberspace, a new kind of body. It does not quite resemble—in look or feel—an actual breast. The breast is a digital model that exists only in virtual space, but it can be probed as though it had material substance. It privileges the user's ability to interact with it—to prod it and have it respond more or less as though it were made of flesh. Unlike cadavers and traditional anatomical models and drawings, virtual models of bodies treat bodies as dynamic systems whose movements and interactions can be resolved into their component forces. Further, although cadaver dissection is unquestionably interactive, dissection is a one-way journey from intact body to barely recognizable parts: dissectors cannot go back if they make a mistake. Computer models allow users to take bodies apart, put them back together, and explore them from atypical angles. And virtual bodies are constructed to inhabit virtual space-time: they are engineered for computers. In these virtual spaces, medicine's messy biological body must be reconciled with the mathematical body of computer science and the mechanical and mathematical body of engineering to create a "hybrid" body developed for use by researchers, users, and computers. New representations are emerging with these technologies.

Third, the "I feel it" game introduces users to haptic devices, such as the suspended stylus, that allow users to probe virtual flesh as if it were solid flesh. The research area developing around tactile and kinesthetic interfaces is known as "haptics."

The psychiatrist's inability to identify the breast can be read either as a story of inadequate technology or, more interestingly, as a story about the sensory means of knowing bodies. The psychiatrist probably has never probed a cyberbreast with a device resembling a pen. Researchers building haptically enabled graphic models, including the breast model, anticipate a future world of medicine in which more training, diagnosis, and treatment occur using remote instruments and networked computers. These technologies separate a doctor's body from hands-on experience of a patient's body. With the addition of medical images, they also create new means of peering into bodies. These reconfigurations of bodies and instruments alter bodies' time, space, and opacity in practice in ways that change and challenge existing objects, practices, and social formations in anatomical and surgical teaching. These technologies are influencing medical practice and perception.

Fourth, the breast is part of a traditional physical exam: palpation for a lump. The breast also is a highly sexualized part of the female body. The jokes rely on the gendered, sexualized, and private nature of the breast. Breasts in Anglo-American culture are usually hidden from view. Men typically encounter women's breasts in medical or sexual settings. The psychiatrist's comment relies for its humor on the two possible situations in which he has felt breasts, as does the gynecologist's suggestion that engineers lack experience with breasts. The gynecologist's comment also relies on the uncanny nature of this breast: it is simultaneously like and unlike a real breast. The jokes play on cultural taboos about breasts and suggest that the computer screen ambivalently invokes

professional ideals of clinical detachment.<sup>3</sup> These bodies are presented clinically, but are outside clinical spaces, such as examination rooms, surgical suites, or anatomy laboratories. These technologies can reinforce or challenge cultural values about bodies, including values about whose bodies can be viewed, probed, or dissected.

“Bodies of information” is my term for bodies created in and for virtual worlds. The term describes bodies transformed into digital information. It also identifies bodies intended to inform medical education and clinical practice, bodies that help create a doctor’s medically informed body. And, slightly altered, the term marks bodies that are in formation, that is, bodies that are digital experimental subjects that promote new practices and meanings of bodies. The significance of bodies of information, I argue, is that they are part of a “bio-engineering revolution” that is leading towards new methods to represent and manipulate bodies. Anthropologist Paul Rabinow describes the ultimate purpose of genetic engineering research as manipulation: “Representing and intervening, knowledge and power, understanding and reform, are built in, from the start, as simultaneous goals and means” (Rabinow 1992 236). So, too, with graphic models and the simulation technologies deriving from them: researchers want to create models that will allow users to view and manipulate the human body more easily. These models and simulations are both material (in the sense that they act in the world like material objects) and semiotic. Their functional uses and their meanings within broader scientific and cultural discourse are important strands to tease apart in an ethnographic study (Haraway

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<sup>3</sup> Physicians in clinical settings, where a comment be inappropriate, sometimes wrestle internally to maintain clinical detachment when a patient arouses them sexually (Konner 1988).

1991). Bodies of information, are silicon bodies designed to allow medical students to manipulate bodies in new ways. They are objects for practicing upon bodies and powerful “objects to think with” (Turkle 1995, 47) that encourage new ways of thinking and talking about bodies in medicine. Their promise is to teach medical students new skills or to become a means of virtual practice to prepare a surgeon for a real procedure. They also suggest a change in the medical imaginary of bodies: These representations of bodies, which are intended to teach future doctors, are dynamic and manipulable, suggesting that exploring and exploiting these qualities of bodies will be a direction for future research.

### **Bodies on the screen**

Virtual reality in medicine emerged as a field in the late 1980s, with research into the uses of virtual reality for surgical planning, for teaching anatomy and surgery, and for medicine’s imagined digital future (Satava 1995). In the preceding decades, modeling, medical imaging, and surgical technologies that put bodies on-screen encouraged researchers to explore new technologies for visualizing and intervening in bodies. Minimally invasive surgery and interventional radiology moved the site of medical intervention onto a video monitor and encouraged researchers to imagine other technologies that would put anatomy and surgery on the screen (Satava 1995). The field is developing overlapping applications with several purposes: building graphic models of human anatomy, building interface devices and software for manipulating graphic models, and building simulators based on these modeling and manipulation tools. Many of these technologies are being designed for medical education and surgical planning. Researchers in the field also imagine that these models, tools, and simulators will one day use medical imaging data from actual patients to create models that allow physicians to

peer inside or to practice upon the virtually reconstructed patient before making a first cut on a real patient. Physicians in specialties from dermatology to cardiology now make diagnoses using the internet and other remote information-collecting devices. This trend is leading researchers into robotic surgery and other means of probing and operating upon bodies at a distance using remote tools. Some of these tools will create complex kinesthetic and tactile relationships across networked spaces.

These technologies are developing against a backdrop of profound changes in medical education and practice that have been occurring since the 1980s. Researchers in medical schools have looked to combinations of computers and medical images to teach medical students in a classroom and clinical environment in which teaching is being cut or neglected at the same time that the skills needed have become more difficult to acquire. Four trends have encouraged this computational turn in medical teaching. First, since the 1980s, academic medical centers have increasingly competed with private centers for insurer dollars. The accounting and industrial languages of efficiency and “throughput” have become deeply embedded in hospital decision-making (Ludmerer 1999). Health maintenance organizations and others have little interest in funding medical education and At some schools, including Stanford, medical students at times have been allowed only to observe instead of practice because time-strapped physicians cannot give students opportunities for hands-on learning. This decrease in time available for teaching has led some physicians to build simulators that might teach students skills outside clinical spaces, ideally giving students more practice and freeing clinicians’ time. Second, the past two decades have brought many efforts, more and less radical, to do more clinical training earlier in the medical school curriculum. These efforts go by many

names and involve many changes. Anatomy teaching has been among departments most affected. Changes range from increases in clinical problem-solving in anatomy courses to the addition of clinical encounters correlated to anatomy lectures (Behrs, Chase et al. 1986; Thomas J. Collins 1994). Many changes in anatomy teaching have included a decrease in time spent dissecting cadavers. Some anatomists have considered computers to supplement dissection and to teach concepts that are more easily understood using animations than traditional texts and images. Third, many studies, especially in the past five years, have revealed the significant numbers of patient deaths caused by medical errors (Kohn, Corrigan et al. 2000). Further studies have shown that practice and repetition by clinicians, especially surgeons, improves outcomes (Mishra 2003). Many simulator makers want to promote simulated practice as a means of reducing errors. Fourth, the advent of minimally invasive surgical procedures in the late 1970s led to improved outcomes and shorter hospital stays. Because these technologies have financial benefits for insurers and hospitals, and therapeutic benefits for patients, there has been a push to increase the number of procedures that can be performed “on the screen.” But minimally invasive surgeries require more training than traditional open procedures. Medical educators are using mannequins and cadavers to teach these skills. The makers of surgical simulators argue that a virtual teaching tool could provide more feedback to the user, would allow more repetitions on more cases of anatomical variation, and would cost less than teaching with cadavers. Most of these technologies are still experimental, however, and exactly how they will be implemented into medical curricula and resident training programs remains an open and important question.

## **Medical perception, embodiment and education**

This dissertation draws from anthropological studies on embodiment and culture, anthropological and sociological explorations of medicine, and science studies work on epistemologies and technologies. Anthropological literatures on embodiment, perception, and medical education provide a useful starting point for considering the cultural context that shapes and is shaped by medical technologies. Throughout this dissertation, I treat medicine and engineering as different but overlapping scientific cultures. Social scientists, particularly anthropologists, have utilized and debated the concept of “culture” as an organizing principle for social groups (Geertz 1973, 89). Ethnography can open up cultural concepts that become naturalized and, thus, invisible to actors within a group (Gusterson 1996, 1). Anthropologists and sociologists of science and technology have shown how scientific and technological research communities are bounded by “common sense” cultural assumptions about and interpretations of the world (Traweek 1988; Gusterson 1996; Knorr Cetina 2000; Forsythe 2001). I consider culture to be a group’s assumptions, interpretations, and values, which often are taken for granted. These assumptions and interpretations are reflected in the symbols, concepts, and practices of a particular group. Culture also is embodied within members of a group; bodily behaviors and embodied ways of knowing are culturally inflected (Bourdieu 1977; Csordas 1990). Culture shapes and is shaped by what we make, what and how we know, and what we perceive in the world.

I begin from the argument that medical education and practice structure the physician’s body and subjectivity. They also structure the patient’s body in relation to the physician’s body. Biomedical ways of knowing and shaping bodies have developed and



changed over centuries of medical practice. And they are cultural. For example, French physicians begin their medical education by studying the signs of disease, whereas North American schools tend to emphasize a rigorous connection between biology and pathology (Good 1994, 71). Medical knowing is the creation of a doctor's body—and later, a surgeon's, radiologist's, or internist's body—that constructs, interacts with, and treats its objects following particular practices shaped by medical culture. During years of medical school, internships, and residency, the student's body becomes a medically informed body,

Medical culture is ingrained in bodies and known through bodies. This argument builds on Pierre Bourdieu's (1977) grounding of culture in the "socially informed body," which generates and structures all practices (124). He argues that cultural practices are largely "regulated improvisation" (11), postures that are embedded in agents' bodies as schemes of perception and thought that are incorporated into members of the group. Bourdieu calls these schemes, "the dispositions of the habitus" (17). The habitus, a term Bourdieu borrows from Marcel Mauss and expands upon, is the unconscious embodiment of modes of thought and action that guide and shape cultural actions, choices, and taste. The habitus is, thus, an unconscious means of producing and reproducing cultural behavior through embodied action. Objects are both produced by the cultural dispositions of the habitus and reinforcing of them. Not all practices are guided by the habitus: a tension always exists between unconscious practice and codified rules. And symbolic stimuli act only when they encounter agents conditioned to perceive them. Particularly important for Bourdieu is the notion that practice contains more than practitioners know: that is, practice, as embodied cultural history, contains an excess of meaning that the

subject remains unaware of (79). I argue that medical students enter a culture of medicine (with a number of subcultures, such as surgery) that constitutes and is constituted by embodied practice. A medical student's body becomes a medically informed body through explicit lessons—rules—and tacit social and bodily training.

Embodied practice within medical culture shapes the medical student's concept of self as an instrument of medical perception and of patients' bodies as the objects of medical knowing. Thomas J. Csordas (1990) argues that using embodiment as a starting point for the analysis of culture allows anthropologists to consider "how cultural objects (including selves) are constituted or objectified" (40). Csordas begins from the argument that the body is the "existential ground of culture" (5) and that a paradigm of embodiment provides a useful methodological perspective for analyzing culture and self in anthropology. He argues that perception can never be the unfiltered reception of complete information about the world. Instead, culture produces and filters perceptual experience, including what counts as an object and what counts as self.

Medical school experiences, particularly anatomy classes and clinical training, are an induction into a new world that constructs the doctor's self and the patient's personhood. Byron Good (1994) argues that medical training shapes a student's ways of seeing, speaking about, and writing about patients, bodies, and pathologies. Good locates the beginnings of the construction of the medical way of seeing in the ritual space of the anatomy laboratory, which students experience as space apart from everyday reality, and in which the "human body is given a new meaning, and a new manner of interacting with the body is appropriate" (72). Within this space, Good writes, students learn new ways of defining the body's interior—it becomes organs, muscles, and other structures, instead of

emotion, thought, or personhood. And students begin to learn anatomical thinking, imagining the body's complex, three-dimensional structures and their relationships. This experience shapes the student's vision. Further constructions of the patient and the patient's body and pathology occur as students learn to write up and present case histories, which set biomedical boundaries around what counts as relevant to the case. Good locates most of this shaping of a doctor's knowledge of patients' bodies and disease in visual and discursive ways of knowing. I consider how touch and technologically mediated practice also shape doctors' and patients' bodies in this medical educational world, particularly in anatomy laboratories and operating rooms.

The social and the technical lessons of medical education, particularly in gross anatomy and surgery work together to create the physician's medically informed body. Mary-Jo Delvecchio Good (1995) looks at how young physicians develop a sense of "competence." She writes that medical students are surprised when they enter their third-year clerkships that the knowledge they have acquired and will rapidly add to during early clinical training is less important than social skill and team orientation in developing competence. Competence develops initially through presentations of the self, as clerks and interns learn to present cases effectively and persuasively. It also develops through the student's ability to discern and adopt the correct subject position regarding those further along in the medical hierarchy: eagerness and the appropriate mix of deference and questioning are important. Later, students learn ways to challenge the system and find that the boundaries of their own knowledge and experience often will be pushed. I argue that technical lessons themselves can reinforce the social lessons of medical culture, and that the social lessons lay the groundwork for their own technical

reproduction. That is, the social and technical lessons of medical culture mutually constitute and reinforce each other.

Scholars of medicine have shown how powerfully cultural, spatial, and technological forces interact to shape medical perception. Michel Foucault (1973) demonstrates how changes in the social spaces of diseased bodies—the collection of patients in hospitals—transformed the relationship between disease and the body in the late eighteenth century (see Knorr Cetina 2000). He reveals how, in the late eighteenth century, changes in medical spaces and institutional structures altered the medical “gaze”—the combined senses of sight, touch, and hearing. In the classical age, physicians began to see diseases less as objects within an abstract taxonomy and more as variations of symptoms localized in the body’s opaque volumes. The development of the clinic was, first, a change in the spatial organization of bodies. The clinic collected patients, pathologies and physicians in one place, giving physicians the opportunity to observe many instantiations of the same disease in different bodies at many stages of the patient’s and the disease’s life cycle (Foucault 1973; Foucault 1977). Pathological anatomy also developed with the rise of the clinic. Earlier, Foucault argues, the development of anatomical correlations to exterior symptoms was hindered by the distance from site of death to the laboratory, a distance that made the pathologies of disease and the decomposition of death difficult to distinguish. But when patients began dying in clinics, where they could quickly be transported to the laboratory, physicians were able to “open up a few corpses” (Xavier Bichat in Foucault 1973, 146) and begin to relate the symptoms they saw, felt, and heard on the surfaces of living bodies with pathologies seen at autopsy. The development of a medical “gaze” brought the senses of vision, hearing,

and touch to bear on pathology in living patients. These epistemic changes, though part of larger cultural and political movements, represented changes in hospital spaces. They also are changes in the body's time and opacity.

Other historical and cultural analyses have shown how technologies also are among the factors contributing to and flowing from epistemic change in medicine. Technologies for visualizing the body's interior, for example, were part of a movement toward a more visual medicine that began with pathological anatomy in the late eighteenth century (Foucault, Reiser, Howell). The trend toward increasingly visual representations and models of bodies continues with late twentieth century imaging techniques (Kevles, Dumit). New technologies are sites of knowledge and power that materially and metaphorically interact with the observer's (in this case, the physician's) body within an "irreducibly heterogeneous system of discursive, social, technological, and institutional values" (Crary 1990 5). The medical technologies I describe in this dissertation contribute to shifts in the relation of the clinician to the patient-body's time through the development of body models that allow physicians to practice a procedure, reset the model, and repeat a procedure to perfection, making the body's time reversible. They change the relation of the doctor to the body's space through techniques that allow remote examination and manipulation of bodies and, seemingly paradoxically, bring the physician's eyes further into the patient's body while allowing the physician to work at a greater distance from the patient's body. And they alter the relation of the physician to the patient-body's opacity by generating new ways to view the body's interior, particularly through the creation of three-dimensional models or technologies that allow medical images to be superimposed on the patient's body.

## **Medical technologies, practices, and knowing**

Science studies scholars have brought into sharp focus the socially constructed nature of technoscientific objects and, more recently, have argued for objects' reciprocal construction of ways of knowing. Stefan Hirschauer (1991) examines in thick, ethnographic detail how surgeons sculpt bodies to resemble anatomical models to see what they are working on. The interplay between scientific object and natural body—the creation of a temporary scientific object within the patient's body—is critical to surgical skill. This allows the surgeon to see the body's messy interior and constructs the surgical site as an anatomical model, a move that makes surgical action socially acceptable. He describes surgery as an antagonistic process, in which the patient's subjectivity is progressively withdrawn from his or her body. The patient's interests then become represented by machines that monitor life-signs and an anesthesiologist, who monitors the machines and the patient. Hirschauer says the preparation of the patient's body allows for a “gestalt switch” (287) of the patient from person to object (see Young 1997). Drapes promote sterility and visually fragment the patient's body. Thus, anesthesiologists, who occupy themselves with the patient as a breathing human being, and surgeons, who concentrate upon the operating site, have very different views of the body (Lock 2002). This preparation allows for a “functional extension” (Hirschauer 1991, 290) of the surgeon's body into the patient's body. Hirschauer describes the disciplining of surgeons' bodies when they scrub and don masks and gowns in preparation for surgery. All these preparations, he argues, eliminate the social stigma of cutting into the body, “wounding somebody has become wounding some body” (299). I am particularly interested in how surgical rituals and hierarchy get reinforced in the purely technical physical action of

surgical teaching and in what social lessons of surgical teaching might change with the adoption of simulators as teaching tools.

Recent work in science studies has shifted focus from the construction of technoscientific objects and the practices of creating and working with them to how objects reciprocally construct the user's knowledge. Bruno Latour (forthcoming) argues that bodies come into being as knowing bodies through sensory training. He describes embodied knowing as a process of training the senses to "articulate" differences in the world. The play on "articulation," which describes the ability to express something in language, the joints of a body, and the making of more connections, allows Latour to discuss bodies and knowledges with one useful term. Learning and knowing are products of sensory interaction with the world. The senses must be trained, coming into being as they learn to register and differentiate objects, a process he describes as learning "to be affected, 'effectuated,' moved, put into motion by other entities, human or non-human" (forthcoming 1). The knowing subject makes more connections and becomes more articulate by means of understanding differences. Subjects are created by objects. Viewed from this perspective, much of medical education is a process of articulating two new bodies: the biomedically defined patient's body and the medically informed doctor's body. Both bodies—as they enter increasingly specialized areas of medicine—become increasingly articulated through ever more specialized and diverse devices, instruments and tests. The idea that sensory and technoscientific mediations articulate the patient's body and the doctor's body suggests a process of mutual articulation of bodies. The mutual articulation of bodies becomes especially important in areas such as surgical education and simulation, where a student learns increasingly refined visual and technical

skills largely by practicing visual and technical skills: bodies teach surgeons while surgeons operate on bodies.

New medical technologies and the practices accompanying them fragment and alter medical knowledge of bodies. Annemarie Mol (2002) explores how knowledges of the body and its diseases are multiplied and enacted through various practices. Mol argues that objects are known through practices. Multiple practices enact a single disease—arteriosclerosis. Equating knowledge with practices allows the philosophy of knowledge to become the ethnographic study of practices, "*ontology* is not given in the order of things, but that, instead, *ontologies* are brought into being, sustained, or allowed to wither away in common, day-to-day, sociomaterial practices" (6). What the body "is" multiplies across medicine's many practices, technologies, spaces, and disciplines. This approach allows Mol to move away from representations of disease, which she says has been the focus of most social studies of medicine, to disease itself (12-13). A concept of the Western body did not precede the practices of Western medicine: they are intertwined (26). Mol says she decenters objects, giving them a multiple, fractured identity in the present, as enacted by different people in different ways for different reasons (43). "New knowledge is not a product of clever minds, it emerges when scientific work is done in new socio-material settings" (60). She says multiple body knowledges must thus be coordinated among knowers in different worlds of practice: practices and knowledges are distributed in the hospital.

Medical training and the inculcation of medical knowledge and practice can be thought of as a nested set of knowledges. Most physicians trained in North America enter medical school with shared values that predispose them to a belief in the mechanistic,



biomedical-anatomical body. Their training reinforces and reifies that view, so the first years of medical school tend to create a common culture built around this biological view of the body (see Good 1994). As students begin to branch out and eventually to specialize, this shared biological view becomes parceled into a multiplicity of devices, practices, and knowledges that shape particular views of the biological body (Mol). Medicine becomes articulated into many knowledges of bodies and many ways of knowing the body in practice. But most doctors share a larger common set of cultural views about bodies—their own bodies and their patients' bodies—that grounds this biomedical world. I argue that the doctor as embodied subject and the objects of medical knowledge mutually articulate each other. They do so through practice that is shaped by pre-existing cultural dispositions. Medical objects progressively shape a doctor's embodied knowledge of medicine, but this is accompanied by extensive cultural shaping within the world of biomedicine—and within the culture that created biomedicine.

### **Doctors, engineers, programmers**

Up to this point, I have discussed culture, embodiment, and the connection between objects and knowing primarily within the context of biomedicine. But virtual medical technologies are being built in collaboration with engineers and programmers, who bring very different knowledges, values, and assumptions into the world of virtual medicine.

Physicians, engineers, and programmers in laboratories building virtual bodies typically have similar grounding in Euro-American beliefs about science and medicine, but formal training in medicine, engineering, and programming leads to very different approaches to problem-solving and the description of complex systems. The disciplines

form distinct “epistemic cultures” (Knorr Cetina 2000). Karin Knorr Cetina coined the term “epistemic cultures” to describe distinct technologies of discovery and knowing in molecular biology and high-energy particle physics. Knorr Cetina shows how, in the world of high-energy particle physics, physicists obsessively tinker with and calibrate their devices to separate shadowy signs of a particle’s existence—experimental results—from background interference. She describes physicists as intensely preoccupied with every detail of the experiment and its apparatus. She calls this kind of knowledge-building negative and reflexive, meaning physicists are obsessive about elaborating every detail of the experimental apparatus and design to sort results from artifacts. Knorr Cetina contrasts particle physicists to molecular biologists, who typically rely on blind alteration of variables to get results. Their results depend upon continual contact with natural and quasi-natural objects, rather than the interpretation of traces that might indicate a particle’s existence. Individuals and small groups conduct molecular biological experiments, which contrasts sharply with the hundreds, even thousands, who may participate in particle physics experiments. These contrasts show how physicists and molecular biologists live in distinct experimental cultures that privilege entirely different methods and results. Similarly, Peter Galison (1997) has shown how physics theorists, experimenters, and instrumentalists have divergent training, different journals, separate meetings and, often, incommensurate conceptual understandings of phenomena. These groups find ways to collaborate, however, within localized spheres of knowledge exchange and are able to sustain “coordination between belief and action” (813). Physicians, engineers, and programmers must coordinate their knowledge to build virtual body models and simulators. Unlike the various types of physicists, whose training

begins from the same base, they bring very different skills and values to the construction of virtual models of bodies and simulators. Thus, they must negotiate to build technologies that function properly and are meaningful as medical teaching devices.

Engineers privilege dynamic systems and quantitative reasoning. Louis Bucciarelli (1994) describes the worlds of technology design as “object worlds,” which are characterized by social processes of design that tend to revolve around instrumental and physical understandings of the objects of design, including physical principles, machines, and processes. He describes the “object worlds” of several engineering design projects as focused on causal, quantitative reasoning. This form of reasoning works hierarchically, attempting to resolve design problems at the most fundamental physical level possible. Bucciarelli describes the process of design as open, negotiated, contested, and social until the design is complete. This means that different participants may bring different worldviews into the process and those worldviews must be negotiated. He describes several facets of discourse across object worlds, saying this type of thinking is deterministic, abstract, causal, concrete and focused on measurement and constraints. Bucciarelli describes problem-solving as the means most engineering schools use to teach their students to resolve the messy, everyday world into increasingly fundamental scientific and mathematical principles, teaching students “to perceive the world of mechanism and machinery as embodying mathematical and physical principles alone...” (107). Even when working with messy biological bodies, engineers tend to seek mathematical and mechanical means of representing bodies as dynamic systems. This focus makes the body representable by computers, but it also privileges mechanical and

mathematical representations of bodies over the descriptive, taxonomic representations found in traditional anatomy.

The values and assumptions of builders get distilled into the technologies they build. Diana Forsythe (2001) describes how medical expert system designers reproduce their own ideas about work and knowledge in their technological productions. Forsythe discusses the culture of artificial intelligence, particularly the world of expert systems designers. She defines this technical culture as a group of people who share some taken-for-granted views of the world, including a technical bias that tends to neglect information about social and contextual issues in system design and use; a tendency toward decontextualized thinking that restricts research to questions that can be addressed using quantitative models; a mathematical, formal bias that seeks quantifiable problems and neglects factors, such as social and psychological phenomena, that are not easily described numerically; an assumption that conscious models accurately represent external reality; and a tendency to believe that only one correct interpretation of events exists. She finds, following Susan Leigh Star, that systems designers often omit the social, creating abstractions from visible, material processes. Expert systems designers also make invisible processes, such as knowledge, visible in the material form of computer code (Downey 1997, 130). Knowledge in this form gets codified as a set of rules and, thus, knowledge becomes reified as universal and formal rules for how the world works, neglecting the socially, historically and culturally contingent nature of knowledge as anthropologists and some philosophers and cognitive scientists would describe it (see Suchman 1987; Haraway 1991; Dreyfus 1992; Varela 1992). Forsythe explores the cultural dimensions of technology, finding that expert systems builders embed their own

assumptions about work and knowledge in the systems they build. Unlike expert systems designers, surgical simulator builders seek to embody human physical skills in their creations. However, they share many of the biases of expert systems designers, such as a quantitative bias and a tendency to omit the social. In the world of surgical simulators, multiple assumptions about bodies come together to create a hybrid body that is neither the biomedical body nor exactly the quantitative body, but something in between.

### **Project beginnings**

This project began in Sherry Turkle's and Mitchel Resnick's Systems and Self class with an assignment to interview people about a "computational object" and to write a paper reflecting on people's reactions. I wanted to write about the shift of high school frog anatomy from preserved frogs to virtual frogs. My interest was in changes in the realm of the senses. All I could remember from my high-school frog dissection were sense memories: the gravelly feel of the knife slicing the frog's belly or the sight of the tiny amphibian hands pinned to the mat. I wondered how these sensations would translate into the virtual world. Abandoning frogs in favor of humans, I began to examine the National Library of Medicine's Visible Human Project, two enormous image databases made from cross sections of two human cadavers and available on the Internet. Interviews with medical and non-medical subjects yielded some fascinating questions. Some viewers were disturbed by the images. They noted that the cross sections look like slabs of meat and full-body reconstructions made from CT scans make the bodies look like inflatable dolls. Viewers suggested that they would be uncomfortable seeing doctors who had trained exclusively on virtual bodies, privileging a doctor's emotional and tactile experience, first with cadavers and then with living patients. They asked how virtual

training might objectify patients. Viewers wanted to know the technical details of the Visible Human Male's and Visible Human Female's creation: how were these bodies made and why do they look like they do? What are the marks that are visible on these bodies? And they wondered about privacy: did these two individuals allow their bodies to be used this way? Did they know that images of their bodies would be disseminated on the web for all to see?

These early questions led me to do an in-depth look at the production of these images. I wanted to see how they were being used within their native context: biomedicine. Interviews with officials working on high-speed computation and virtual image databases at the National Library of Medicine led me to several laboratories, including the Stanford University Medical Media and Information Technologies (SUMMIT) laboratory, where I did more than ten months of participant-observation. SUMMIT is one of several dozen laboratories in the United States, Europe, and Japan dedicated to this kind of research. There are several hundred other laboratories and individual researchers who also contribute to this community. SUMMIT fit several of my research needs: It is located within a medical school, not within a computer science department. Some computer science departments are working on applications for the visible humans, including medical applications, but I wanted to study a laboratory where physicians, engineers, and computer experts actually work, rather than a laboratory that uses physicians as consultants. SUMMIT employs four surgeons and has collaborations with physicians in dermatology, radiology, and several other fields of medicine. The number of computer experts and engineers varies depending on the projects under way, but the laboratory was founded and is run by an electrical engineer and no fewer than

eight engineers and computer experts (from web designers to programmers) work in the laboratory at any given time. And SUMMIT researchers work on projects geared in two directions: on practical technologies with immediate application to the medical school community and on more experimental applications, whose payoff might be decades away. This combination of the practical and the experimental keeps SUMMIT researchers focused on the everyday practice of medicine and medical education, as well as on the more theoretical problems in the field. The combination was ideal.

This dissertation is an ethnography: combining participant observation and interviews. I spent more than ten months at SUMMIT. While there, I attended group meetings, talked with researchers, and watched them work and give demonstrations. I also watched surgeries and attended anatomy classes. And I helped the group write a major grant proposal to the National Library of Medicine. At SUMMIT, I created a group discussion forum, a weekly coffee during which group members and guests discussed anatomy, surgery, medical teaching, simulation and other topics relevant to the field. I also took a six-week anatomy course at Tufts University and did two brief visits to researchers in a laboratory at the University of Washington, where researchers are redesigning anatomical taxonomies for use by computers. In 2002 and 2003, I attended Medicine Meets Virtual Reality, a leading conference in the field that tends to focus on simulation research in medicine. In 2003, I attended the American Telemedical Association conference, which focuses on remote and networked medical technologies. My extended stay at SUMMIT allowed me to develop an in-depth picture of a single laboratory and the technologies it builds. My other ethnographic work allowed me to

move beyond the individual laboratory to create a broader picture of this emerging interdisciplinary field (see Forsythe 2001).

The picture of this community of researchers that emerged from my fieldwork was of a relatively new community tied to the larger community of bioinformatics researchers. The Stanford researchers' community is not tightly bounded: researchers move into and out of it from other academic and clinical departments at Stanford and other research laboratories. Collaborations reach to individuals and groups at other universities and in private corporations. Most of the group's funding comes from internal Stanford sources and federal grants, but the group also collects some money from private and foundation sources.

### **The dissertation: A Journey into the Machine**

This dissertation has been structured to follow bodies as they become increasingly embedded into the computer: beginning with the context for virtual reality medicine and ending with model bodies and user bodies as they are defined for computers. The first chapter presents the ethnographic setting in a laboratory at Stanford University Medical School and with a group of researchers where "body objects" come into being. The second chapter discusses epistemic shifts in the science of anatomy as the discipline has become increasingly computerized. Anatomy has been a descriptive and taxonomic science and now is undergoing an epistemic shift toward an applied mathematical and computational engineering science. The third chapter describes the material creation of the Visible Human Male. I argue that this method of creating a body in cyberspace represents a new way of seeing and interacting with bodies. The fourth chapter looks at the modeling and haptics (kinesthetic and tactile) simulation technologies needed to build



a surgical simulator and considers how a computable body is created in this setting. The final chapter takes an in-depth look at traditional surgical training, an apprenticeship model embedded in a powerful social context to consider what social and structural factors must be considered in a move to simulate surgical training.

**Chapter 1:**  
**Building Body Objects: From clinics to technics**

“There’s a big difference between doctors and engineers. Engineers tend to work with dynamic systems. Doctors work more pictorially, in list fashion, with graphs.”  
- electrical engineer

I arrived in Silicon Valley to begin fieldwork in a laboratory building computer applications for the Stanford University School of Medicine in November 2001, just two months after the terrorist attacks of September 11. More devastating to the region was the demise—beginning at the turn of the millennium—of the dot.com boom, called the “dot bomb” by some in Silicon Valley. Regional unemployment had gone from 1.7 percent in January 2001 to a high of 8.9 percent in October 2002 (Zhang 2003, 1). Rents were dropping, though housing prices in the mid-ranges (by inflated California standards) had risen as newly former millionaires traded down. Highways, bridges, and commuter rail cars that had been packed with commuters were nearly empty at rush hour. Stretches of U.S. Highway 101 held new, now-vacant buildings with acres of empty parking lots and glass facades revealing bare space inside. Brightly colored names and logos adorned these concrete-and-glass tombstones. They seemed to be epigraphs as much of a lifestyle and an absurd dream of ever-expanding markets, as of individual companies. These empty buildings reminded me of the ghost towns in northern California, disturbing remains of another boom and bust. At the time, speculation was high that even some of Silicon Valley’s stars, such stalwarts as Silicon Graphics and Sun Microsystems, might

not survive the crash.<sup>4</sup> Almost everyone I talked with had friends who were recently out of jobs and restaurants and bars had an unusual number of mostly young, white male waiters: former dot-commers, a friend of mine insisted. It was a moment when, amid terrorism and recession, the world seemed smaller and more uncertain than it had months before.

The Stanford University Medical Center's core buildings, in contrast to the Romanesque, mission style of the main campus, combines a classic nineteenth century 'pavilion' layout (Rosenberg 1987, 128) with a Moorish façade. The School of Medicine consists of a wing of classrooms and laboratories at the hospital's western end. Spreading west and north from the medical centre, mapping in modernist architecture the growth of the clinical sciences, are a series of research buildings, some of long duration, some under construction, such as the 'Bio-x' building, the 'x' standing for the large but unspecified number of biological and bioengineering research laboratories to be housed there. Surrounded by the signs of crash, Stanford, especially the School of Medicine, showed no evidence of the bust. Quite the contrary: Stanford was attracting talented technologists seeking the security of academia and the medical school was in the midst of a building boom that had no fewer than four buildings in some stage of construction or renovation.

The Stanford University Medical Media and Information Technology (SUMMIT) laboratory occupies half a floor of a burnt-sienna stucco office building at the far northwest corner of this cluster of medical buildings. SUMMIT's role at the medical

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<sup>4</sup> Both companies' stock prices crashed in 2001. SGI has recovered substantially; Sun's stock remains about one-fifth its pre-recession high.

school combines computational services, such as design and maintenance of a web-based curriculum and content service, with applied research, such as the construction of a simulator for teaching gynecological surgery, and basic research, including studies of cognitive aspects of human touch and kinesthetic experience.<sup>5</sup> The laboratory shares a floor and a loose affiliation with Stanford's Medical Informatics group. The laboratory looks at first glance like a small Silicon Valley cubicle farm, containing offices, a computer laboratory, a server room, and a small conference room. A closer look reveals the presence of its other major interest: medicine and medical education. In an open hallway and waiting area, copies of the *Journal of the American Medical Association* occupy shelves next to *Internet Week*, *Syllabus*, *Academic Medicine* and, bridging the disciplines of medicine and computing, the *Journal of the American Medical Informatics Association*. In computer rooms and individual offices, atlases of anatomy and histology occupy space on bookshelves next to handbooks on programming and designing with C++, Perl, and Director. Specially engineered devices, usually attached to computers, hint at the presence of a third major discipline in the laboratory: engineering. These objects begin to reveal the heterogeneous disciplines that SUMMIT researchers draw from when building technologies.

This chapter introduces SUMMIT as a laboratory where workers from multiple disciplines build computational models, applications, and devices. It discusses the heterogeneity of disciplines that collaborate at SUMMIT and in other laboratories where researchers build computational tools for medicine. This heterogeneity moves well

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<sup>5</sup> The laboratory was divided into two groups, one more focused on service, one on research, after I left. Throughout this dissertation, however, I treat SUMMIT as a single laboratory.

beyond the three major disciplines—medicine, engineering, and computer science—that form SUMMIT’s workforce because none of these disciplines is itself homogeneous and because other disciplines, such as education research and cognitive science, also play a role.

During a discussion following a meeting about surgical simulation, a hand surgeon drew a chart with two poles. One pole had the words “implicit/apprenticeship.” The other pole had the words “explicit/VR,” (“VR” stands for “virtual reality”). He said that to go from the apprenticeship model of medicine, in which knowledge remains implicit, to the construction of virtual reality simulators, knowledge must be identified, decomposed, translated from clinical action to technical language, and then recomposed as clinical action. In this chapter, I argue that this set of steps—the objectifying and making explicit of medical knowledge that has hitherto remained tacit or implicit is fundamental not only to the construction of these technologies, but to a technological ethos moving into this area of medicine.<sup>6</sup>

### **Technologies and disciplines**

This chapter examines SUMMIT as a laboratory where interdisciplinary groups of researchers work to decompose clinical objects and actions into technical language to create computer technologies. This decomposition follows the logic of technical fields, particularly engineering and computer science, which values quantification and objectification over experience and intuition.

Although she focuses on the epistemic cultures of molecular biology and high-energy particle physics, Karin Knorr Cetina examines laboratory cultures in ways that are

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<sup>6</sup> My thanks to Ruthanne Huising for a series of conversations that helped me articulate this idea.

useful for this analysis (Knorr Cetina 2000). She describes how laboratories reconfigure natural objects, subjecting objects even as seemingly remote and infinite as the galaxies to a process of “enculturation” (28) that makes them available to the social order of the laboratory. To do this, scientists make images, fragments, purifications, and other representations and extractions from natural objects to make them available when and as often as scientists want on a scale scientists can manage. Laboratories and their objects also reconfigure the social worlds of scientists, so the social, too, is transformed by the scientific work of the laboratory and scientists themselves become “workable” (20) in relation to their objects. Knorr Cetina uses as an example the transformation of medicine from bedside to clinic in the eighteenth and nineteenth centuries. These clinical spaces contributed to the creation of medical communities with specialized languages, which gave physicians power over patients, and technological means of investigating pathologies at autopsy, which gave them power over diseases (see also Foucault 1973). At SUMMIT, interdisciplinary researchers are forming a new field that is transforming patients’ and physicians’ bodies.

Louis Bucciarelli describes the instrumental logic of engineers as “object worlds” where causal, quantitative reasoning dominates (Bucciarelli 1994). This form of reasoning works hierarchically, attempting to resolve design problems at the most fundamental physical level possible. Bucciarelli describes the process of design as open, negotiated, contested, and social until the design is complete. This means that different participants may bring different worldviews into the process, worldviews that that must be negotiated. He describes several facets of discourse across object worlds, saying this type of thinking is deterministic, abstract, causal, concrete and focused on measurement

and constraints. This type of discourse structures narratives created in these worlds. Bucciarelli describes problem-solving as the means most engineering schools use to teach their students to resolve the messy, everyday world into increasingly fundamental scientific and mathematical principles, teaching students “to perceive the world of mechanism and machinery as embodying mathematical and physical principles alone...” (107). Design projects also are shaped by webs of relationships that Bucciarelli describes as external infrastructure, internal organization, and all manner of constraints. Bucciarelli says representations of projects often have value not because they accurately portray some facet of the project, though they also may do this, but because they are created by social consensus. Similarly, the contexts for such designs are socially “shaped, constructed, maintained, and destroyed” (191). Bucciarelli’s concept of an object world is a valuable starting point for considering how an interdisciplinary laboratory builds its objects, whether software, graphics, devices, or entire systems.

Diana Forsythe (2001) examines medical expert systems, particularly medical problem-solving tools, and critiques five tendencies that she finds among system designers, including technical bias, which she describes as a tendency to ignore social and contextual issues of how users think and work; decontextualized thinking, which is a tendency to construct and evaluate systems without considering the social and organizational contexts in which they will be used; a quantitative bias, which neglects problems, such as social and psychological factors, which are not amenable to quantification; a privileging of conscious models as accurate representations of the world, which involves the assumption that a conscious model of the world and an external reality are identical; and an assumption that one answer will fit all contexts and one

expert has all the answers. Forsythe also finds that systems designers tend to define their work as writing code, even when that is not what they spend most of their day doing, and tend to replicate in the technologies they build this bias toward defining the work described in expert systems as strictly cognitive. Forsythe's work provides a useful touchstone both for comparison between the homogeneous world of expert systems designers who tend to use medical experts as consultants and a much more heterogeneous world in which engineers, computer experts, and physicians work together from a technology's inception. Further, Forsythe's work also is useful for revealing some values of technology builders and their contrasts in medicine.

Bringing engineering principles into medicine is not a new phenomenon. One particularly relevant nineteenth-century example of this is the physiological work of French physician Etienne-Jules Marey. Marey described himself as a "medical engineer" who was committed, according to his biographer François Dagognet, Marey sought to create a "dynamic image of life" (Dagognet 1992 12) by building specialized devices to measure by inscriptions such physiological functions as pulse and arterial contractions. He rejected sensory knowledge and sought to find technological means of direct inscription by adapting existing recording and photographic devices to his own ends. Dagognet places Marey at the beginning of a modern concept of dynamic movement in art, cinematography, aviation, and other sciences, though Dagognet's evidence for this is more suggestive than thick. Marey's method was, first, to describe movement by way of an inscription that captured the essence of, say, a bird in flight or a galloping horse or a running man. Marey then worked to convert those descriptions to mathematics in the hope of elaborating the principles behind various motions. Finally, he tried to synthesize



these motions in new forms. Dagognet says Marey's analytical system was worthless without a synthesis, "...analysis was worthless unless it was confirmed by a synthesis. A given phenomenon had to be 'reproduced' (by a corresponding image or graphic mark) but it then had to be 'produced' (reversibility)" (153). Thus, "...once nature had been transposed, relieved of what encumbered and veiled it, it could be recomposed" (184).

### **Origin stories: A tradition of federal and industrial connections**

Frederick Terman's electrical engineering department at Stanford and Terman's efforts to intertwine industry, academia, and federal funding, along with stories about William Shockley's Transistor Co. and its spinoffs, crop up so consistently in tales of Silicon Valley's rise that they have the quality of "origin stories," densely woven tales that collapse many aspects of a culture's self-image (Haraway 1997, 175). I recount them here because they give a sense of the broad context of SUMMIT's entrepreneurial spirit and use of local technology companies and federal grants.

Leland and Jane Stanford established Stanford University in 1885 on their 8,000-acre horse farm in Palo Alto. The doors opened to students 1891. During the first years of World War II, Stanford languished. The university lacked a major research laboratory and lost more than forty faculty to war-related work by January 1942 (Lowen 1997, 52). Stanford's share of federal patronage picked up toward the end of the war, particularly for research into electronic components and equipment (Saxenian 1985, 22). After the war, electrical-engineering professor Frederick Terman returned to Stanford from wartime research in the east as dean of the engineering school. From the beginning, Terman made his interest in developing federal and industry ties clear, arguing for creation of a "community of interest between the university and local industry" (Terman

quoted in Saxenian 1985, 23). Terman built the engineering department and, later, as provost, other science departments on this ethic.

In 1946, Stanford established the Stanford Research Institute, which was devoted to defense-related research and stimulation of West Coast industry. In 1950, the university created the Stanford Industrial Park, 660 acres adjacent to Stanford dedicated to attracting businesses that would have some utility for the university and vice versa. In 1953, Terman established the Honors Cooperative Program, which allowed area electronics companies to send some employees to Stanford to study part-time towards master's degrees. In the 1950s, Terman strongly influenced the flow of federal funds to Silicon Valley (Saxenian 1985, 24). The period saw the rise both of home-grown semiconductor industries, such as William Shockley's Shockley Transistor Co. and the so-called "traitorous eight" who left Shockley in 1957 to form the company that became Fairchild Semiconductor Co., which itself spun off fifty companies between 1959 and 1979 (Saxenian 1985, 25; English-Lueck 2002, 20). In the 1950s, manufacturing plants of many major US corporations, including Westinghouse, Philco-Ford, and Sylvania also located in Silicon Valley. When military funding declined after the Vietnam War, military demand for Silicon Valley electronics had fallen in importance relative to the industrial and computing markets (Saxenian 1985, 28). The region became known as Silicon Valley in the 1970s and now boasts 22,000 high-tech companies (Zhang 2003, 1). These types of interrelationships of industry, academia, and federal money continue today, although venture capital plays a more dominant role in funding corporate growth (Saxenian 1994; Sunder Rajan 2002; Zhang 2003).

The history of Stanford's medical school up to 1959 is rather different than that of the rest of the university. In 1909, Cooper Medical College in San Francisco merged with Stanford. In 1953, the university's board of trustees decided to move the medical school from its original home in San Francisco to the Stanford campus. The rationale for the move was that medicine should be more tightly linked with the physical, biological, and social sciences; trustees said they wanted to give the medical school the advantages of a location within a larger university (Lowen 1997, 171; Wilson 2000, 37:3). Manuel Castells, who argues that Silicon Valley contains the model infrastructure and inspiration for a society based on network connections, cites spatial concentrations of research centers, higher-education institutions, advanced technology companies, and related suppliers as necessary for the formation of "milieux of innovation" (1996, 65). English-Lueck attributes Silicon Valley's success to dense, intertwined, highly mobile networks of people (English-Lueck 2002). On a smaller scale, SUMMIT's location within the medical school, but also as part of a larger university, benefits from the richness and intellectual diversity of the Stanford campus and from ties to the larger Silicon Valley community. These connections allow the group to create temporary and long-term research collaborations with faculty in engineering and other departments and to hire students with diverse skills as needed. Connections to the larger technological community have provided the group with skilled web developers, engineers, and network specialists, with some private research funding, and with collaborators on some federal, small business research grants. Research efforts at SUMMIT have benefited greatly from the concentration of highly skilled engineers, computer experts, physicians and others found on Stanford's campus and in the region.

## **SUMMIT's origins**

SUMMIT began in 1990 as part of the medical school's Anatomy Division. The group developed out of a project called "the Electric Cadaver," an effort to build an anatomy teaching system based on Stanford's Bassett Collection, a complete set of stereo photographs of human anatomy. The creators of the Electric Cadaver, an anatomist and former hand surgeon named Robert Chase and a computer expert, began the project intending to market it. When the computer expert left Stanford, Chase asked Parvati Dev, an electrical engineer, if she would be willing to take over the project. Dev declined, but a collaboration that led to SUMMIT's development ensued. The group began as a research group within anatomy, but Dev insisted that group should be able to do research within any area of medicine, rather than being limited to anatomy. Several years later, SUMMIT added technical support for the medical school curriculum to its mission. This combined mission—information technology research and service to the medical school—keeps SUMMIT's research focused on medical education. "It grounds us," Dev says.

An example of the technology development the group does is the construction of a virtual reality simulator for teaching laparoscopy surgeries, as described in Chapter 4. One important service application is the Curriculum Web Project, a set of web sites that gathers videos of all lectures and all handouts in the medical school. Students told me they consult the CWP on an almost daily basis. Students who miss a lecture can watch it from the website: all lectures are videotaped and posted. The CWP is, to use a military metaphor adopted by Bruno Latour, an "obligatory point of passage" for medical students, a point where all must pass and where the medical school can concentrate

knowledge resources (Latour 1988, 43). While taking opportunistic advantage of public and private funding sources, the group tries to keep medical education as its constant focus. For example, when, after the terrorist attacks of September 11, 2001, requests for federal grant proposals began to encourage research into security-related issues, such as disaster management, bioterrorism, and medical responder training, SUMMIT researchers considered and ultimately rejected retooling its research to take advantage of these funds.

Much of SUMMIT's work falls within the emerging field of medical informatics, a broad field that applies computer science and technologies to medicine (Berg 1997; Bowker and Star 1999; Forsythe 2001 3). SUMMIT's research primarily falls within a niche of medical informatics focusing on building virtual reality and graphics technologies, particularly for teaching medicine. The field of virtual reality in medicine got under way in the late 1980s, as groups around the country began integrating advanced medical imaging with computer graphics and modeling. According to SUMMIT's director, one push for the field came from Dr. Richard Satava, a surgeon who spent several years in the early 1990s at the Defence Advanced Research Projects Agency (DARPA) and channelled research funds into the new field. Satava, who now teaches medicine at the University of Washington, remains active in the field, predicting and encouraging trends in high-technology medicine. He has called for the fusion of minimally invasive surgical techniques, digital medical imaging, electronic databases and networking to enable physicians to "dissolve time and space", the physician can 'be' at a distant place at the same time as another person without needing to travel there. But of utmost importance is the fact that the physician can simultaneously bring in many

different digital images, such as the patient's CT or MRI scan, and fuse them with real time video images, giving the surgeon 'x-ray vision'" (Satava 1995, 335). Researchers in this field have begun to realize various pieces of this high-tech dream, though most applications remain experimental. Much of SUMMIT's research focuses on areas within each of the fields Satava mentions. SUMMIT's research arm includes the creation of surgical simulators; research into high-bandwidth computer networks as part of the medical side of the federal and private Next Generation Internet project<sup>7</sup>; development of a large medical image database that will house the clinical, pathological, radiological, and anatomical image collections of Stanford physicians and other faculty; and studies to show the effectiveness in teaching of various virtual reality and physical simulators.

Researchers come to SUMMIT from communities of practice in medicine, computing, education, and engineering. The group employs roughly equal numbers of men and women at all levels and has an exceptional diversity of races, ages, and cultural backgrounds of U.S. and non-U.S. origins, reflecting a cultural pattern among Silicon Valley residents that values 'dense networks of skilled, mobile, and 'diverse' professional workers' (English-Lueck 2002, 20). The laboratory employs eleven full-time workers and twenty to forty students, including a director, seven or eight researchers, web designers, project managers, students, and support staff. Researchers in the lab include four surgeons, mechanical and electrical engineers, an educational technologies expert, and a

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<sup>7</sup> The Next Generation Internet (NGI) project began under the Clinton Administration and was a joint government, academic, and industry effort to research and develop high-bandwidth internet infrastructures and applications, including medical applications. While the NGI Initiative has officially ended, it has spun off similar, Internet-related initiatives.

physicist who does cognitive research.<sup>8</sup> Collaborators, including computer programming and networking experts, work from other laboratories at Stanford and in other universities, connecting with the group via telephone, email, and video-conferencing systems. SUMMIT also participates in efforts among laboratories throughout the United States to develop “collaboratories,” means of dividing up research tasks, sharing information, and parcelling out grant money to avoid duplication and share research and resources (Kouzes, Myers et al. 1996).

### **Merging disciplines, emerging technologies**

Researchers at SUMMIT tend to fall into one of two groups that can be loosely described using terms borrowed from information theory: The physicians and educators, ‘content’ people, develop the pedagogical contents of applications and ensure their accuracy and validity as teaching tools. The ‘information’ researchers, mostly programmers and engineers, study ways to transmit those contents—information—to users, doing networking research, device building, and programming. A three-dimensional photographic display of a flayed hand, rotating on the computer screen, and progressing through several layers of anatomical dissection provides an illustration of the information-content divide. I have observed several physicians notice the hand and indicate the beauty of depicting its various planes of dissection, a difficult concept for anatomy students to grasp. I have also seen programmers, project managers, and others indicate their discomfort with the image—usually by shuddering or making ‘ick’ sounds. When I pointed this distinction out to the laboratory director, an electrical engineer with

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<sup>8</sup> Like most research laboratories, the composition of staff, researchers and collaborators shifts somewhat with new projects and grants, but the group remained stable while I was there.

years of experience doing bioengineering research and building medical technologies, she stared at the hand for a long moment, as though considering its effect, and then remarked simply that the disturbance of seeing dissected bodies eventually “just goes away.”

Though the cultures of medicine, computing, and engineering are distinct,<sup>9</sup> a danger exists in describing laboratory members as rigidly bound to any one culture. The physicians and others I have described as occupying the ‘content’ side of SUMMIT’s research work are all highly computer literate. They have learned mechanical concepts and terms from the group’s engineers, and all participate, at various levels, in computing, the high-tech culture of Silicon Valley, and ‘a computer culture that in one way or another touches us all’ (Turkle 1984, 18).<sup>10</sup> Three of four surgeons working in the group have studied programming, hardware wiring, or web design, and the fourth has done extensive work with digitized medical images and models. Conversely, most of SUMMIT’s engineers and programmers, who I describe as ‘information’ people, have spent years creating medical devices and applications. However, as the group director pointed out to me, every lab member received training within one dominant culture and very few can create both contents and the information structures to deliver them to users. Further, surgical simulator design requires, at a minimum, software writing and computer

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<sup>9</sup> More epistemological overlap exists between computer science and engineering than exists between either field and medicine.

<sup>10</sup> Silicon Valley residents are among the most computer literate people in the nation: Californians who responded to a survey by the Public Policy Institute of California said they 76 percent use computers, compared to 72 percent for the rest of the country; Similarly, 65 percent of Californians said they use the Internet, compared to 60 percent of other Americans. And 82 percent of Bay Area residents said they use computers, and 73 percent said they use the Internet (PPIC 2001).



modelling skills, mechanical and electrical engineering, knowledge of anatomy, and surgical skill.

Technology is built into the daily fabric of the group's working lives in ways that struck me as amazing, even after working in the technology-heavy MIT community for several years. During my second week at SUMMIT, I attended a meeting of the group working on Next Generation Internet research, a federal effort to develop and test a gigabit-speed network for scientific and business purposes. The meeting began with the group gathered in SUMMIT's conference room speaking with a collaborator at the University of Wisconsin via an Internet-based video conferencing system. Several participants were discussing their research into means of measuring how applications run over the Internet and the problems data-heavy applications run into during moments of heavy traffic. Networking jargon flew furiously. The group had planned to link to a group working on similar types of research at a Michigan university, also via videoconference. SUMMIT's director was working with a technician to set up her laptop as a server, so the researchers in Michigan could receive large images and display them on the wall while SUMMIT's director gave a presentation via videoconference. While the director spoke, we watched a video of a hand anatomy application transmitted from Stanford to Michigan, displayed on a wall in Michigan, and transmitted back to Stanford over the video conferencing system. In the midst of this, the telephone rang. The director's daughter was calling from Lusaka, Zambia, at which point the director clasped her head between her hands and said, "This is too much sometimes, huh? We are all very connected." Everyone laughed. Group members take this level of technological

connectedness mostly for granted, displaying exceptional ease with mediated communications and with virtual interactions.

SUMMIT's projects bring researchers' diverse knowledges together in interactions around objects: hardware, software, terminology. These 'object worlds', communities formed around material or conceptual objects (Bucciarelli 1994, 62), become focal points for negotiations about bodies and machines, medical and engineering practices, and how they interact. For example, during the Next Generation Internet meeting I describe above, I watched the arrival of a new interface device for the virtual reality pelvic simulator. The device was designed to mimic the look and feel of handles used in laparoscopies, a set of minimally invasive abdominal procedures. A surgeon, who has retired from his gynecological post in the medical school and now is a full-time simulator researcher, examined the device together with several members of the lab, including remotely linked collaborators. The gynecologist fiddled with the device for a few minutes, feeling its handles, their weight and movement, then said:

This is a significant advance ... It's lighter-weight and it doesn't feel so resistant in your hand. ... These [handles] are lighter weight. They feel less metallic. They are less metallic because they're plastic and it gives a better sensation. They're still wide. They're still heavier, but they've got to accommodate a lot of stuff. And the rotation works smoothly, just the way it ought to.

A bit later, the gynecologist introduced the device to one of the remote collaborators, calling it the 'Number three interface for the surgery workbench' and describing its 'five degrees of freedom and force feedback.' The surgeon considered the handles wider spaced and heavier than instruments actually used in surgery and, in considering the device and its surgical analog, he was thinking and talking like a surgeon. When he

described it as an interface, and discussed its degrees of freedom and force feedback capability, he was thinking in engineering terms as a component in a surgical simulation system. Scientists reconfigure natural objects into laboratory objects and laboratory objects reconfigure the social worlds of scientists (Knorr Cetina 2000, 28-32). This is true of SUMMIT's technologies, including the simulator interface. They are products of negotiations among physicians, engineers, and computer programmers who must absorb knowledge from scientific cultures outside their own—physicians learn some programming, programmers learn some medicine—to create these objects. The fields represented at SUMMIT—surgery, engineering, computer science, and education—are not merging in this new disciplinary space merely because researchers inhabit a shared space, but because they work together to build these hybrid objects. This work of negotiation and construction is the work both of developing a new field and building objects that are the field's 'signatures' (Traweek 1988, 49). Bringing computers into the teaching of surgery means bringing engineers and computer experts into the study of surgery.

Heterogeneous groups of researchers engineer representations of human bodies so they can inhabit computers. I call these representations "body objects." Body objects are teaching tools, diagrams, and models that reflect SUMMIT's character as a computer research laboratory for creating medical teaching tools. On a shelf in the director's office sits a cardboard model of a child's skull, an artifact from an early project. Researchers created the model by programming a computer to calculate the curves of a real skull from the outlines depicted on a series of CT skull cross-sections. Those calculated curves then became outlines of cross-sections of skull, which were cut out of cardboard. Stacking

sequential cardboard cutouts created the three-dimensional skull model, an early physical proof-of-concept of graphic models now common in medical modelling. In another office is a whiteboard drawing of a finger overlaid with a schematic intended to show the physics of finger motion and what happens mechanically when it fractures. The drawing was a conceptual sketch for a computer animation of a broken finger driven by a mathematical description of its motion. A third office contains a small pink and white foam model of a uterus pinned to a bulletin board. The uterus served as the model for a CAD (computer assisted design) model, a prototype for a virtual reality surgical simulator. The CAD simulator project, a commercial venture by a SUMMIT researcher, failed and the researcher began building models that originated from images of real cadavers. Each object reflects a body part as it has been built or defined in relation to a particular technology: the skull is understood as a collection of computed cross-sections, the finger as force vectors that change if the finger breaks, and the uterus as a foam model that would have to be resolved into its most elementary shapes and reformed in the computer as a CAD model (see Downey 1998). Regardless of their purpose or success, such objects reveal how the combined engineering, computational, and medical knowledges of the group come together in these body objects.

To build virtual reality simulators, researchers must create body objects that are incorporated in the computer. This requires a crucial epistemic move: the body must become mathematical, described using equations the computer can interpret. Actions and sensations surgeons usually experience physically must be calculated, just as the finger's motion and the skull's curvature must be calculated in the examples cited above. In the world of surgical simulation, a virtual body must interact with both computer and user as

a mathematical and a visual-physical entity. The laboratory director describes the mathematics of creating deformable models of bodies that can interact with virtual tools:

The only way the computer can understand things is, in this case, through geometry. It needs geometry. It needs to know how to compute a sequence of forces with equations, which previously, in a sense, [surgeons] did in their heads. You knew how to predict what was going to happen. You didn't solve an equation to do that, it was just part of the experience. So it's the computer that forces you to put that mathematical construct on.

As this engineer says, surgeons predict the consequences of their actions based on their own experience and others' experience distilled in papers, procedural scripts, and apprentice-style teaching. In contrast, computers must "understand" bodies and their actions mathematically. The computer requires that each step in a body's motion be modelled as a discrete mathematical state acted upon by the movements—forces—of tools wielded by the surgeon. The feel of surgery, which surgeons' bodies typically experience phenomenologically—as they practice—must be parsed, calculated, incorporated into the computer's programming, and ultimately, fed back to the human user, who then will experience the sensations of performing a surgical procedure phenomenologically. This is the creation of a technical language derived from clinical action, as the surgeon describes earlier in this chapter.

Body objects are hybrids: each, in its own way, is both a medical and a computational or engineering object. They are models and representations of bodies, all originating in medicine, that have become intertwined, visually and semiotically, with knowledges culled from engineering and computer science and, physically, with sensors, wires and processors. Body objects also are narrow: because the computer requires specific mathematical descriptions to calculate a line or determine a trajectory, body

objects cannot be loosely described in ways humans understand intuitively. In this, they do not resemble the boundary objects Star and Griesemer because boundary objects, such as the natural history museum collections they describe, are useful to many types of researchers precisely because they retain a certain looseness in their construction (Star and Griesemer 1989). Body objects serve only two kinds of “users,” computers and human users of computers. Body objects are representations of bodies articulated graphically and haptically, so humans can understand them and mathematically, so computers can understand them.

### **Language**

The multiple worlds that come together at SUMMIT became most evident to me during discussions about language. The ways researchers use and play with language reveals this world’s hybrid nature. For example, on my first day visiting SUMMIT, during another Next Generation Internet meeting, a gynecologist and a hand surgeon described their work on surgical simulation. They described their goal of creating a “thriller app,” or computer application. The gynecologist explained, “We’ve made a semantic change from ‘killer app’ to ‘thriller app.’” As if on cue, the hand surgeon clarified, “Somehow ‘killer app’ doesn’t sound quite right in surgical simulation.” A “killer app” is a common term in the world of computing for a highly successful application: an application that comes to dominate the world it addresses, killing the competition. But describing a surgical simulator as a “killer” would be inappropriate. So the two surgeons renamed their application for a more suitable purpose. Examples of these kinds of language games abound at the laboratory, revealing how knowledges and sensibilities from the worlds of computing and medicine come together.

During another meeting, a large group gathered in SUMMIT's small conference room to discuss the Media Server, an on-going project to develop a database for medical images, a seemingly mundane data storage project whose development seemed anything but mundane. Questions had arisen about what to call a temporary storage area for researchers who want to choose a few images and then decide later whether to actually download them. Amazon.com calls this kind of temporary storage a "shopping cart." The issue was how to signal that what's being stored are medical images. Some people in the meeting were comfortable with the term "shopping cart," but others objected that it was too commercial. Two other terms, "album" and "slide box" were offered. A hand surgeon who is one of the lead researchers on the project said the issue raises the question of what language the group will draw from for its terminology. She says photographers and histologists use "slide box." As the discussion deteriorated, someone became frustrated and suggests "cesspool." The hand surgeon finally suggests, semi-seriously, "cistern." The group finally settles on "slide box," but the discussion illustrates, in an important way, how this interdisciplinary group must literally choose the language, whether computational, medical, or other, from which it will create its terms.

Another example comes not from Stanford, but from the University of Washington, where I did two brief research visits to the medical school, looking at an effort to revise anatomical taxonomies to serve as a substrate for anatomical expert systems. The group has divided anatomical knowledge into what it calls "spatial," meaning visual, knowledge, and "symbolic," meaning terms. But this division creates intriguing semantic debates for the group, as the group director explained to me:

And we've divided the information into two kinds, symbolic and what I was calling spatial, but we're having a debate about what really means.

Spatial can also be represented in text format, anterior to, posterior to, that's also spatial. And so my initial idea was symbolic is the kind of thing you study in artificial intelligence, knowledge organization. Spatial is the kind of thing you study in computer vision, graphics, geometry. [A senior anatomist in the group is] calling it image-based, but I don't like that either. We haven't decided what that means. It's sort of doesn't really matter in a way, but it's kind of interesting. How do you classify anatomical information? Each one of these ways of classifying information leads to different fields of study. For example, symbolic information is AI and knowledge representation. Spatial, what I'm calling "spatial," is more computer vision, graphics, databases.

The group director, who is a physician and an expert in medical informatics, describes how the group has an ongoing debate about what the terms "spatial" and "symbolic" mean because classical anatomical terminology provides some spatial indicators, locating one structure as "anterior" to another, for example. So within anatomy, the terms may be somewhat misleading. But the group director says he originally was thinking about the terms in relation to the subfields of computer science that they address. Thus, spatial knowledge signifies the world of computer graphics and computer vision, whereas symbolic knowledge signifies artificial intelligence. The conscious choices researchers in this field must make when they choose words represents a true interdisciplinary space and this is reflected in the self-conscious ways they choose terms: evoking medicine, computer science, even popular culture. They must also—as in the example of the "killer app," be sensitive to potential pitfalls in adopting terms from one discipline that may have inappropriate connotations in another. Thus, in this interdisciplinary space, researchers must make conscious choices about whether and how to categorize their word and language choices.



## **Interdisciplinary biographies and technologies**

In this section, I examine pieces of the life histories of three SUMMIT researchers and three technologies they have worked on or that have influenced them. My purpose is to show in each case how medical knowledge that was implicit, tacit, difficult to communicate, or largely intuitive gets made explicit by technology builders. I do not wish to label these moves as positive or negative, or to criticize them. Rather, I want to show the logic of how certain types of knowledge get externalized.

My first example is of a general surgeon with a doctorate in education who works part-time at SUMMIT and part-time performing surgery at an area hospital. She is in her thirties and says she has been fascinated with medicine for much of her life. She performed amputations and transplantations on her dolls as a child. She loves anatomy's mechanical quality and loves teaching. Her interests focus deeply on the uses of the senses in medicine.

I realized I loved everything about surgery. I loved anatomy. I can take it apart, put it together, fix things. ... I wanted to teach anatomy to students. Being close to it, I would also be able to offer surgeons what I call, "the surgical eye." It relates to a visual gift—being able to see things in three-dimensions—that I knew I had. I could identify other surgeons who had it when I was watching them. ... When you've done a deep incision, you close in layers. Not everybody sees the tissue planes. I'm interested in teaching people to see those things.

This surgeon describes surgery as a mechanical skill of taking things apart and fixing them, but also as a visual art, describing herself as having a gift for seeing bodies in three dimensions and seeing difficult-to-discern tissue planes. She says watching a surgeon who does not see tissue planes gives her a sensation like hearing fingernails scrape across a chalkboard: she feels something wrong at a visceral, embodied level.

During her doctoral coursework, the general surgeon took a course on human-computer interaction and a lesson on the uses of sensors inspired her to apply them to pelvic and prostate exams, two physical exam skills that are difficult to teach because, with living bodies or traditional mannequins, neither teacher nor student can see what the other is palpating or gauge the pressure being applied. The surgeon wired sensors into a rubber mannequin of a female pelvis and taught herself C++, a programming language, to create a computer interface that shows which structures a student is palpating and with how much pressure. The resulting simulator, called an “e-pelvis,” bypasses verbal explanations of the feel of a cervix or an ovary in favor of a set of pressure readings on a monitor. This gives teacher and student a means of evaluating what one is teaching and what the other is learning without the need to translate tactile concepts into language.<sup>11</sup>

As the surgeon says:

When I’m teaching this, how can I describe it? There’s no uniform language for teaching how a prostate feels, or how a cervix feels. . . . It’s also very difficult to do the three-dimensional visualizing of the vaginal vault and cervix.

The e-pelvis creates a means of objectifying knowledge typically contained in the physician’s hands. The search for precise language to describe a physician’s tactile readings of bodies has long been a concern in medicine, especially with readings of the pulse (Reiser 1978; Kuriyama 2002). The e-pelvis does not bypass the physician’s skill, so much as it creates a means of measuring that skill and, ideally, teaching it to other

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<sup>11</sup> Gilles Deleuze (Deleuze 1988) argues that what we see and what we say, the visible and the articulable, can be related, but are never identical; one can never be fully communicated by the other. The same is true for tactile (or haptic) and verbal knowledge: physical sensations are difficult to describe (Reiser 1978; Scarry 1985; Kuriyama 2002).

physicians by revealing the values of those measures. This is an example of a physician who learns computational tools and builds computational logic, the logic of making medical skill explicit, to create a teaching tool.

Another surgeon in the group, a hand surgeon who trained in India and the United Kingdom, also had a longstanding interest in computing before he came to work at SUMMIT. He was among the first in his medical school class to use a word processor to type his thesis. From this simple beginning, a deeper interest was born. But this surgeon's interest in simulation has roots outside computing, in the logic of checklists and protocols. He says:

I remember one lecture, given by ... a professor of surgery, right early in the medical school time, the second year. And he says, When you go into the surgical suite, into the operating room, you want to be absolutely sure that you don't overlook certain steps and you don't miss out on certain things and so on. And so he said that, What I normally like to do is I like to make a checklist that I have done this step, this step, this step, and I just check it off as I go through, either mentally or on paper. It depends on the place where you are working, and what is the system and so on. It's nice if you do it on paper. He says, I like to use the word "cockpit drill" for this. Many of us were not quite familiar. He says, You see, when a pilot goes into a plane, they have a checklist. They have to check, this is working, that's working before they take off. It's a legal requirement. And it makes sure that they don't miss out on any steps. And probably that got me thinking. I thought, Aha, cockpit drill, that's pretty nice. Actually in my time working since then, particularly when I am going for any surgery either as an assistant, or if I'm doing it, I like to have this checklist. I normally do it on paper, but I certainly always do it mentally. And so I don't miss out on anything. And I like to do certain things in a specified order. I won't do something before something else because then I will say, Oh that will just mess me up. ... And so I like to use the word, "cockpit drill."

This hand surgeon describes how the concept of the cockpit drill helped him think of surgical procedures as a series of steps or a checklist or, possibly, a flowchart. He now

creates a checklist—either in his mind or on paper—before every surgery he performs. This assures him that he has completed every step in the correct order.

The comparison of surgical simulation to flight simulation is ubiquitous in the field of surgical simulation, though whether flight simulation has supplied technology or has been an inspiration for surgical simulation remains to be explored. What is clear from this passage, however, is that the concept of a cockpit drill, of a protocol that makes the steps and the order of a surgical procedure explicit has been a powerful tool for this surgeon. Just as the e-pelvis creates an objectified space between teacher and student, so the cockpit drill, whether on paper or in the mind, makes explicit a set of steps, a procedure, that might otherwise remain implicit. It moves surgical action further along the continuum toward the explicit. Further, as a conceptual tool, it can be reincorporated, becoming an internal checklist (see Berg 1997).

Another example of the blending of knowledges that tends to make knowledge explicit in this world occurred at the Medicine Meets Virtual Reality conference, the primary conference in the field, in 2002, I sat next to SUMMIT's director during a demonstration of an animation of the human jaw. The animation showed only two of the major jaw muscles involved in chewing and no others,<sup>12</sup> but unlike many musculo-skeletal animations, this animation showed the motion of the jawbones as initiated from the muscles, rather than vice versa, as is easier to animate, but anatomically incorrect. SUMMIT's director looked at the animation and wondered aloud how useful it would be. Such an animation would be much better, she said, with arrows superimposed on the

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<sup>12</sup> The director of the group that created this jaw animation told me that calculating the interactions of all muscles in a complex joint, such as the jaw, would require a supercomputer.

muscles to show strong and weak forces as they interacted. I have heard similar ideas from other engineers working on animations of human anatomy. They want to show that human anatomy is dynamic, something that is not easily demonstrated by cadavers and to show how human anatomy is dynamic by using animations to reveal the force vectors of muscle movement. This displays the preference for quantification that Forsythe calls a “bias,” but that I prefer to call an epistemological preference: the engineers I encountered in this world wanted to make the enormously complex system that is the human body comprehensible by representing it in terms of its dynamic properties, which is a basic tenet of engineering education (Berg 1997; Downey 1997; Forsythe 2001).

The preference for creating representations of human bodies as dynamic systems also revealed itself as a preference for mathematical precision and predictive models over intuition, judgment, or experience, which surgeons often cite as the qualities they look for when judging who is a good surgeon.<sup>13</sup> Earlier in her career, this engineer developed a computer model that predicted the effects of reconstructive hand surgeries, calculating mathematically the effects of, say, the reattachment of a particular tendon at a particular location. In an interview, she described having to gather quantitative anatomical data and what this type of modeling could bring to medicine, particularly surgery:

**Engineer:** When I first got into this reconstruction of the wrist, I would find all these pictures of the bones and even what looked like 3D drawings, but nowhere could I find something that told me what the actual size of it was in millimeters. So I couldn't find, for example, the moment arm of the tendon that's gliding over these bones and in the end, I had to slice. I had to work with [a hand surgeon] and slice bones and reconstruct it to get that geometrical information, so it was new knowledge in that sense.

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<sup>13</sup> I discuss the qualities surgeons look for further in chapter 5.

**RP:** Was it someplace that for you, as an engineer, was a completely natural place to go with it?

**Engineer:** Oh yeah, absolutely.

**RP:** Was it completely natural for someone like [the hand surgeon]?

**Engineer:** He understood it immediately. That's because he's a hand surgeon. He has to think about the mechanics, even if he doesn't have the mathematical ways of thinking about it.

**RP:** Is the world of medicine ready for a more mathematically oriented anatomy?

**Engineer:** Most people don't need it, I don't think. The people who are forced to need it, they learn it. It can actually do things. For example, for surgeons, it can predict the effect of variations in certain surgeries. You move the tendon five millimeters this way, what's it going to do? The surgeons work that out through their own knowledge and intuition, but you could tell them mathematically that it's going to move the finger in this direction that you don't really want and you can actually quantitatively tell them.

The engineer describes how the anatomical and medical literature she consulted lacked mathematical calculations of distances and sizes of wrist anatomy. She had to ask a hand surgeon and anatomist to section a wrist so she could make precise mathematical measurements of the sizes of structures.<sup>14</sup> This was, she says, new knowledge generated about human anatomy. As an engineer, quantifying the anatomical relationships was a natural move for her and that the hand surgeon she worked with understood it immediately because hand surgery is among the most mechanical of surgical disciplines. But the idea that a mathematical model of wrist mechanics could predict the outcome of particular surgical actions was new to the hand surgeon's experience. She says this type of mathematical modeling, however, could help create predictive models of the effects of

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<sup>14</sup> I discuss sectioning in chapters 3 and 4.

surgical actions, effects that surgeons typically gauge using experience and intuition.<sup>15</sup>

The engineer clearly values creating a quantitative, predictive model over modeling based on surgical intuition. This is a case of new knowledge coming from the application of a set of skills drawn from engineering into medicine. It required the development of new, quantitative knowledge about the human body and values the predictive abilities of quantitative knowledge over surgical intuition.

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<sup>15</sup> Surgeons highly prize experience, judgment and intuition as components of surgical knowing and problem-solving (see Abernathy and Hamm 1995).

## Chapter 2

### Anatomy's Death Has Been Greatly Exaggerated

The word “anatomy” derives from the Greek “ana” and “temnein,” meaning simply “to cut.” It is synonymous with “dissect” and, in some uses, “analyze” (Webster, 9th edition, c.v. 'anatomy'). As it is practiced and taught in U.S. biomedicine, human gross anatomy is the study of human structure from its largest components down to a fuzzy border with histology where tissues become cells. Anatomical terminology originated with Aristotle's and Galen's dissections of animals and was updated and, in some cases, corrected beginning in the 16<sup>th</sup> century with Vesalius (for a discussion of Greek anatomy, see Kuriyama 2002).<sup>16</sup> Anatomical terminology is one means of describing the body, of describing densely packed tissues, their locations, and their functions. To give a simple example, the *flexor digitorum superficialis*, is a set of tendons in the wrist that allow the fingers (the digits, hence *digitorum*) to flex (hence *flexor*). This set of tendons is more superficial—closer to the skin—than another set of tendons with a similar function (hence *superficialis*). Anatomical terminology is organized as a classification system, a taxonomy. This terminology is one way the discipline of gross anatomy cuts up (dissects, anatomizes) the human body. As such, it can be considered an extremely useful tool, or model, or representation of the body.

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<sup>16</sup> A surgeon who I worked with at Stanford described this legacy from animals as leaving vestigial inaccuracies. For example, the “rectum” indicates a straight passageway and the rectum is indeed straight in certain primates, but not in humans. This chapter does not address anatomy's history, nor the history of its terminologies, but many physicians I encountered during my fieldwork were fascinated by these types of terminological variations.



The gross anatomy that medical students learn today is primarily about representations of the human body, such as the descriptive language described above. This language forms a platform for medical communication: doctors can rapidly communicate the location of pathology using terms more or less common to all medical disciplines.<sup>17</sup> But language—the articulable knowledge of the human body—is not the only way to cut up the human body. Medical students also are expected to understand anatomical relations in three dimensions. Though related to the logic of anatomical terminology, this understanding is visual and spatial. Anatomy is about seeing organs and tissues and understanding their relations in the body’s space. These two interlocking knowledges—a language and a three-dimensional structure for the human body—are the core of anatomical knowledge that medical students face.

Anatomy teaching has become controversial. The controversies bubble, not over whether medical students need to understand how to see, talk about, and connect the body’s structures, but about how exactly such knowledge should be acquired, what tools best aid anatomical teaching, and what other lessons a gross anatomy course can or should provide medical students. The use of human cadavers as the privileged model of anatomical teaching lies at the center of this controversy. Cadaver dissection has been an important rite of passage in medical education (Good 1994; Van Gennep [1908] 1960).<sup>18</sup>

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<sup>17</sup> Anatomical terms tend to “drift” a bit from discipline to discipline. Thus, an anatomist described to me that the apex of the lung is, for anatomists, a particular point at the top of the lung. In contrast, the apex of the lung for radiologists is a larger region in the same location. Nevertheless, even with this drift, the terms are close enough for most medical communication.

<sup>18</sup> The first formal anatomy course in the United States was taught in 1745 at the University of Pennsylvania. Grave robbing was common practice until, following a British example, the states began to pass laws, starting with Massachusetts in 1831, that provided cadavers of unclaimed bodies to medical students. The federal government passed the Uniform Anatomy Gift Act in

Anatomists and medical school administrators are challenging the need for cadaver dissection to introduce human anatomy to medical students. Since the late 1980s, the ability of computers increasingly to offer visual and linguistic lessons of anatomy, as well as to add connections between structure and function, has added fuel to the debate, which pre-existed computerized anatomy. As I show, the debate does not revolve around the technological abilities of computers and other technologies to represent human anatomy, but focuses instead on more profound questions about the relationship between a doctor and a patient. With what tools does a doctor come to know—to see and to speak about—a patient’s body? What capabilities do those tools provide and what do they forbid? What kinds of bodies do these tools represent to the doctor? And, underlying the technological questions, how should a doctor relate to a patient?

The debate about the use of computer tools for teaching anatomy rests, in part, on a debate about continuing the practice of human dissection in the first years of medical school. The terms of this debate rest, in part, on defining what a cadaver is, whether it should be treated as an object, as a human being, or both. As such, this debate rests squarely within longstanding discussions of objectification in medicine: does biomedicine as currently conceived objectify the human body and dehumanize the patient (see Young 1997; Cussins 1998)? This chapter examines debates about the use of cadaver dissection for anatomical teaching and discussions among anatomists and others about the cadaver’s ontological status. It looks at the technologies medical students and others now use to physically and conceptually dissect the body and at some new technologies

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1968, which created the cadaver donation system in existence today (Richardson 1987; Tward and Patterson 2002).

that represent the body as an object for manipulation, rather than merely for identification and description. Gross human anatomy as a research science, as a science of the description of human form, reached saturation some time ago: few new muscles or nerves or vessels remain to be named.<sup>19</sup> Anatomy has begun to remake itself as an engineering science, a science in which human structure is no longer described in linguistic and spatial terms, but rather is mapped according to Cartesian coordinates that a computer can use to identify structures and calculate modifications mathematically. This shift may further challenge the cadaver's status as a teaching tool. This chapter addresses the ontology of the cadaver—as former person and medical object—as well as the physical and conceptual technologies, including computers, used to dissect the cadaver. My purpose is to examine the positions anatomists, medical students, and physicians take towards dissection and to use these positions to take a new look at the lessons cadaver dissection can provide. I argue that cadavers are ontologically unstable—they are persons and things—and that this instability is precisely what physicians must learn to manage. Technologies—material, visual, literary, social and computational—all provide means of “cutting up” the human body, whether conceptually or physically. These technologies, and the practices affiliated with them, make the cadaver multiple in ways that help the physician manage that instability. Managing instability, even by objectification, does not, however, mean that the body is dehumanized.

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<sup>19</sup> Hugh Gusterson, following Clifford Geertz, calls this withering of a field of knowledge “involution” (Gusterson forthcoming).

## **Object and person: organizing instability**

I locate this chapter within an emerging stream of science studies literature that focuses on the lack of unity within medicine and medical practice by opening up the heterogeneity and multiplicity of tools, practices, patients, and bodies in medicine (Mol and Berg 1998). This literature reveals that no one factor, whether social, technological, or epistemological, determines medical knowledge and practice. Rather, socialities, practices and technologies mutually constitute medical knowing and each other (Berg 1997; Wailoo 1997; Mol and Berg 1998; Luhmann 2000; Mol 2002). This literature includes discussion of how the ontology of the patient's body can be mobilized by patients to manage threats to personhood (Cussins 1998) and by doctors to manage competing clinical and administrative demands (Dodier 1998). I add to this literature is examination of how the cadaver's indeterminacy as person and thing contains an ontological instability that physicians learn to manage with various technologies, an instability that, I argue, ultimately helps medical students develop and manage a clinical stance toward living human bodies.

As anthropologists have shown, boundaries between such categories as life and death or body and person are historically and culturally contingent (Lock 1993, 134; Lock 2002, 32). As Margaret Lock has described, since the nineteenth century, death in North America has been increasingly medicalized, removed from the social and theological realms and reconstituted as biological (Lock 2002, 35). But the biomedical redescription of death has coexisted uneasily with other views, particularly because some essential questions related to the nature of life and death, such as the nature of

personhood, resist scientific investigation (Powner, Ackerman et al. 1996).<sup>20</sup> The philosophical, historical, and cultural attitudes of North American culture toward death are beyond the scope of this chapter, but what my ethnographic fieldwork reveals is that the cadaver's status—as person or thing—is by no means settled in present-day anatomy.

In a magnificent essay on the role of the autopsy in the second year of medical school, Renee Fox argues that this ritual helps create an attitude of “detached concern,” the detachment and concern that is a hallmark of the medical professional (Fox 1988, 56). Fox argues that the autopsy experience encourages students to, in one student's words, remain aware of the “human implications” of their actions, while “working on the body of a person who was once alive and now is dead” (ibid.). Fox describes how the setting, the tools used, the rituals, the students' normative behaviors, and the stance taken by pathologists toward the body all help form this attitude. This continues the students' education about death, the human body, and the roles of patient and physician. The students Fox quotes say they want to overcome their emotions, but never to forget that they are working on a human body. She describes the autopsy as a step between gross anatomy and work on the living, part of a progression that makes emotional distancing possible. The second-year autopsy is a thing of the past (Fox's fieldwork was done in the mid-1950s), but some aspects of gross anatomy teaching have changed to accommodate some educational functions formerly filled by the autopsy.<sup>21</sup> Fox's discussion of the dual

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<sup>20</sup> That medical, social, and theological views about bodies coexist uneasily became clear to me in part through discussions with several Jewish medical students, at least one of whom planned to study surgery, who had to confront and manage religious prohibitions on cutting into bodies and their chosen profession.

<sup>21</sup> One critical difference between the gross anatomy and autopsy teaching of the 1950s and gross anatomy at the turn of the millennium was the use, in the 1950s, of cadavers of unclaimed bodies.

nature of the medical students' stance toward patients, and the way this is created through objects, such as medical charts; rituals, including an invocation of patient families and the need for respect; and through scientific study, which is the stated purpose of participation in the autopsy, are critical concepts for this chapter. I build both on this notion of a duality at the heart of medical attitudes towards bodies and on the role of technologies for knowing bodies to consider the cadaver's role in medical education and the role of technologies, including computers, for understanding and developing a stance toward cadavers.

Writing about female patients' agency when they undergo in vitro fertilization, Charis Cussins (1998) argues that objectification may not be antithetical to personhood. She says women actively participate in their own objectification, naturalization, and bureaucratization in these clinics and that these moves, which remake the ontology of the woman's body and body parts, allow her to construct narratives about successful or unsuccessful procedures that protect her personhood. For example, a woman can distance herself from an unsuccessful procedure by blaming an objectified body part that she ontologically constructs as "not her." Thus, objectification may not be antithetical to the woman's personhood or agency (167). Cussins describes her approach as the flip side of the social construction of technology, suggesting that technology can play a complex role

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Unclaimed bodies arrived in the anatomy laboratory physically and socially dead. In the 1950s, autopsies included permission forms from families and injunctions to students to protect the privacy of the family and, thus, the students became aware of the social connection of corpse to its past as a patient with a family (Fox 1988). Now, without the autopsy to remind students of these social connections, students are reminded that cadavers—though still anonymous—donated their bodies to science and, often, memorial services for these donated cadavers include their families. Thus, the social connections that the autopsy made between the body on the table and the patient and his or her family has shifted into the gross anatomy laboratory although in somewhat different forms (see also Gawande 2001).

in the construction of selves (see also Dumit 1997). Cussins makes a statement about IVF clinics that also applies to anatomy laboratories, “It is the genius of the setting—its techniques—that it allows these ontological variations to be realized and to multiply” (170). From the time of death onward, the body that will become a medical school cadaver certainly has little agency in its uses. But the donor’s choice to give his or her body to medicine gives the cadaver an agency that matters to medical students.<sup>22</sup> Further, Cussins’ notion that particular tools encourage a particular ontological construction of the body or its parts is quite powerful when thinking about how tools for conceptually or physically dissecting the body help manage the cadaver’s ontological instability. With Cussins, I argue that objectification may not be dehumanizing. Rather, for physicians as for patients, alternating objectification and personification of bodies may allow physicians to engage in practices that are otherwise culturally unacceptable.

Annemarie Mol (2002) argues that bodies in medicine are multiple; they are produced, managed, and known through different practices in different parts of the hospital. For Mol, this multiplicity is reconciled and managed in various ways, including by distribution across several disciplines of medicine. Here, I extend Mol’s argument about multiplicity to an object—the cadaver—whose ontological status is constructed through various technologies as unstable—as simultaneously object and person.

In this chapter, I draw out how technologies and practices construct multiple realities—often multiple bodies—in medicine. Anatomy, as a science that “cuts up” the human body, utilizes many technologies to dissect the body. I use technology here to mean a “knowledge-producing tool” that can be material, literary, or social (Shapin and

Schaffer 1985, 25 fn. 4; see also Wailoo 1997). The technologies used in anatomy also can be visual, which makes a distinction between material technologies that divide a body's physical substance, literary—or linguistic—technologies that articulate body parts and relations in words, and representational technologies that make features of the body visible (see Deleuze 1988). These technologies give the medical student or physician a conceptual lens through which to view the body, a lens that allows a physician to examine the cadaver in a particular way, but that may also give the physician a means of productively maintaining the cadaver's ontological instability.

### **Anatomy teaching under fire**

This chapter is based on fieldwork at three primary sites and on many conversations with anatomists. The primary sites were an anatomy class that I took at a Boston-area university; a laboratory working on computerizing anatomical terminology at the University of Washington; and the Stanford University School of Medicine (both at SUMMIT and in Stanford's Anatomy Division). I have described the fieldwork I did at Stanford, but I should add that the little dissection I did took place there, many months after my first introduction to cadaver prosections and to watching others dissect bodies. At Tufts, I took a six-week anatomy course for occupational therapists during the summer of 2001. The course included lectures and a few opportunities to examine a prosected cadaver. On one occasion, I also spent an afternoon in the laboratory with the professor while he dissected the spinal column in preparation for a prosection demonstration a few days later. At the University of Washington, I interviewed six laboratory members over two days of fieldwork. I also have discussed the state of anatomy education with several anatomists and computer experts at Medicine Meets Virtual Reality, an annual



conference in the field of virtual reality in medicine, and at a conference titled, “Image and Meaning,” held at MIT in June 2001. Talking with anatomists around the country, I gathered much information about the state of anatomy teaching and the challenges the discipline faces.

For decades, medical students studied anatomy for a year or more (Becker, Geer et al. 1961, 81). Now, in most medical schools, human gross anatomy occupies from six to twelve weeks as a separate course or embedded within an introduction to human structure and function. Medical school bureaucracies have challenged the structure of gross anatomy teaching, citing several justifications. Institutional reasons for curbing anatomy teaching include the expense and difficulty of maintaining a willed-body donation program.<sup>23</sup> Anatomists cite the field’s decline as a research science and, at many schools, its absorption into molecular biology departments, whose leaders have no experience with or interest in human gross anatomy, among reasons for the decline of anatomy teaching. Medical schools interested in curriculum change also fret about the amount of time gross anatomy takes in the curriculum. And curriculum reformers have pushed to change the structure of teaching to focus more on clinical problem solving and less on the kind of large-scale memorization of names that traditional anatomical teaching tends to inspire.

Stanford’s experience is instructive. Within medical schools, the prevailing wisdom is that gross anatomy has reached its end as a research science; that very little

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<sup>23</sup> Anatomy programs appear also to be facing competition from other brokers of cadavers, who are in competition (sometimes illegal) to find bodies for continuing medical education programs and tissue banks as news stories in spring 2004 about the legal and illegal trade in cadavers and body parts attest (Cheney 2004; LATimes 2004). Competition for cadavers never came up as a concern among anatomists I interviewed.

new information can or will be discovered by anatomists. Anatomists themselves are viewed as dinosaurs. According to this argument, what's new and exciting about the human body is at the level of cells, tissues, or molecules. Since the late 1950s, anatomy departments have become increasingly submerged within molecular biology departments, often becoming part of large "structural biology" departments. Anatomy at Stanford is housed within the Surgery Department. The department moved into the Surgery Department from a structural biology department in the early 1980s, after strong lobbying by anatomists, including Dr. Robert Chase, an influential former hand surgeon and anatomist. Among the reasons for the move was to have gross anatomy taught to medical students by surgeons, for whom anatomy is a skill used daily. Further, Chase argued in a letter to the head of Stanford's physiology department, the move would strengthen the division's ability to provide anatomy instruction for continuing medical education and to work with engineers to develop a more mechanical understanding of anatomical function, as well as to further surgical training and research (Chase 1980).

Anatomy teaching at Stanford consists of a combination of lectures and dissection. This is still the norm at most North American medical schools. Dissection at Stanford and in many medical schools typically is taught in groups of four students assigned to one cadaver. At Stanford, two students dissect on any given day and then spend time in a section with their laboratory partners discussing what they dissected; then the pairs trade off (see also Hendelman and Boss 1986). Anatomists at Stanford, several of whom are retired or semi-retired instructors or professors, describe themselves as traditionalists, a vanishing breed of "true" anatomists (that is, not medically trained anatomists, rather than molecular biologists pressed into anatomical teaching) (see Zuger

2004). Their anatomy courses are heavy on the naming of parts and lectures involve careful and rather elegant diagrams of human structures that the anatomist outlines on a chalkboard and progressively fills in with multi-colored chalk. These diagrams bear little resemblance to photographs of dissected bodies or medical images of living bodies and are themselves a representational tradition: Anatomists say this kind of progressive filling in of structures is important, particularly when explaining how structures develop (developmental anatomy can make understanding complex structures much easier).

While I was at Stanford, the anatomy curriculum faced cuts in teaching time, cuts that ultimately were implemented the year after I left. A new dean had pledged to reform Stanford's traditional curriculum to better integrate both clinical experience and research opportunities. According to educators at the medical school, Stanford remained firm in its commitment to a traditional teaching style, but this debate fits within a broad movement toward medical curricular reform. Since Harvard Medical School pioneered its New Pathways curriculum in (Good 1994; Good 1995), medical schools have wrestled with curricular reforms that challenge the wisdom of a traditional medical curriculum that typically consists of two years of pre-clinical basic sciences, including gross anatomy, followed by a year or two of clinical rotations and internships. The model now considered traditional has existed since the 1950s (Becker, Geer et al. 1961). Curricular reformers have argued for bringing clinical experience into medical education earlier and for what is known as "problem-based learning," an approach that places less emphasis on factual learning and stresses learning the sciences through exercises that pose clinical problems as a means of teaching both the science and the problem-solving skills physicians need. Many medical schools around the country have adopted problem-based

learning in more or less radical forms and many have applied it to anatomy teaching (Collins and Given 1994). Anatomists who identified themselves as traditionalists, including those I encountered at Stanford, argue that problem-based learning is excellent for teaching medical skill, but leaves enormous gaps in knowledge when applied to fact-intensive disciplines, such as anatomy.

Anatomists in the department were seeking ways to justify maintaining the program unchanged. Simultaneously, they expressed a new willingness to experiment with computational tools for teaching anatomy, spurred by connections to SUMMIT, the presence of a few technological experimenters associated with the program, and a desire to find better methods of teaching skills and procedures that medical students often struggle with, such as the connection of instructions contained in a dissection manual to actual practice. The division was beginning to experiment with technologies for teaching three-dimensional structure, using stereo images displayed on specially equipped computers and with providing dissection instructions using photographic demonstrations of the steps as a supplement to a dissection manual. The debate at Stanford remains unresolved. At its core lie discussions about two facets of anatomy teaching: the role of cadaver dissection in physician training and the technologies future physicians will use to understand the human body.

### **Two challenges to dissection**

Debates at Stanford focused in part on whether and how to maintain cadaver dissection as the centerpiece of the curriculum.<sup>24</sup> Arguments for and against cadaver

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<sup>24</sup> I should note that most anatomists and medical students who I encountered at Stanford favored continuing an extensive program of dissection, though some medical school administrators had

dissection also are prevalent within the larger anatomical community, as I learned from other anatomists, both at conferences and through a list-serve for anatomy teachers. I heard many anatomists say computer tools eventually would replace dissection, but the reality is that no programs, except the commercial Adam software, which some students use, provide labeled anatomical models of the entire body and no anatomists I spoke with use computers beyond showing images using Powerpoint or teaching cross-sectional anatomy using sections drawn from the on-line Visible Human Male and Visible Human Female datasets. But computers and the promise of computational anatomy teaching, have heightened debates about the value of cadaver dissection. In this section, I describe two challenges to dissection. They touch on two key reasons for cutbacks: the first, that dissection cannot be shown to improve scores on board exams; and, second, that the expense of running a cadaver donation program is incommensurate with the time available to dissect.

During my first visit to SUMMIT in the summer of 2001, I sat in on a meeting in which laboratory members, including engineers and anatomists, discussed the value of dissection. The meeting was about computer technologies that could supplement or replace dissection, but the discussion really was less about computers than about dissection. One meeting participant was the director of an Australian medical program, who is a psychiatrist by training and has also taught anatomy. His program primarily uses photographs, models, a few cadaver demonstrations using pre-dissected materials, and plastinated specimens to teach anatomical visualization. Plastination is the replacement of

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begun to question how much time should be devoted to its study, so this discussion is skewed in favor of dissection, though I attempt to give alternative views where possible.

fluids in the body with polymers to create a permanent model based on real tissues. He said students do some dissection in their first year. "I think [dissection] will go because there isn't much evidence that it makes much of a difference," he said. "It's going to go." The Australian said his program focuses on preparing students for their internships, rather than for actual clinical practice. Thus, students learn touch and other skills anatomists cite as important lessons of gross anatomy in later courses. He predicted that cadavers eventually will disappear from his program altogether, saying studies indicate that dissection has little impact on student success during internships. In a 1961 study of medical education, Becker and others described how students in their first semester of medical school rapidly realize they must set priorities about what to study, especially in "big courses," such as gross anatomy, that require mastering of massive amounts of information (Becker, Geer et al. 1961, 110). The students have two choices: they can study what they expect to be on the exams or they can study what they deem to be clinically relevant. Most students, even those who initially prefer the clinical view, eventually began studying for the exams. The Australian's position is similar: teach students only what they need to know to reach the internship phase of their training. For this, he argues, dissection is unnecessary.

A second position was adopted by an anatomist at the University of Washington, who continues to support dissection, but who has begun to question its expense and its efficacy given the time students now spend dissecting. He says:

It's kind of become a sacred cow in anatomy, dissection. I am not saying that dissection is not important. It has its place. But it's the sort of a sacred cow that you mustn't cut back on it and you mustn't eliminate it. But what must you do for a class of 120 to 130 students? You must generate at least 25 or 30 cadavers for a class of 100. And you have to have a body donation program that operates statewide that educates the public that it is

a good thing to do. And then you've got to screen them. You've got to prepare them. You've got to embalm them. You've got to have a whole big setup here to deal with these bodies. And so it's a big, big expense. And then what has happened is the amount of time that is allowed to students to dissect has been cut back and cut back. So what they do is literally tear through, not having even enough time to really get the best out of it because they don't know what they are doing. They are trying to learn anatomy by doing dissection. And they destroy most of what they are trying to dissect because they don't know it. ... If I sit down and dissect a hand of a cadaver, I do a very fine job and, even though I know it all, I always learn something new. But if a student is given a hand to dissect, before they know the hand, they're going to ruin 80 percent of the stuff you could ruin. What they have learned, they could have learned without dissecting the hand.

Although the anatomist describes his colleagues' attitude toward dissection as treating it like a "sacred cow," he privileges dissection as something that ought to be done with enough time and care that students get the most out of it, another kind of sacralization of dissection. As teaching and laboratory time have declined, students no longer have time to properly dissect, greatly diminishing dissection's effectiveness as a learning experience. The anatomist also points to a difficulty inherent in the object itself: The body resists understanding. He describes the human body as an immensely complex entity, not fully knowable even after fifty years of practice. First-year medical students don't have the skill to open a cadaver and properly illuminate its insides. Once students or anatomists destroy the cadaver by dissection; they cannot go back. This is a one-way process.

### **In defense of dissection**

I heard many arguments about the value of cadaver dissection. Most revolved around three primary positions, each of which is controversial: first, that dissection is a medical student's first introduction to a medical relationship with the human body and,

for many students, to death and dying; second, that dissection is a medical student's first introduction to a medical relationship with the human body and, for many students, to death and dying; and third, that dissection is one of very few open-ended laboratory experiences in medical school.

The first argument, which I have heard anatomists, physicians, and students repeat often, is that anatomy is a medical student's first introduction to working with the human body and, often, his or her first introduction to death and dying. An eloquent physician, who trained in the Philippines and now works on creating digital anatomical taxonomies at a Pacific Northwest medical school, described anatomy thus:

Why cut dissection? What is your alternative? What is an effective alternative? One important thing people forget is that in the field of medicine, you deal with human beings. You deal with treating human beings. You're dealing with life and death. If all you're dealing with are cold holograms or plastic models, you lose that respect. If you're dealing with a cadaver, you're dealing with a real human being. That can translate later on when you're deal with real people. It helps you deal with human beings as human beings, rather than objects.

This physician states what may seem so obvious as to be nearly tautological, but which was repeated so often in these discussions that I began to wonder if physicians, in the world of charts and tests and images, themselves felt some anxiety on this point:

medicine is about treating human beings. The logic of this position about dissection is this: medical students begin their education by dissecting a human body, by creating a form of intersubjective relationship with a human body. Ideally, this experience helps them develop respect for the human body that carries into their treatment of living human bodies.

The second argument, that dissection uses all the senses and effectively teaches three-dimensional understanding of the body, came up often. According to proponents of



this view, many of whom were surgeons, tactile input helps form a mental model of anatomy, which physicians need to do their jobs. In other words, touch reinforces sight.<sup>25</sup> Some anatomists and physicians argue, in a similar vein, that bodies are dense and laboriously taking the body apart gives students an appreciation of this density. This argument goes together with the argument that the cadaver is especially useful for teaching three-dimensional spatial skills, one of the most important goals of anatomical teaching. A discussion about anatomy teaching that occurred while I was at SUMMIT made this very clear. A retired gynecologist said successful surgeons must develop the ability to extrapolate from two-dimensional images to the three-dimensional body (this skill also is fundamental to interpretation of radiological images). He said prosections—cadavers dissected for the student by an instructor—fail to provide the sense of three-dimensional connections that dissection can provide. A second-year medical student agreed.

You learn that three-dimensionality is drastically different from the two dimensions. I can tell you we were going in to dissect and we had *Grant's Dissector*. It's this book that tells you what to do and it has pictures and it even says, step one, cut here, step two, do that. And we would get totally lost because the body is just so complex and there are so many variations that you don't always understand what structure you're looking at or how deep to go or what to do and you really need a clinician next to you, or an anatomist to show you what you're looking at and where to go and give you some tips. You know, it's complicated. It's not just look at a picture or get a recipe and then execute it and find what you want.

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<sup>25</sup> Ian Hacking describes George Berkeley's eighteenth century theories of vision as an integration of two-dimensional vision with tactile perception to make vision three-dimensional, that is, "we have three-dimensional vision only after learning what it is like to move around the world and intervene in it" (Hacking 1983 189). This argument resonates with more recent experiments in cognitive science indicating that physical exploration of an environment speeds the acquisition, at least in cats, of perceptual abilities (Varela 1992).

The student says the body's three-dimensional nature and structural complexity make correlating a two-dimensional image to a three-dimensional structure very difficult. And bodies vary enormously, so understanding what is normal structure as presented by an atlas, what is anatomical variation, and what is pathology is very difficult. Anatomists and surgeons I have spoken with said repeatedly that, even after decades of practice, they still have much to learn about anatomy.

Anatomists cited learning three-dimensional relationships among structures in the human body as one of the most important justifications for dissection. Developing three-dimensional visualization skill is difficult and is most important to surgeons and radiologists, but also to any physician who uses medical images, or a physical exam, for diagnosis. Though this extrapolation is a skill prized among radiologists, its difficulty has been one justification for the development of CT scanners capable of building three-dimensional models. By this logic, the cadaver is a three-dimensional model, the best model available of human structure, a model that reveals anatomical variations and pathology.

I heard the third argument, that dissection is an open-ended laboratory experience, from physicians and medical educators, sometimes with an explicit analogy to bench science. As a Stanford hand surgeon sitting in on a discussion about the anatomy's future said, "... the human body is somewhat of a black box and you have to explore it hands on to get a sense of the context. If someone shows it to you, or it's on the computer screen, it's already packaged for you. You don't get that kind of exploration yourself." This physician argues that exploring a cadaver gives the student a sense of context and encourages the student to organize material on his or her own instead of relying on

lessons that are structured in advance (Becker, Geer et al. 1961, 110). I heard a similar argument at Stanford, from physicians, anatomists, and medical students who opposed the substitution of prosection for dissection. Dissection exposes the student not only to the body's regions and systems, they argued, but also to the ways dense flesh is connected and compacted, to fat and to fascia that might be anatomically irrelevant, but that might help form a clinical picture of, say, the effect of an injury or the difficulty of penetrating a region surgically. This argument connects to the arguments about the cadaver as a tool for teaching three-dimensional structure, but anatomists described another pedagogical facet of open-ended exploration: the possibility of making a mistake. Mistakes stick in a student's memory, they said. As a retired hand surgeon and anatomist told me, "It's ... the hands-on thing, the hand-brain notion. Another thing is that you learn where a structure is because you don't want to cut it and, therefore, you dissect carefully. ... If you want to have something stick in your head, if you cut the facial nerve, you will forever remember what it was." This position strikes a balance midway between the position that the cadaver is the best model of human structure and the position that anatomy is partly about teaching a relationship to a patient: cadaver dissection is an open-ended experience that allows exploration of structure, but making a mistake—cutting a nerve critical to functioning in the living—has an emotional charge that strongly reinforces memory.

These positions in defense of dissection are not incompatible with one another: I heard several anatomists argue that dissection is an economical use of time and money because of the many social and technical lessons it provides. The cadaver's ability to provide a dense, situated learning experience rests, in part, on its ontological instability.

The cadaver is neither a human being in the fullest sense of the words nor is it merely an object: it is both and neither. Even experienced anatomists struggle with this instability as I show in the next section.

### **Ontological instability: the cadaver as model, human, and model-human**

Even experienced anatomists and physicians engage in philosophical debate about the cadaver's ontological status: is it a model, a human being, something in-between? Those who argued for dissection's role in teaching respect for human bodies and understanding of death and dying favored the idea that cadavers are dead human beings, but some also shifted comfortably between viewing the cadaver as a human being and as a model. Others argued that the cadaver is a model, a particularly rich one, but a model and that the experiences students have of cadaveric tissue are far different from living tissue because embalming changes tissue colors and textures. While I was at Stanford, a group of anatomists on an email list-serve reaching anatomists around the world held a discussion about the future of anatomical teaching. The status of cadaver dissection became a critical part of that discussion and, by extension, the ontological status of the cadaver also became a critical part of that discussion. Here, I elaborate some positions the anatomists described as a means of opening up the cadaver's ontological instability.

An anatomist from the southern United States, who was rebuilding his laboratory after it had been destroyed by a tropical storm, posed the original question. Building from scratch provided him with an opportunity to ask his colleagues about the future of gross anatomy teaching and what a new anatomy laboratory ought to contain. The discussion included posts about how programs now are teaching anatomy and also what anatomy teaching ought to do. It is an invaluable resource describing the state of anatomists' views

about anatomy teaching and dissection. After a number of exchanges, a German anatomist addressed the cadaver's ontological status at length. He wrote:

I think it is not helpful to see the anatomical cadaver as "THE human body" or as "the real thing" because it is not. As more methods become available to "look" inside living human bodies (for diagnostic measures as well as for teaching), the more the difference between cadaver anatomy and "real" anatomy will be felt. To say that, e.g., computer programs "are not reality" is not a good argument in favor of dissection because neither is "the real thing."

I think anatomists should admit to seeing the cadaver as a "model," perhaps the closest you can get, but still a model. I am in favor of dissection, but I think the pros and cons of this "model" should be openly discussed. In particular, to convince others, more than anecdotal evidence will be needed in favor of "our" model.

This anatomist, responding to earlier, fragmentary comments about the cadaver's realness and humanity, says the cadaver differs from living human bodies in ways that will become increasingly evident as imaging studies of living bodies reveal differences between living and dead, preserved bodies. Basing arguments for dissection on the cadaver's "realness" will fail because the cadaver is not "real." He argues that the cadaver should be examined as a "model" of human anatomy and suggests that anatomists focus their discussions on the adequacy of the cadaver as a model because, among other reasons, dissection proponents will require good evidence about the benefits of dissection to make their case.

The German anatomist's position is multi-layered and complex, but he points to several important aspects of the debate around cadaver use. First, he argues that imaging technologies will show differences between cadavers and living human beings. Medical images increasingly are critical parts of anatomy teaching and diagnostic practice. As imaging becomes more important, the cadaver's status as a model of living anatomy will

face challenges. And as new tools become available, the appropriateness of the cadaver to teach understandings of the human body that fit with what the new tools reveal will come into question. The anatomist argues that the debate is best framed in terms of the cadaver's adequacy as a model used to teach living structure: if the tools students use to examine patients in future reveal the cadaver's differences from living bodies, then dissection's relevance will become questionable. Treating the cadaver as a "model" would provide a stable position from which to discuss its merits as a representation of living human anatomy.

Other anatomists on the list-serve objected to the German's viewpoint, so an anatomist, who teaches at a Pacific Northwest medical school, reminded the group that the German anatomist favors dissection, but wants anatomists to openly explore the pros and cons of the cadaver as a tool, if for no other reason than to provide strong justifications for continuing to teach dissection. He wrote:

[The German anatomist] clearly states he is in favor of dissection, but he calls for an open mind. Is that what the argument is against? I am often troubled by the fact that, when the role of dissection is discussed, there is little evidence of the kind of open mind we take for granted in relation to our research or other academic activities. Indeed, many of the arguments presented come close to discussions of religion by the faithful. I do not believe that such an attitude furthers our cause, whatever that may be.

This anatomist points to how emotionally charged discussions of dissection become and says the debates resemble those surrounding religion. He calls for an open-minded discussion of dissection's value. This anatomist and the German anatomist both are trying to rope off the cadaver's status as a former human being—and the emotional connotations of the cadaver's human status—to encourage a discussion of the cadaver as a model of human anatomy, a model whose effectiveness should be interrogated. Human

corpses, of course, have enormous religious significance in most cultures (Mitford 1963; Metcalf and Huntington 1991; Hertz [1907] 1960). And many medical schools explicitly acknowledge that significance in memorial services for donors held either before or after the dissection. The Pacific Northwest anatomist suggests that arguing over the cadaver's status from a place of emotional or religious attachment will not help anatomists take an effective stand—or any stand—on the value of dissection. Thus, the anatomist promotes putting the debate on the grounds of “scientific merit,” rather than emotion.

An anatomist at a southern California medical school argued strenuously for the cadaver's humanity and “realness.” She wrote:

The corpses we use at our institution are individuals who donate themselves for use by our medical and dental students as a learning tool. They know the value of hands-on learning versus visual-only, and we attempt to honor their unselfish giving act.

Finally, I also think there is a misunderstanding between “real (=genuine, authentic, factual) things” and “living (=alive, breathing, active) things.” Our cadavers are real. I don't know about someplace else.

In our university, the freshman medical & dental students with the anatomy department do a commemorative service at the end of the course, after which, we feel a closure between life & death, with a tribute to those who gave the ultimate “thing” that they have left after their last breath, the human body.

This anatomist notes the German anatomist's linguistic slippage between “real” and “living,” saying a cadaver is real, even if it is not living. I have heard this slippage often in discussions about cadavers. It suggests that people contemplating the cadaver consistently mark it as “other” than the object of medical intervention, the living human patient.

The anatomist says people who donate their bodies do so with the recognition that these bodies will become hands-on learning tools, different from—and used in different ways than—medical images. Her university, which houses both a medical and a dental school, holds a memorial service for dissected remains. She says the memorial service gives the living a sense of closure in relation to the dead and acknowledges the gift donors have given them. Twice, in a few short sentences, the anatomist notes that the cadaver was donated by a living person. She defines the cadaver as human in part by giving it agency: the person who donated his or her body. There was an agreement between living person and the medical school to use the body as a learning tool. She brackets the body's status as cadaver by discussing two moments in its trajectory when its humanity is incontestable, when the living person agreed to donate his or her body and, after the dissection, when the anatomy department and medical students hold a memorial ceremony as a tribute to the donors and as “closure” for the living. The body is that of a human being—and is, therefore, real because the first act, that of donating a body, could only be performed by a living human being and the second act, the memorial service, is a service that explicitly thanks the individuals who made the donation. Such a ceremony would make no sense for an object.

One way to read these two moments of human agency is in terms of Marcel Mauss' essay on gift exchange, which says that an act of gift giving must be reciprocated with a second gift exchange some time after the first act (Fox and Swazey 1992; see also Fox and Swazey 2002; Lock 2002; Mauss [1950] 1990). The donor gave “the ultimate ‘thing’ that they have after their last breath” for use by medical students. The student's learning experience—often couched in terms of future clinical skill is the



reciprocal exchange. As a student at Tufts University Medical School wrote in a student publication, “I needed that moment of silence we shared on the first day to privately thank this remarkable woman for letting me use her body to learn. I had to appreciate this gift she gave me before I could make that first incision” (Aguilera 2001). This student says the woman who donated her body gave her a gift to learn from. The student needed a moment of silence—part of the preliminaries to anatomy classes at Tufts—to thank the woman and to appreciate this gift of a body for education. A final memorial service provides “closure” for the living. The donation marks the cadaver as a person who is able to—who intends to, in a legal sense—give his or her body. The student is encouraged to “reciprocate” by recognizing the gift as an opportunity to learn a discipline that will help him or her heal other bodies in the future.

Another anatomist from southern California argues for defining the status of the cadaver as the student’s first patient. He wrote:

One intriguing proposition has come not from our Anatomy department, but from Pathology (although we anatomists wholeheartedly agree with it). That is, that we make the cadaver the first “patient” for the student; we get medical files for the patient (the willed body program can provide them and blank out the names on the copies), including lab data and x-rays, and then, as dissection proceeds, a pathologist goes over the organs and such the student, helping them see pathologies and recognizing things they wouldn’t see otherwise. Currently, when the students find cancerous lymph nodes destroying normal tissue, they get frustrated because they can’t “see” what’s expected of them. This way, it will cause interest in what the effect is on the patient. We also get students frustrated by “anomalies” that are only minor variations. With this, they will learn what is a variation and what is normal.

The anatomist argues that the cadaver can be a first case study for a student, particularly by bringing pathologists, medical files, and x-rays into the anatomy laboratory. The cadaver then becomes a study in recognizing and finding pathology. This approach, he

says, would help make clear for students the connections between normal anatomy and pathology and also between abnormal anatomy and anatomical variations.

This anatomist takes no direct position on the cadaver's humanity, except by positing the cadaver as the first patient and suggesting that the cadaver act as a pathological case study for students. Several other anatomists on the list-serve said they tried this approach and found it educational. What interests me in this statement is the how the addition of a case file, lab reports, and medical images can effect a shift in ontological status from "cadaver" to "patient" (Good 1994; Cussins 1998). Such an approach, the anatomist says, will help students learn to make distinctions between normal and pathological anatomy and between normal and variant anatomy. Giving medical students exposure to variation—of pathologies and anatomies—is one argument, contested by some, that anatomists make for dissection, particularly for dissection in a laboratory containing many cadavers for comparison.

An anatomist who teaches at a different medical school in the southern United States, objects to any humanizing of the cadaver as patient or person. He writes that the respect due to the cadaver is merely part of the agreement with the donor or with the donor's family. The cadaver has no status beyond that of an inert object. He wrote:

My personal conviction is that the ethical status of a dead human body is the same as that of other lifeless objects. A donated cadaver should be treated with some degree of respect because that's part of the understanding with the donors—either with the person who offered his or her body after death for scientific study, or with the relatives—but the cadaver per se has no moral or ethical standing. That's why it can be dissected or cremated. Whatever ritual gestures of respect accompany its destruction are for the comfort of the living, not because we owe it to the dead. The cadaver isn't the student's first patient (which means "sufferer") because it's not suffering anything, or suffering from anything. Thinking of it as a patient seems to me to be no less serious a category error than thinking of a genuine patient as an anatomical specimen. The difference

between being alive and being dead is as all-important in morals and ethics as it is in everything else.

This anatomist equates the cadaver with any other “lifeless object” and says it has no “moral or ethical standing.” This lack of standing allows cremation or dissection.

Memorial services and other rituals solace the living, not the dead, he says. The word “patient” means “sufferer” and, he says, the cadaver does not suffer. Equating cadaver with patient is a category error, he says, and invites comparison to the opposite notion: that a living patient is an anatomical specimen. He says the distinction between alive and dead is important to morals and ethics.

By denying the cadaver any status as patient, this anatomist places the cadaver squarely in the category of object. The human body’s status as alive or dead is, for this anatomist, the crucial distinction necessary to create a moral or an ethical stance that determines what can and cannot be done to a cadaver. He worries that any confusion of categories will encourage a slippery boundary between patient and anatomical specimen. This anatomist’s reasons for giving respect to the cadaver is paradoxically in keeping with the notion of gift exchange: although the cadaver has no standing, the medical school, including anatomists and students, made an agreement with the donor or the donor’s family to treat the body with respect.

Finally, the German anatomist who began the discussion by suggesting that the cadaver should be defined as a model, after several days and many more email exchanges, objects to the southern anatomist’s position that the cadaver is merely a lifeless thing:

Whatever you think of rituals dealing with bodily remains, you seem to think that the only alternative is to see the cadaver as a mere thing. I think

we should accept that it is at best ambiguous: a very material thing on the one hand and, at the same time, reminding us of a living person on the other hand. How you deal with the latter is, of course, a question of culture, not anatomy. But I think it should be part of “medical school culture” that students understand this ambiguity rather than just ignore it.

In this posting, the anatomist argues that the ontological status of cadavers, at least when couched in cultural terms, is ambiguous: the cadaver is both a material object to be explored and the remains of a living person. He suggests that encouraging medical students to recognize this ambiguity and to learn to work with it is an important part of medical school acculturation. He seems to want to carve out a space for the cadaver within gross anatomy that is free from cultural concerns, just as the Pacific Northwest anatomist wants the debate to be free of emotional or religious concerns. He also recognizes, however, that medicine and medical education are not free of cultural concerns that inflect the stance medical students take towards cadavers.

The German anatomist’s position that the cadaver’s ontological status is ambiguous articulates precisely the “ontological instability” that I argue is one of the lessons of cadaver dissection. The cadaver’s status is fundamentally unstable: It is an object of medical inquiry and a set of material remains; it is also a former subject who willed his or her body to medicine with the intent that it provide an opportunity for exploration and learning. Medical educators can and should work with this ambiguity.

The ambiguity of the cadaver’s status comes up often in medical student reports about their experience. One medical student at Tufts, writing in a student newsletter, expressed her struggle:

This dissection is definitely something completely new. I don’t feel at ease with it, but I am surprised by how easy it is to carry out. I am definitely enjoying learning about anatomy by taking apart an actual body, but I

have been avoiding thinking about the cadaver as a former person. To me, this week, the cadaver on the table has been a fascinating object. I am sure that my brain is compartmentalizing the experience, because when I try to think about the person who inhabited this body, these thoughts are immediately pushed aside for as long as I am in lab. On the other hand, the numbness that surrounded my brain during the first few hours of dissection, protecting it from its own natural line of inquiry, seems to be slowly lifting. I hope that in a few more weeks those compartments will start to come back together, and I'll be able to handle a greater appreciation of what I'm doing. I would like to be able to understand the cadaver simultaneously as a former person as well as an object. I'm trying to work out why this is important to me. I think it has something to do with how I understand my purpose working in medicine.

So, I need to be sensitive, but I can't be squeamish. I need to recognize that, although there is certainly violence in our dissection of this cadaver, there is no harm being done. I had to think about that for awhile, because it feels counterintuitive. It's all right to enjoy taking this body apart. It's all right to enjoy the process as well as the information gained. In the end, the gift of this experience will come around and be given back as I approach my living patients with knowledge and confidence. Eventually, I need to learn how intimate inspection, physical or emotional, can be done with respect and purpose. This dissection is part of an important acculturation, by which my inhibitions will be broken down so that I can be responsible to my future patients. For this reason, I'm going to try in the next few months to confront my unease rather than ignore it, and to blend together my ideas about the cadaver as a specimen of anatomy and as a dead person.

This student remarks that, at least in the first week of anatomy, she has been unable to imagine the cadaver as a person, preferring instead to see it as an object. But she hopes to integrate the two views of the cadaver because she believes such a position might help her as a clinician. The student recognizes that the violence done to the cadaver is permissible, both because of the clinical lessons she will learn and because the donor has given his or her body for this purpose. And she recognizes that she will have to learn to adopt a clinical, but respectful position toward her patients. She sees that cadaver dissection is her initiation into medical culture. Clearly, in this passage, the student is

wrestling with the issues of detachment and concern that Fox (1988) describes. Further, the student recognizes that, at least for the moment, she must objectify the cadaver to manage dissection emotionally. But she does not want this objectification to remain her only stance toward the body. She wants to be able to consider the cadaver—and eventually her patients knowledgeably and respectfully.

Anatomists, those who, along with pathologists, morticians, and coroners, have more experience than almost any other profession at dealing with dead human bodies, cannot agree on the cadaver's ontological status. In grappling with this issue, they evoke various rituals and technologies to help them settle the ontological status of the cadaver: a person donated his or her body, therefore the cadaver is human; the cadaver can be dissected or cremated because it has no moral or ethical standing and cannot be thought of as a patient because it does not fit the definition of "sufferer." Medical students also express similar sentiments. The German anatomist's last statement and the Tufts student's comments make what I argue is the most productive point: the cadaver's status is fundamentally ambiguous. That is, the cadaver, as a human body that once contained life, is ontologically unstable. Its precise status cannot easily be pinned down because it is both object and former person. It can be figured as closer to object or closer to person depending on the technological, rhetorical, and ritual practices in which we wrap it, but the cadaver *as such* cannot be definitively established as person or thing.<sup>26</sup> What I show

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<sup>26</sup> In a particularly poetic passage, Julia Kristeva articulates the corpse's ambiguity as the border between living being and object: "No, as in true theater, without makeup or masks, refuse and corpses *show me* what I permanently thrust aside in order to live. ... If dung signifies the other side of the border, the place where I am not and which permits me to be, the corpse, the most sickening of wastes, is a border that has encroached upon everything. It is no longer I who expel, "I" is expelled. The border has become an object. ... The corpse, seen without God and outside of science, is the utmost of abjection. It is death infecting life" (Kristeva 1982, 3-4).

in the next section is how the various tools of physical and conceptual dissection move the cadaver from ontological instability to ontological multiplicity: that is, the anatomist's tools, whether scalpels, memorial services, or computer programs, all cut up the body in different physical, social, and conceptual ways, ways that take a particular stand on the question of the cadaver's ontological status and that point to the cadaver's relevance for treatment of the living.

### **Cutting tools**

In this section, I look at various technologies for dissecting the human body and ways they address a body's ontological status. To begin, I provide one long, dense description of a dissection experience, my own, to open this discussion of the ways bodies get "cut up." As discussed above, the anatomy course I took was for occupational therapists and focused heavily on the musculo-skeletal, nervous, and circulatory systems, including the heart, at the expense of other organ systems and reproductive anatomy. Knowing my interest in anatomy and anatomy teaching, the professor invited me one day to come to the laboratory to watch him dissect the cadaver for a demonstration of the anatomy of the spinal column. I accepted. On a warm day in June, I took a bus to the medical school with the anatomy laboratory. The medical school and its affiliated hospital are in a rundown section of Boston. The anatomy laboratory was through a set of double doors at the end of a long corridor containing lockers. The first time a student group had attended a prosection, the professor, who I will call Dr. Z, gathered us in the hallway before we entered the laboratory and gave us a short talk about respect for the cadaver and about what to do if one of us needed to leave the room. He had spoken about

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this during the lecture as well, and I realized that he was trying to help us grow accustomed to the cadaver in several short sessions. This time, Dr. Z and I went to his office while he gathered tools, put on a white lab coat and found another coat for me. His office was littered with artifacts—drawings made by his children, Star Trek memorabilia, and some cooking magazines (Dr. Z liked to cook). We went down the hall to the main dissecting area.

The laboratory itself was a large room divided by cement columns. It had windows overlooking the hospital complex and industrial safety showers with triangular pull-down handles sprinkled around the room. The room also had several large stainless steel sinks. Rolling, stainless steel tables that during the school year would have held cadavers were corralled up against one wall. The room was empty. The cadaver was in a smaller room adjacent to the main dissection laboratory. The smaller room held cabinets, another sink, and a bench covered with tools and models of bones. Also in the room was a stainless steel table with the cadaver on it, zipped into a bright blue body bag. This was the second time I had seen the cadaver and I felt some of the same dread I had felt the first time. Dr. Z spent some time bouncing around the laboratory, frenetically getting gloves, putting blades on scalpels, finding gloves, puttering. He later explained that he uses this manic behavior to distract first-time dissectors from what they are about to do. He explained the relevant anatomy and the dissection he was about to do. The procedure is called a “laminectomy” and he showed me on a model spine how he planned to chisel open several vertebrae to reveal the spinal column and its associated nerves. I wrote the following passage as soon as I returned to my office:

We went into the inner dissecting room. ... The procedure involves removing the dorsal part of the vertebrae ... to reveal the spinal cord



beneath. Dr. Z racked up a scalpel for me, but I couldn't cut. He began by gently removing some of the muscle on the back that hadn't already been removed. Cutting and peeling away flesh this gently was a little hard, but not impossible to take. ... Then he began to cut into the deep muscles of the back. He cut all the way down to the bone and had me run the scalpel through the cut to see how deep the muscle lies. In the lower back, the spinal column is inches deep, through about three inches of muscle, at least on this guy. As I ran the scalpel through the cut, I could feel it bumping over bone, which were the transverse processes. ... The next step involved peeling away the muscle and it was nasty. It basically involved hacking away large strips of muscle tissue and tossing them into the red bucket below. When he had cut down to bone, Dr. Z asked me to feel the depth of the muscle with my hand. It was really pretty incredible, but not fun. The dissection was a lot like butchery, except it was messier. ... The next step involved chiseling away the spinous process. This involved a hammer and a mallet. Dr. Z offered me the chisel, but I certainly wasn't ready to do that. He said, and I found this interesting, that he works both by feel (often not even looking at the body) and by sound. The sound of the chisel changes when he pushes through the bone into the underlying cavity. At that point, he began clipping away large chunks of bone. This was very messy. And I kept looking at the chunks of bone and muscle coming out of the back and getting set down next to the body for eventual deposit in the red bucket. So Z removed one vertebra to reveal the spinal column below. ... After snipping another six or eight inches away, he had opened up the spinal column to view. The spinal column was red, not white, as I had seen in books. ... Then he snipped away the *dura mater*, a thin, but tough membrane, which I actually felt. You could see the *cauda equina*, which looks much more like a horse's tail than any drawing I had seen. You could also see dorsal root ganglia, which were really cool. They are very distinct bumps on the nerves. After that, Z snipped a little further up to find the *conus medullaris*, the end of the spinal cord proper. ... At certain points in the dissection, the meaty smell rose up from the body enough that I had to step away. At other points, the view of the inside of the body was so fascinating that I wasn't at all aware of the fact that this was a dead human person. ... Afterward, Dr. Z cleaned up and zipped the body back into the bag. I washed my hands, twice, but could still smell what seemed like the meat smell on my hands. Dr. Z and I went back to his office so I could interview him a bit, but truthfully, I was completely out of it ... I struggled through a few questions, then quit. ... Even after, I could still smell meat, though I'm certain it was my imagination.<sup>27</sup> ... I got off the No. 1 bus at MIT and walked across campus. I passed street construction and was looking at the archeological layers of cobblestones

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<sup>27</sup> I later learned that the smell was not imagined: phenols from cadaver preservation leach through latex gloves.

and other things under there when I noticed yellow-wrapped fiber-optic cables lying in the hole, looking like a spinal cord, as though Mass Ave. had also had a laminectomy. A little further and I was passing the Strata Center construction site and I saw a set of six or eight big pipes running from the base of a hole in the ground into its side. They reminded me of ribs. I thought this was funny, except that everything was reminding me of opened up bodies. I had to wash my hands before I went to the Chinese food trucks, thinking that I needed to do it even before I touched the styrofoam box. I went to the trucks thinking I was hungry. I ordered mango salad, which I thought was completely innocuous, except that the fried tofu on top looked like trabecular bone, which I had held in my hand so recently and, oddly, it seemed to taste like chemicalized meat. I couldn't eat much of it and I certainly couldn't look at it. I also had to toss out the sweet pink lemonade.

Writing these notes was a cathartic way of grappling with the intensity of the dissection.

By late that night, however, I was reflecting on various theories of the medical gaze, while still remembering that I had run a scalpel across a dead man's spine. Robert Hertz ([1907] 1960) in his discussion of the double funeral describes the time between initial ceremony and final burial as a process of mental disintegration and eventual synthesis for mourners. At the point when the body receives its final burial, the social and psychological fabrics of the community torn apart by the death have been reknit. I underwent a disintegration and synthesis within the ritual space of the laboratory. The process involved a passage through the body, to the point where the world around me revealed its spinal cords, ribs, and bone. In that passage through the world-as-body, I believe the body incorporated me, so I could later incorporate it. I wasn't finished being disturbed, but the next time I was in the laboratory, I found myself absorbing the anatomy and thinking critically about the experience, while also thinking about the man on the table (Douglas 1966; Turner 1967; Van Gennep [1908] 1960).

This passage into the laboratory, into the spine, and out through the symbolic body of MIT reveals many key issues related to studying anatomy using the cadaver as

the privileged teaching object. Overshadowing all is the intensity of the emotional experience and my efforts to grapple with it. Underlying this are the technologies used to open the cadaver physically and conceptually, which include the scalpel, the spine model, and the anatomy atlas; the training of sight and touch; the language of anatomy and its connections to the dense, three-dimensional structures seen and felt during dissection. As suggested by the number and diversity of lessons contained in this dissection experience (as well as the lessons not contained here), the cadaver provides a dense, complex, situated learning experience (Suchman 1987; Haraway 1991). In the remainder of this section, I will describe the social, material, linguistic, and visual technologies used to open up the cadaver.

Though they do not appear in this passage, several social technologies help medical students manage the emotions dissection evokes and learn to take a humanistic stance toward the cadaver. The first is the knowledge that the donor gave his or her body for scientific exploration. As noted above, this gives the donor agency: he or she wanted and expected the dissection to happen. Several medical students I talked with described this as comforting and I experienced it similarly. The second social technology is the lectures the professor gave about respect for the cadaver. Dr. Z and other anatomists I talked with said they stress the idea that cadavers are human remains and inappropriate jokes or uses of the cadaver would not be tolerated (Hafferty 1988). These reminders about respect keep the cadaver's humanity in view. Accompanying this is social modeling of the sort Fox (1988) describes when she talks about pathologists: anatomists treat cadavers with respect, but also with clinical detachment. They do not appear disturbed by the cadavers' nakedness, by handling the body, or by cutting. Anatomists

model a particular clinical stance toward the cadaver that is one of medical students' first lessons in clinical behavior. The final social lesson that marks the cadaver's humanity is the memorial service that many medical schools conduct for those who donated their bodies. I did not have the opportunity to experience one of these services, but several medical students told me that the services provided an opportunity to thank the donors and, sometimes their families. Each of these social technologies produces knowledge about cadavers that places them in a social frame, as a donor with agency, as a body that must be treated with clinical respect, and as a former human being, who deserves to be memorialized and thanked.

Related to these social technologies is the idea of the cadaver as a part of an important initiation into medical culture. The following excerpt from a group discussion I convened on the future of anatomy at Stanford University School of Medicine captures many of the issues:

**Anatomy professor:** And that is another reason why anatomy comes under attack because it can't say that new knowledge is being generated on a weekly basis. I mean, that's true.

**Retired anatomist:** But neither is it in the French language and yet if you go to France, it would be awfully nice to know how to speak French.

**Anatomy professor:** I think we have to base our argument on exactly that. We don't try to compete with genetics or biochemistry in terms of the explosion of knowledge. We say, look, it's a language. It's an acculturation process, becoming a member of the medical community. And it applies to more of what lies in their futures, perhaps, than some of the other courses do because it's a fundamental language of description, of function, of nouns and verbs.

**Educational technologies expert:** And you can't replace it with a computer because...

**Retired anatomist:** That you can talk to students about and you'll find that the transition from undergraduate school to medical school is a very

important period. And students time and time again will say, you know, I finally recognized I was in medical school when I walked in the room and here were cadavers and we were doing something human, with human beings. And it's very important that they experience that, I think. They learn a lot about death and dying. They learn a lot about family relationships because we spend a little time telling about where cadavers come from, poems by the donors and things like that.

This short piece of a much longer discussion captures one of the reasons for cuts in anatomy teaching—anatomy is no longer a research science (its cost is another). But the Stanford anatomists also describe anatomy as an initiation into medicine in several important ways. The retired anatomist describes gross anatomy as an initiation into the language of biomedicine, comparing it to the study of the French language. Anatomical terms are the lingua franca of medicine, the basis for much of medical communication. And the anatomy professor argues that gross anatomy is an initiation into a culture and a community (see also Collins et. al. 1994, 288). Further, the retired anatomist sees anatomy as an initiation into a fundamental truth about medicine: medicine involves the treatment of mortal human beings. And anatomy is a confrontation, for many students their first, with death. The retired anatomist describes gross anatomy as a rite of transition (Van Gennep [1908] 1960) from undergraduate school to medical school. This transition includes learning a new language, new practices for working with the human body, and learning about death and dying. It has the classic three-phase structure of an initiation rite: first-year medical students are separated from their earlier lives both in the ritual space of the anatomy laboratory and through the sheer amount of time they must spend studying with one another (Becker, Geer et al. 1961, 88). They enter a phase in which their relationship to the bodies of others bears little resemblance to previous experience, in which bodies become anatomical (Good 1994), but they have not yet learned a clinical

stance. They begin to learn the norms and behaviors of the medical profession, their new group (Turner 1967; Van Gennep [1908] 1960). They are becoming doctors. The cadaver's role in this drama is to help initiate students into this entirely new relationship to the human body. Dissection remains—in most medical schools—the first, most important rite of passage into medical knowing.

The material technologies described in this passage are the scalpel and chisel. Dissectors use many simple tools, including chisels, scissors, saws, and particularly hands, used to physically open up the cadaver. This may seem obvious, except that even these primitive tools create a particular relationship between the medical student and the cadaver and create a particular articulation of the cadaver. Hands, and the tactile experience of dissecting, should not be neglected as technologies of knowing. As one medical student described, holding up her hand, “You know, this is the best tool; it's smooth, it's not sharp and it can feel everything perfectly” (Jennifer Hannum quoted in Giegerich 2001, 107). During the laminectomy, Dr. Z encouraged me to use my hands to measure the depths of various muscles and to touch the spinal column. As the passage reveals, this tactile experience was instructive: back muscles are far deeper than external visual or tactile inspection seems to indicate: this kind of information is instantly accessible to the fingertips and becomes part of the three-dimensional understanding of the body.

Haptic knowledge—the knowledge that develops through tactile and kinesthetic perception—is difficult to articulate and to quantify as haptics researchers at SUMMIT continually reminded me. And its relevance for anatomical learning—as the psychiatrist and anatomist who challenge dissection say—is unclear. Though some computer

technologies are being developed at Stanford and elsewhere that would provide haptic feedback for various educational simulations, these efforts are not being directed to simulations of anatomical dissection. Haptic experience of the cadaver would probably be the most obvious loss if anatomy became entirely computational. One supporter of dissection described dissection's haptic dimension:

I still think at this point that there's no substitute for the cadaver. You get the actual feel of the structures. You actually see the spatial relations between objects that you can't grasp with a two-dimensional object. You can see whether the tissues are soft or hard, loose or dense, and you get the tactile perception. The other thing about cadavers: it gives you an instantiated model, not a canonical model. ... Actual cadaver dissection is instantiated. A lot is the same for you and me and for everybody else. But the variations are infinite. They are in the granularity, in the details.

Cadavers give students some sense of how tissues differ by feel. It also provides a sense of spatial relations that are unclear in two-dimensional representations. They give a sense of how tissues are packed together. And they give a sense of the vast variation of bodies. This is especially true when dissection occurs in a laboratory with many cadavers that can be compared. But even during my anatomy class, which had only one cadaver, the professor pointed out a few unusual branches the man had in his brachial plexus, the major complex of nerves in the arm and shoulder.

Dissection opponents argue that some kinds of haptic knowledge are needed only for surgeons and that three-dimensional skill can be taught in other settings. And proponents of computer modeling say they eventually will program major anatomical and pathological variations into their systems (though I have never seen or heard of a program that incorporates variations). But this anatomist's statement contains a suggestion that the cadaver as a model, because it is an example of a body, even though of a body that is

irrevocably altered, is closer to a living human body than any other representation and, further, that the cadaver aids the development and use of tactile and spatial skills in ways that most other models do not.

The language of anatomy—the classification of the human body—is a technology that symbolically cuts up the body’s parts. These Latin names form the basis of much medical understanding. As noted above, this language describes the function and often the location of anatomical structures. Because anatomy is a visual discipline—and the language that describes the body is closely tied to visual identification of structures—it is difficult to describe anatomical taxonomy without reference to the visual-linguistic models anatomical teaching attempts to instill in students. But they are not identical. Two examples of this interrelationship suffice. Anatomy students in an undergraduate course I observed at Stanford divided themselves into two groups: one group would dissect while the other group pored over an atlas. The groups then worked together to identify the structure of interest in the cadaver, compare it to its visual equivalent in the atlas, and then repeat the name several times to begin to fix the term in memory. The key skills most anatomy exams I have seen involved identifying a structure based on its location or function; naming a structure based on a functional deficiency, such as nerve damage in a particular region of the body; or naming a tagged structure on a dissected cadaver. These examples make clear that gross anatomy teaching is about learning the names of structures and learning to visually identify these structures in the human body.

As an anatomist at the University of Washington, who is working on computational visual and linguistic models of anatomy, says:

And so I thought that in order to be able to reason anatomically as a physician, because that's what you have to do when you are examining a



patient or when you interpret any kind of medical data, for that you needed two things: You had to have a mental image, a mental model of what was underneath the skin and you also had to have a kind of a more abstract symbolic model of the knowledge, of what were the relations what was the kind of information that related to certain kinds of things. That sort of dual modeling problem has been a part of our big anatomy research. The research now is concerned with modeling, creating graphical models of the human body ... but parallel to that, to make sense, to give meaning to that graphical model that is represented by pictures or 3D graphics or whatever, you have to have a mental model and I call that a symbolic model because the symbols, you have to use some kind of symbols. For humans, the most meaningful symbols are terms.

These visual and symbolic languages of the body are primarily about identification and description. They provide the topographical map of the body that allows clinicians to locate pathology (Foucault 1973). Many visual tools have developed to help students learn to identify structures in the body. Atlases and model body parts provide visual aids for students. Each uses particular visual conventions to help make this possible (see Lynch 1988; Lynch and Woolgar 1988). The models are extracted from the context of the body, so they provide a partial view. Atlases often exaggerate a particular structure to make it more readily identifiable, as I learned during my anatomy course when an artist taking the course and attempting some anatomical drawings realized that the tendons in the human wrist, as depicted in Frank Netter's *Atlas of Human Anatomy* (1997) could not possibly be the size shown in various drawings and still fit in the wrist: the atlas magnified the tendons to make them more readily identifiable. This is a form of "upgrading visibility" (Lynch 1988, 51).

Medical images, such as CT scans, MRI images, and three-dimensional graphic models, clearly also are technologies that visually dissect bodies in particular ways and following particular conventions. X-rays, for example, extract hard tissues from soft,

revealing bodies as black-and-white shadows. MRI images reveal the soft tissues, but in hazy swirls that take extensive training to read. CT and MRI images also are cross-sections of the body, cutting the body into visual slices that respect neither organ nor system boundaries, creating a new space of the body that I discuss further in Chapter 3. Though radiological images are rarely a large part of anatomical training, medical students typically have some cross-sectional anatomy and the importance of learning to correlate these two-dimensional images to three-dimensional structures and vice versa. We have come to take for granted the naturalness of peering into the body using the light, sound, and magnetic spectra, through even a cursory glance at the early history of the x-ray reveals how deeply disturbing the idea was just a century ago (Reiser 1978; Howell 1995; Mann 1995; Kevles 1997). As the German anatomist cited earlier suggests, the ability now to examine living bodies using these technologies may eventually show just how different the cadaver is. More importantly, these types of images may lead to a view of the body that places more emphasis on the connection of structure to function, as some anatomical computer technologies are beginning to indicate.

### **Computer technologies and anatomy**

Computer technologies that represent human anatomy are varied. Most still are research projects available to medical students only as prototypes, usually covering only fragmentary areas of the body,<sup>28</sup> or embedded within other technologies, such as the surgical simulators described in Chapter 4. But some of these research efforts—and their

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<sup>28</sup> One anatomist described this to me as a serious gap in federal funding: funding is available to develop an application covering one area of the body, but almost never to develop a robust, usable program that covers the entire body. Often the gap between research applications and commercial development is too great to make up the difference, so promising educational technologies often remain on the shelf.

products—provide intriguing representations of the body. Anatomists I have talked with describe several goals for anatomical computing: they want whole-body models that can be dissected, put back together, and dissected again until students understand the anatomy. They want programs that connect structure to function within animations. They want programs with enough “intelligence” to reveal the logic of anatomy beyond its fact base. And they want three-dimensional representations, whether from stereo photographs or as rotatable, manipulable graphic models.<sup>29</sup> To achieve these goals, anatomists, engineers, and computer scientists have begun to build some component tools that do pieces of this work.

The University of Washington anatomist who argues in the last section that anatomical knowledge is spatial and symbolic is working with a medical informatics research scientist to build computer expert systems (Rosse 1995; Brinkley, Hinshaw et al. 1999; Rosse n.d.). The group has revised existing taxonomies, called “ontologies” in the world of computer knowledge representation,<sup>30</sup> contained in two standard reference works, *Gray’s Anatomy* and *Terminologia Anatomica*, to make the classification

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<sup>29</sup> Stereo photographs use two cameras set at a particular distance, and special viewing technologies, such as a Viewmaster or a pair of goggles, to create a three-dimensional view. They have had some influence on anatomical teaching since their invention in the last century, though their use has been limited because of the technologies required to display them. Stanford houses the Bassett Collection, a complete anatomical dissection photographed in stereo and some universities, particularly in Europe, still contain viewing areas to look at anatomy in stereo. As one anatomist explained to me, experienced physicians do not need stereo, but it can hugely aid beginners to visualize three-dimensional structure.

<sup>30</sup> The world of classification systems in medicine and medical informatics is enormous and fraught. There are no fewer than thirty-five distinct classification systems, excluding the anatomical system I describe above, and thirteen sets of standards, used in all areas of medicine. These systems all are designed for specific purposes, such as classifications of pathologies, drugs, or treatments, with much overlap (see Bowker and Star 1999 for a discussion of medical classification).

sufficiently precise to become the representational infrastructure for an anatomical expert system. What these anatomists have discovered is that, to make existing taxonomies precise enough for the computer, they often must define exactly how one body part relates to another, such as whether one structure is “part of” another or a “an example of” another. This kind of classification has long been part of anatomical taxonomy, but the anatomists at the University of Washington often must define relationships that have been effectively irrelevant to anatomical research because the computer dictates that they must create a specific logical relationship between parts. So these anatomists often must decide what the relationship is when it has remained unclear. For example, on a day when I visited the laboratory, an anatomist was working on classifying skin, which is a type of organ. Skin can be either hairy or smooth, according to existing anatomical classifications. This anatomist had to decide whether hairy skin is part of smooth skin or vice versa, or whether both are examples of skin. Occasionally, the group also has had to name anatomical areas that previously had no names. For example, the outflow of a particular heart valve has a name, but its inflow (same blood on the other side of the valve) had no name because the information is clinically irrelevant. But computer representation requires a name. This anatomist says his job is to make explicit anatomical concepts that, sometimes for centuries, remained implicit, “all [computer] applications require logical, consistent, and explicit representations of anatomical entities.”

The reconstruction of the anatomical taxonomy occurred because the group wanted to represent anatomy computationally. As the medical informatics researcher explained to me:

**RP:** I wondered whether you wouldn't come up with this more structured way of representing anatomy in a world in which you weren't organizing things to put them on the computer.

**Researcher:** Not at all, you're absolutely right. It's the computer. ... I worked on expert systems for a little while ... and, when you try to put knowledge on a computer, it forces you to make it logical. That's the reason why this is here. [The senior anatomist] went to a meeting of anatomists and they've been meeting for thousands of years and they were really receptive to this, which I guess he was a little surprised at because they realized that the newer media require you to reorganize anatomy. This is an attempt to reorganize anatomy. And if it succeeds, it'll be a major revolution in anatomy.

The researcher says computers require information to be logically structured for knowledge representation projects to succeed. He also says that anatomists acknowledged the need to revise their classification system to meet the computer's needs. This type of restructuring will be effectively invisible in most computer programs: it is the logic base that will underlie computer applications. But this type of thinking reflects a deeper shift in anatomical thinking.

As stated earlier, the senior anatomist who is building this system describes the anatomical knowledge he wants to impart to his students as spatial and symbolic. He says he has worked with these concepts for many years, but the terms themselves derive from computer science and artificial intelligence. He argues that, "The biggest reason to expose students to a cadaver dissection is because of the kind of mental image they are going to form for themselves of the way the human body is put together." By describing anatomical learning as the construction of a mental image of human anatomy, including a knowledge of three-dimensional structure and its identifying terms, he creates a view of anatomy that leaves out the social, cultural, and material dimensions of anatomy. Marc Berg (1997) describes how medical practitioners began to take a cognitive stance toward

physician problem-solving, a view that treated the physician's mind as an information-processing system that develops "symbolic mental representations" of problems that must be solved (27), and equating the physician's thought processes with formal decision-support tools, such as expert systems and protocols. Although the senior anatomist believes dissection still has a place, his view, built from an artificial intelligence model of anatomical knowledge, places lessons about death, the rite of passage into medical culture, and the reinforcement of knowledge created by tactile interaction with the body at a lower level of importance than the mental model the physician will develop, regardless of how that mental model is acquired. For a discipline that is entirely about the human body, this cognitive view of anatomical knowledge deemphasizes the role of the body—and the emotions—in anatomical learning and early physician training (see Varela 1992 for a discussion of the body's role in cognition).

Other technologies intended to represent human anatomy attempt to do so mathematically. Repeatedly while doing fieldwork, I heard anatomists and engineers say the future of anatomical research will be quantitative. Complex modeling problems will require mathematical, rather than descriptive, relationships to be created among body parts. One example of this type of research was done by SUMMIT's director while working in industry in the late 1980s. The project involved mathematically modeling the human hand and the effects of reconstructive surgery. To do this work, the group director asked a Stanford anatomist to cross-section an arm. She then built a model hand using the graphics modeling techniques described in chapters 3 and 4. From this, she also generated algorithms describing the mechanical effects of, say, reattaching a muscle at a particular point, an effect surgeons typically gauge through anatomical knowledge,

experience, and by sight. This type of research, along with anatomists' desire for a "reversible" anatomy, is a move toward a science of anatomy that researches function and manipulation, rather than description. This is in keeping with the ethos of manipulation of the human body developing in various worlds of bio-engineering and biomechanics, including research into genomics and tissue engineering. If anatomical research moves in the direction of bioengineering, then the German anatomist's comment that the cadaver's inadequacy as a teaching tool will be revealed may well come true. The cadaver clearly does a fine job of teaching structure, but is much weaker at teaching function and manipulation.

### **What is dissection good for?**

In this chapter, I have discussed at length the cadaver's ontological instability and the material, sociocultural, linguistic-visual, and computational technologies used to cut it up. The technologies I discuss above do not fix the cadaver's ontological instability. Rather, they produce knowledge about the cadaver in ways that allow medical students to manage the dissection. As students and anatomists suggest, these frames carry over into medical work. An example comes from a surgeon I worked with at Stanford, who described the metaphors she uses to discuss surgery:

You're doing something that is not natural, which is cutting into human flesh. There's personal defense mechanisms that you have to develop, the gallows humor, the kind of stuff that we talk about so we can accept that we are doing something that the rest of society doesn't do or doesn't choose to do. And, therefore, you have to kind of brace yourself in ways, It feels like a grapefruit. I actually used to use the expression all the time with cartilage, it feels just like coconut, because it gives you something tangible and displaces what you're actually doing.

This surgeon says the metaphors she uses for herself and when teaching residents are drawn from cooking—cartilage feels like coconut, she says (she also describes nerves as resembling various sizes of pasta). And she describes what she’s doing using the classical psychoanalytic term, “displacement,” the replacement of highly charged symbolic elements with less-charged elements (Freud [1900] 1998, 342-3). Here, then, the surgeon uses metaphors drawn from the world of food to describe what she does with human flesh. She objectifies patients in this way, but with a very specific end in mind. She does not forget that her patients are human. If she did, she would not need the food metaphors. On the contrary, she displaces what she is doing to her patients using the language of cooking to make what she does to her patients acceptable. The material technologies—scalpel, scissors—are similar. But this move makes the body—whether of cadaver or patient—ontologically multiple. The human body is both object and person in this passage. If it were only an object, the work of displacement would be unnecessary and cutting into bodies would be easy. If it were a person, the work of surgery would be unacceptable.

As the quotation from this surgeon and from the student quoted above who was struggling to integrate two positions toward the cadaver suggest, learning to treat living bodies as people, but also like objects to the extent needed to perform particular treatments, begins in the anatomy laboratory working with cadavers. The cadaver is closer to the world of objects than a living body and may provide a useful progression for medical students, an object that itself is ontologically unstable enough—and constructed as such through various technologies—to begin to teach students that the human body in biomedicine is multiple. It is person and thing, subject and object. As several anatomists



say, continued use of cadavers as teaching tools should rest on an assessment of their value for teaching anatomical and medical knowing. But anatomical and medical knowing are no more stable entities than the cadaver. They are constructed by and construct the technologies used to produce knowledge about the human body. And they rest, finally, on how the profession defines medical knowing. If anatomical knowing is conceived as a purely cognitive mental construction, then perhaps the cadaver is not the right tool to teach this. If the goal of anatomical teaching is to prepare students for their board exams, then perhaps the cadaver is not the right tool. If anatomy and medicine become sciences of the engineering of human bodies, then the static cadaver might be the wrong teaching technology. If, however, the goal of anatomy teaching is to give medical students an embodied knowledge of the structures of the human body, then perhaps the cadaver is the right model. Or if anatomy teaching is partly about teaching a complex, multiple stance toward the complexities of knowing and treating the human body, then perhaps cadaver dissection should remain a rite of passage into the art and science of medicine.

### **Chapter 3**

#### **Artifacts of Living, Artifacts of Death: The Case of the Visible Human Male**

On July 3, 1981, Joseph Paul Jernigan and a teen-age accomplice burgled the Dawson, Texas, home of 75-year-old Edward Hale. They stole a microwave oven and a radio. As they drove away, they passed Hale on the dirt road leading to his farmhouse. Fearing they would be recognized, Jernigan went back to the house, where he “bludgeoned Hale with an ashtray, stabbed him repeatedly, and then fired at him three times with a shotgun” (Grice 2001 36). Jernigan’s wife turned him in a few days later. Jernigan evidently lived in Waco. Some news stories say he came from Corsicana; others say he was born in Illinois and moved to Texas as a child. He dropped out of school in the 10<sup>th</sup> grade, had worked as a mechanic, had served time for two other burglaries, and told reporters he was discharged from the Army for doing drugs. After his arrest, he confessed to Hale’s murder and was sentenced to die in the Texas Department of Corrections facility in Huntsville. Jernigan told a reporter a few days before his first scheduled execution date that he was sorry he killed Hale and frightened, “I catch myself counting the days. It’s hard for me to sleep at night. I’m real jumpy. Every time I close my eyes that (execution) room keeps flashing through my eyes” (UPI 1984). The execution was delayed five months while judges rejected two appeals claiming Jernigan had reformed in prison. On August 4, 1993, he refused to eat his last meal. Just after midnight on August 5, he went to the death chamber. Lying on a gurney in the 12-foot by 18-foot room, Jernigan nodded to his brother Bobby in the adjacent viewing area, then looked at the ceiling as a lethal mix of drugs flowed into his arm (Graczyk 1993). The injection mix consisted of sodium thiopental, a sedative, potassium chloride, which

stopped his heart, and pancuronium bromide, a muscle relaxant to collapse his lungs.<sup>31</sup> He was pronounced dead at 12:31 a.m. He had no last words (Grice 2001 36).

Jernigan had signed an organ-donor card before his execution, but he did not know what the eventual fate of his body would be. Just ninety minutes after his death, following a short family viewing at a funeral home, representatives of the Texas State Anatomical Board took delivery of Jernigan's body. The anatomists took blood samples to test for hepatitis B and HIV; both came back negative. They drained blood from Jernigan's femoral vein through a large incision in his right thigh. Because of concerns about deterioration caused by the lethal injection mix, they lightly embalmed the body by injecting a mix of 1 percent Formalin and an anti-coagulant into the right femoral artery, perfusing it through the body (Spitzer 1996 119). This was about one-tenth of the typical Formalin mix used to preserve cadavers. A higher concentration of embalming fluids would significantly change tissue colors, turning whites to gray and reds to brown, making them appear less lifelike. The anatomists stitched up the incision in Jernigan's thigh. Eight hours after death, the Texas anatomists shipped his body by air to a Colorado morgue, where it received the number "6022" and began a new existence as a scientific research object. Researchers later described the body as "A white male, [who] was 71 inches tall and weighed 199 lb" (Spitzer 1996, 119).<sup>32</sup>

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<sup>31</sup> Recently, news articles have highlighted controversies over the use of pancuronium bromide among proponents and opponents of the death penalty. The drug paralyzes the skeletal muscles, but leaves brains and nerves unaffected, raising the possibility that the recipient is in great pain, but cannot speak. Some states have banned the drug for use in animal euthanasia.[citesXXXX]

<sup>32</sup> National Library of Medicine officials have never publicly acknowledged Jernigan's identity, but they released the cause and date of death when they debuted the images at the Radiological Society of North America meeting in Chicago in 1994 and newspaper reporters rapidly tracked down and made public Jernigan's name.

Joseph Paul Jernigan can be envisioned in many ways: as a murderous burglar whose impending execution frightens him; as a cadaver undergoing preparations necessary to become the object of anatomical research; or, as we will see, as one of infinite possible digital reconstructions of his dead body. This chapter describes how Jernigan's material body became the digital body of the National Library of Medicine's Visible Human Male.<sup>33</sup> The Visible Human Male is an archive of cross-sectional images of Jernigan's cadaver that can be accessed over the Internet and used to make digital models. Four digital bodies now exist in cyberspace: the Visible Human Male, the Visible Human Female, a Visible Korean Male, and a female pelvis called the Stanford Visible Female. Jernigan's life and death are the best documented of the four bodies and he is the only one who is not anonymous. The use of an executed criminal's body, and the subsequent release of Jernigan's name and biography by the press, has given these bodies an extraordinary amount of attention they probably would not otherwise have received. That attention has led to a discourse about digital bodies, their potential for computer manipulation, and the medical technologies that will flow from them that tends to downplay or delete the ways that these bodies were constructed. This chapter describes the work that went into transforming Jernigan's body from a material cadaver into the Visible Human Male. My goal is not solely to give the details of the visible man's creation in all its gruesome detail. Rather, I want to contrast images of the destruction of

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<sup>33</sup> Three other digital bodies followed Jernigan's: the National Library of Medicine's Visible Human Female, a Visible Korean Male created at Ajou University School of Medicine in Suwon, South Korea, and a female pelvis sectioned at Stanford University's School of Medicine. Each body raises fascinating questions about gender, race, and age in medicine, which are not the topic of this chapter. I focus on the Visible Human Male because it was first and is by far the best documented of the bodies.

Jernigan's material body to the construction of its digital incarnations. Keeping the means, motives, and results of these constructions in view reminds viewers that ways of seeing bodies are culturally and technologically shaped (Kuriyama 2002). The story of this new anatomical body's construction matters, I argue, because the body's history is a critical component of how medicine constructs persons as patients.

Throughout this chapter, I keep in view the stories that surround Jernigan's body—living, dead, and digital—because each story shapes the type of representation that the digital body becomes: the biographical story creates a portrait of Jernigan as a living man; the laboratory story moves Jernigan into the realm of scientific object; the digital story suggests infinite possibilities of computational manipulation. I consider the digital bodies' institutional and technological development in the context of one of their primary audiences: medical students and medical technologies researchers. I use technical literature, some news accounts, and ethnographic interviews and observations at the National Library of Medicine, the University of Washington School of Medicine, the Stanford University School of Medicine, and at Medicine Meets Virtual Reality, an annual conference in the field, to trace the social and technical details of the Visible Human Male's construction and deployment.<sup>34</sup>

The small existing literature on the Visible Human Project has emerged within several disciplines and focuses on some important themes. These early treatments all acknowledge the novelty and importance of the visible humans. All gloss the facts of the visible humans' production, but they consider the digital bodies primarily in terms of

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<sup>34</sup> The medical schools at both the University of Washington and Stanford University are developing important digital technologies for medical education.

their public reception. They also all tend to focus less on images produced from the project databases than on metaphors and discourse surrounding them. Taking a women's studies approach, Lisa Cartwright (1997; 1998) focuses on questions of sexual difference raised in research and news reports about the Visible Human Male and the Visible Human Female. She locates the creation of the visible humans within a striking moment in the early 1990s when reports emerged in medical journals and newspapers about American medicine's systemic neglect of female bodies in clinical trials and anatomy atlases. The reports argued that the relative invisibility of female anatomy, other than reproductive anatomy, constructed the male body as the medical norm against which the female could only be measured as other and that this lack had profound consequences for the treatment of women (see Treichler, Cartwright et al. 1998). Cartwright describes how the creation of a male and a female digital body appeared to be an improvement on traditional medical constructions of gender and yet how the male, criminal body of the Visible Human Male nevertheless became the standard body in most applications. Research and news accounts often dismissed the Visible Human Female, even though she is technically superior to her male counterpart, because her body was post-menopausal and, thus, was viewed as inadequate in a world in which women's value is equated with reproduction. Ethnographic evidence confirms Cartwright's observations: I have often heard the Visible Human Male described at conferences and in conversations among researchers as "*the* visible human," the unmarked male standard, while the female is always described as the "Visible Human Female." The Visible Human Male is treated as both a standard body used for proving new digital technologies based on body images and as a representation of medically normal, male anatomy.

Working in a cultural studies tradition, Catherine Waldby (2000) describes the visible humans as figures; that is, as representational entities to be read using the textual practices of literary criticism. She makes extensive use of the textual practices of reading and writing as interpretive frames for understanding digital bodies. She coins the term “bio-value” (33), arguing that the visible humans are one among many contemporary technologies that extract value from bodies, especially socially marginalized bodies, and “transform them into technologies to aid in the intensification of vitality for other living beings” (ibid, 19). These digital bodies, then, contribute to the building of “exscription” technologies, that is, computational technologies that extract visual images and other information, including genetic data, from the body’s interior and reorder them according to the logics of computer space. This is, Waldby writes, part of medicine’s “iatrogenic desire,” which she defines as the desire for a fully visualized and stable mechanical body, rather than the chaotic, flowing body of actual patients. The interest in creating externalized, stable, digital bodies makes the body and its parts more available as “exchange objects.” (ibid, 114). The concept of the creation of bio-value implicitly points to the work involved in constructing the visible humans, work that turns material human bodies into objects that are more easily exchanged or commodified, but also work that always involves decisions about the form these objects will take and how they will be exchanged.

Anthropologist Thomas J. Csordas (2001) locates the visible humans at the intersection of representation and phenomenal experience. He considers media articles about the visible humans and analyzes metaphors about them to ask critical questions about their subjective effects on viewers. He categorizes the visible humans as “shades,”

distillations of actual people's bodies that exist in cyberspace and can be superimposed on others' bodies. Examining the symbolic structure of the visible humans, he looks at the deeply essentializing quality of the metaphors that crop up often in discussions of the visible humans, including those of Adam and Eve, birth and immortality, mapping of virtual terrain, and the aesthetic world of Leonardo da Vinci. Csordas focuses on the relation between representation and being-in-the-world, arguing that the visible humans, as representations that are made from real cadavers, exist in a liminal space between representation and being. He takes seriously the idea that representations can have phenomenal, embodied effects and that a consideration of representation beyond purely textual or semiotic readings might strengthen claims about the effects of representation. His question, ultimately, is not how the visible humans have had their bodily existence altered, but how they will alter viewers' and users' bodily existence.

This chapter begins from the argument that how the visible humans were made is the first, crucial step in understanding their impact. I have two reasons for this: first, describing the work and the choices that went into creating the visible humans shows the material conditions that help determine the images' form and content and, second, the artifacts produced by this process shape the images' phenomenal effect. Science studies, particularly the sociology of scientific knowledge, has staked its disciplinary grounds in part on the assumption that the situated construction and context of scientific and technological production, including design choices and technical methods, matters (Lynch and Woolgar 1988 4; Hess 1997 81). The importance of this commitment to construction and context becomes more difficult to see when the product of a technological process is an image archive designed to be disseminated widely, further



adapted, and manipulated. But the visible humans represent, I argue, a fundamental change in the structure of the anatomical image that depends precisely on its technological and social “determining conditions” (Deleuze 1986 5) as a set of serial cross-sections imported into the computer, analogous to serial snapshots laid on a celluloid base. Building on the work of Henri Bergson (1998), Gilles Deleuze describes the cinematic image as representing a fundamental transformation of the representation of movement from the privileged instant, which is the embodiment of a form or idea in an eternal and immobile pose, to the any-instant-whatever, which is a section captured as “a function of equidistant instants, selected so as to create an impression of continuity” (ibid). This shift occurred within the historical and scientific context of modernity, but also as a particular technical assemblage of photographs, requiring the development of the snapshot, the “equidistance of snapshots,” the transfer of these equidistant snapshots onto a frame (perforated celluloid), and a mechanism for moving the images (ibid). These determining conditions define the cinematic image’s shape as it moves into the world, including its form and the conditions under which it will be received. Thus, a reading of the image detached from its determining conditions allows analysis of its content, but fails to reveal how its form also shapes what is given to be seen. The visible humans represent a similar shift of anatomy from privileged, functional forms (organs and systems) toward the body captured as a series of equidistant, serial sections in which no single section necessarily reveals any fundamental aspect of the body.

The visible humans are not only a shift towards bodies as sections, but they also are the first anatomical bodies constructed in a digital medium, a space which, as a pioneer of virtual reality in medicine writes, gives the physician extraordinary powers:

In taking this approach, we are able to ‘dissolve time and space,’ the physician can ‘be’ at a distant place at the same time as another person without needing to travel there. But of utmost importance is the fact that the physician can simultaneously bring in many different digital images, such as the patient’s CT or MRI scan, and fuse them with real time video images, giving the surgeon ‘x-ray vision’ (Satava 1995 334).

Most researchers view the visible humans as interim steps toward technologies that create models for visualization and practice from real patient data. Researchers are working on technologies will use CT and MRI data drawn from real patients, along with remote surgical technologies, to fulfill the vision of a physician who can work on a patient at a distance, or practice surgery on a virtual patient as many times as necessary to perfect the operation, or be able to overlay an x-ray or MRI image onto the body’s fleshy interior without hindrance. Michel Foucault (1973; 1978) has argued that profound changes occurred in eighteenth-century medicine when doctors were able to collect and compare diseased bodies in one space, shorten the time separating death from dissection, and gain useful information about disease by opening up dead bodies. Similarly, throughout this chapter, I show how the digitization of Jernigan’s body reconstructs the body’s time, space, and opacity through digital means. This is another way in which the technological form of this body’s production as a digital body shapes how the body can be seen.

Second, science studies literature indicates that laboratory objects usually are natural objects with key features extracted, visualized, or made more manipulable (Latour 1987; Rheinberger 1997; Knorr Cetina 2000). My ethnographic research suggests that the story of how Jernigan’s individual human body became the Visible Human Male matters

in a way it might not with another type of research object. Physicians I have observed and spoken with in several settings have insisted, sometimes strenuously, that building computer applications from real bodies is extremely important for virtual, medical research. The only answers I received as to why using real bodies might be important always boiled down to a statement of fact: physicians treat real bodies, not models. In other words, actual, individual bodies, mediated or interpreted through many types of models and representations, remain the fundamental basis of medical action. In this chapter, I examine what marks Jernigan's body as that of a specific individual and where tension arises between the individual body and its status as model body.

During a pilot phase of my research, I sat more than a dozen people from medical and non-medical backgrounds down in front of images of the visible humans culled from the Internet. I asked these viewers to reflect on these images and their reactions to them (Prentice n.d.). Some viewers were curious. Some were disturbed. But nearly all asked me to explain why the bodies look the way they do. People asked why the Visible Human Female's face looks strained, for example, and why models built from CT scans look oddly smooth and strangely colored.<sup>35</sup> They asked me to explain the marks they saw on the visible human male and female bodies, marks primarily made during the bodies' preparation and imaging. These marks are, again, signs of the work that went into producing these bodies. Returning to Csordas' question, these marks clearly formed part of the phenomenal effect these bodies had on viewers. Jernigan's 39-year-old body was marked with artifacts of life, artifacts of death, artifacts of sectioning, and artifacts of

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<sup>35</sup> <http://www.crd.ge.com/esl/cgsp/projects/video/medical/vishuman.html>. Accessed: November 11, 2003.

imaging. As Byron Good (1994) points out, medicine constructs persons through histories of bodies. These artifacts reveal the history and specificity of Jernigan's body. They serve to remind viewers that these digital bodies once were genuine human flesh and that flesh has a history.

### **A communications mission and an educational desire**

Anatomy education began to change in the late 1970s and 1980s. Gross anatomy had for decades been a crucial rite of passage into biomedicine's language and culture of bodies. As a research science, gross anatomy had declined. Few new discoveries about gross human structure remained to be made and the rise of molecular biology led to the absorption of anatomy into departments dedicated to research into molecular structures. In a report justifying the National Library of Medicine's development of computational tools for teaching anatomy, including the visible humans, the library's Board of Regents wrote, "Indeed, the current emphasis upon molecular biological mechanisms of health and disease has led to a de-emphasis of gross anatomy in the curriculum, and fewer hours dedicated to 'structural biology'" (NLM Regents 1990 13-14). The report assumes that computer technologies might improve anatomy education despite cuts in teaching time. As gross anatomy teaching declined, imaging and computer technologies that suggested new directions for anatomy teaching began to develop. Computerized tomography and magnetic resonance imaging, for example, both present bodies as cross sections, encouraging anatomists to teach more cross-sectional and radiological anatomy. Anatomists also began to shift anatomy's focus away from basic structural research toward applied research intended to meet various needs in bio-engineering, medical imaging, surgery, and other disciplines (Beahrs, Chase et al. 1986 229). Computers

entered debates about gross anatomy teaching in the mid-1980s. Those enthusiastic about developing computational tools for teaching anatomy argued that it held promise for reducing the costs of teaching gross anatomy and improving the quality of teaching, particularly because of the possibility of creating programs that depict three-dimensional, labeled anatomical structures that can be manipulated by students (Rosse 1995). Others worried that the introduction of computers into anatomy teaching would facilitate further erosions of teaching and laboratory time. By the late 1980s, many anatomists agreed that computer tools would become an increasingly important supplement to dissection. Thus, computer technologies did not cause dissection's decline. Rather, they came on stage at a time when anatomy's decline as a research science and its expense already had eroded its primacy in medical education. Computers heightened this pre-existing debate by providing a promising alternative or supplement to traditional teaching. However, the computer technologies that could seriously challenge dissection's efficacy as a teaching tool did not exist in the late 1980s and, even with the Visible Human Project and other tools, largely do not exist today.<sup>36</sup>

The Visible Human Project came about in the late-1980s at the juncture of a communications mission and an educational desire. The National Library of Medicine, the nation's repository for medical information, wanted to investigate new technologies for storing and disseminating medical images using computers. The library's mission

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<sup>36</sup> Reasons for the slow development of computerized tools for teaching anatomy can only partly be addressed in this chapter, but they include the structures of research funding, the proprietary nature of some data developed from anatomical data sets, and on-going resistance from many anatomy programs to adoption of such tools.

since the 1950s had been to find ways to get medical information into hospitals, operating rooms, and clinics. As a computing technologies director at the library explained to me:

In the late '50s, then Senator John Kennedy, soon to be president, and Senator Lister Hill from Alabama came up with the notion that it's really nice that the world's medical literature is at the National Library of Medicine, but that the patients are out there in the field. And you can't tell the patient, 'Don't get any sicker, I'm going to go to Washington and look it up.' So therefore the library should have a research and development program, which is how to get the content of the library to the bedside, where, when, how and whatever was needed.

Nearly a half century ago, the library's political minders recognized the movement of information as a fundamental problem in medicine: information had to reach doctors at patients' bedsides—it had to become mobile. Following this wisdom, in 1987, the library's board of regents developed a 20-year, long-range plan for the library, recommending that the library's Center for Biomedical Communication “thoroughly and systematically investigate the technical requirements for and feasibility of instituting a biomedical images library” (Regents 1987 quoted in NLM Regents 1990). The library recognized medicine's visual nature and collected print images, but the regents' report anticipated technical challenges related to storing and disseminating digital images. This, then, was the communications mission.

In the mid-1980s, the National Library of Medicine began encouraging and funding development of computer applications for medical education. In June 1987, the library's computer technologies director encountered the University of Washington anatomist, who told him anatomy could be a fruitful area for research into computational applications. As the library official recounted the conversation to me:

He says, 'If you really want to use computers in medical education, you should do it in the subject of anatomy.' Immediately, I figured that's why he's an anatomy professor. So, I says, 'Why?' And he says, 'Because you

can't study anatomy. You take it apart and then what? You can't study it like you study mathematics. Or you study any of the sciences. You do the experiment. You read the book. You work the formulas. You can keep regurgitating it. You can't do that with anatomy because you're exposed to it once. You take it apart. Anatomy is three-dimensional. You do it from the top-down [meaning from the outside in]. You never saw it from the bottom up. It's different. ... You can't back it up. You can't reset. You can't do any of that. So if you could do it on a computer, you could do all of the above.'

Mathematical and chemical formulas are reversible. That is, one can solve the equation one way, then try it in reverse to see if the logic holds. The chemical equation also is an abstraction, a convenient theoretical representation of how molecules ought to behave in practice. Dissection, however, uses a real body whose time cannot be reversed.

Dissection also proceeds from one angle of vision—from the outside in—and its products cannot be put back together. Students have no opportunity to go back if they make a mistake. A well-designed computer program, the anatomist argued, would allow users to take apart the computerized body, put it back together, change the angle of approach, and repeat the process as often as needed to learn how structures fit together, making dissection a two-way process. This was the educational desire.

In June 1988, NLM gathered representatives from eight medical schools and asked them about existing image and computing resources for teaching anatomy. The University of Washington anatomist and his group had developed a system for three-dimensional, computational "slicing" of brains using CT data, and others had similar systems for other body parts, but these programs ran on a large, specialized graphics computer system. Nothing robust and inexpensive enough for medical students existed and no one had a program representing the entire body. The gathered experts wanted the NLM to provide a database of cadaver images that could be easily adapted to other uses.

The anatomists and developers recognized the lack of a standard, publicly available set of body images that would allow researchers to test modeling and other algorithms on medical images without encountering concerns about patient privacy (Ackerman 1998 508). They also wanted images to come from a single body, so they would align and match. Many anatomists had cross-sectioned individual organs, joints, or portions of bodies, but all these parts came from separate bodies and no means existed to combine them or to navigate from one body region to the next.

At this point, uncertain whether imaging cadavers fit the regents' idea of studying an image library, NLM officials returned to the regents, who called for yet another meeting. NLM gathered thirty-three anatomists, radiologists, animated filmmakers, computer experts, and others, who encouraged the library to pursue the project. After the meeting, the board of regents in 1990 approved a supplement to the long-range plan giving the go-ahead for what by then was called the Visible Human Project, "NLM should undertake a first project, building a digital image library of volumetric data representing a complete normal adult human male and female" (NLM Regents 1990 2). The report acknowledged that images derived from the first two bodies would be prototypes used to establish a method, develop standards, and create a "point of reference" for future image collections (NLM 1990, 15). It specified that up to three male and three female bodies would be imaged and the best chosen for sectioning. These bodies would be fresh or well-preserved at the time of death and would show few structural abnormalities (NLM 1990, 19). The images would provide a base set of cross-sectional images, a mechanical, photographic "truth" on which researchers would base later creations.



The National Library of Medicine's 1990 report listed three categories of goals for the technological development and deployment of the visible human data: First, the library planned to develop standards and methods for acquisition, representation, and storage of this type of medical data. Second, the library wanted to spur creation of methods for linking and transporting the data, through links to other image collections, development of methods to link image and textual data (labeling), and research into high-speed computer networks needed to transport large image files. Third, the library planned to promote development of methods, tools and standards needed to build three-dimensional models from these two-dimensional cross-sections, as well as programs to correlate two-dimensional with three-dimensional data (NLM 1990). The report emphasized the drama and utility of a computer program that could "isolate, highlight, 'reversibly dissect,' rotate, and view from multiple angles single and grouped tissues, organs, body regions, and physiologic systems" (NLM 1990, 9).

The researchers who imagined and created the Visible Human Male and the Visible Human Female dreamed of bodies whose destruction would be digitally reversible, bodies whose movement in time would no longer be linear, and whose opaque parts would no longer resist being opened and examined by physicians and students. And they dreamed of a mobile body whose presence could be materialized anytime and anywhere by anyone. They envisioned standard bodies that would be usable by many researchers and normal bodies that would teach students anatomy. A laboratory object is either a piece of the original or, as in this case, an image of the original, that is detached from its natural environment and is no longer beholden to the original's temporality (for example, a preserved cadaver decays much more slowly than a natural body—its time has

been altered to better suit scientific needs) (Knorr Cetina 2000 27). The move to shift the cadaver from material, preserved body to digital data body—and the power gained from this shift—also fits Bruno Latour’s notion of the creation of information, that is the extraction of the “*form* of something without the thing itself,” which Latour calls a compromise between presence and absence (Latour 1987 243). What this particular type of abstraction does, he says, is to increase an object’s mobility, stability, or combinability, making it an “immutable and combinable mobile” (ibid, 227). In effect, researchers imagined creating bodies that would be more mobile and manipulable laboratory objects than cadavers.

### **From vision to visualization**

Once the project received the regents’ approval, the library sent out a request for proposals asking for bidders to create approximately 2,000 cross-sectional photographs of a male and a female body. The library planned to create a database of cross-section photographs of the bodies that could be aligned and correlated with CT cross-sections (CT is inherently cross-sectional and digital). The CT scans would be made with an intact body and then the frozen body would be ground down at 1-millimeter intervals, a process known as cryo-sectioning. Photographs would be taken of each exposed cross-section. NLM received six proposals in response, representing more than 100 medical schools and other organizations that had come together to submit proposals. Library reviewers narrowed the six to three with the highest likelihood of success and asked them to cross-section and image the mid-section of an animal at least the size of a rabbit or a guinea pig to see how the respondents handled a reasonably sized animal’s thoracic area, which has the largest variability among tissues. After reviewing the three sets of images, the

committee unanimously chose the University of Colorado at Denver to be the contractor. According to the technologies director, Colorado's images provided the cleanest, clearest views of the body; other photographs submitted to the review committee contained undesirable artifacts from sectioning and photography.

The 1991 contract called for the University of Colorado researchers to provide NLM with magnetic resonance images and with cross-section images from CT scans, as well as photographs taken using 35-millimeter and 70-millimeter film, one using negative film, the other using positive (slide) film. The two sizes and types of film would allow researchers to choose the best grain size and color balance. Each type of film also would come from one emulsion lot and would be processed on the same day—all to ensure color consistency. In the two years between approving the final contract and finding Jernigan's body, digital photography also became available and, thus, digital photographs of the bodies were added into the original contract. The choice of contractors and photographic technologies followed a logic of trying to minimize technological impediments to viewing the entire body with as few artifacts of imaging as possible.<sup>37</sup> The eventual tripling of photographic processes also was an acknowledgement that bodies would be sectioned only once. As material bodies, they would conform to the time of all bodies, living and dead: sectioning would not be reversible.

To begin the process, Colorado researchers first had to find suitable bodies. This became, in the technologies director's words, the "rate-limiting step," engineering jargon

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<sup>37</sup> Most images now available of the Visible Human Male and Visible Human Female come from digital photographs, even though the film photographs sometimes show greater detail. For the most part, the film images have remained in NLM vaults and have not been scanned or made available to the public.

for the slow step that determined the speed of the entire project. NLM and Colorado set up a consortium of the State Anatomical Boards of Maryland, Texas, and Colorado. These boards oversee the arrangements for willed-body donations and handle distribution of bodies. The three boards together guaranteed that the University of Colorado would have up to 3,000 potential candidates a year. The consortium made medical information about candidates available to the NLM's Visible Human Selection Panel, a group of radiologists and anatomists, who decided which were most suitable. The committee reviewed medical records, looking for signs of disease, surgery, scars, or other factors that "might have altered or distorted the cadaver's anatomy or otherwise render [sic] it unsuitable for the project." They eliminated obese and emaciated candidates. They also eliminated candidates who were more than six feet tall because of limitations in the sectioning equipment (Spitzer 1996 119). From the beginning, the bodies were fit to the technology, rather than vice versa.

Researchers acquired, prepared, froze, and scanned three candidate bodies, then sent the scans to the NLM selection committee. At that point, they encountered a hitch. A radiologist looking at the CT scans noted that they looked like scans intended to show calcifications and other hard tissues, as opposed to seeing the soft tissues researchers wanted to see. The federal technologies director explained to me:

What could be wrong? We did an experiment. It turns out, you cannot CAT [CT] scan a frozen cadaver because it freezes and the ice reflects the x-ray and you lose all the detail. You're CAT scanning the differential in the ice. That's it. You can't scan the tissue anymore. You're CAT scanning the ice. Who would know? Who should know?

As the technologies director's questions indicate, creating a body with aligned CT scans and frozen sections was a new technological enterprise. Researchers did not realize that

frozen tissue behaves like ice when CT scanned. The frozen body could not be seen as a fleshy body when CT scanned, an impediment to the kind of surgical “x-ray vision” mentioned in the epigraph above. This created a new problem for researchers in Denver. They wanted the CT scans and photographs to align perfectly so users could alternate between radiological and anatomical views. But if you cannot CT a frozen body and you cannot section a fresh body, how do you ensure that the body position is identical for both types of image? The solution was simple and ingenious. The researchers sprayed a substance called Alpha Cradle around the bodies. Alpha Cradle is a quick-hardening foam used to create position molds for radiation treatments. The researchers CT scanned the boxed bodies at room temperature, then froze them with the Alpha Cradle in place, keeping them immobilized in their original position. Anatomists and technicians developed this type of craft knowledge while doing the project and made the University of Colorado’s Center for Human Simulation something of a center for this type of work (see Collins 1985).

While the Colorado anatomists searched for suitable bodies, several prisoners on death row in Huntsville agreed to donate their bodies to the Texas State Anatomical Board at the urging of a priest, who apparently told them such a donation would contribute to society (Hopper 2002). Lethal injection made these men ineligible for organ donation because the fatal mix of chemicals poisons the organs. Early on, project directors identified executed prisoners as a potentially desirable pool of bodies because most would be younger than typical organ donors and most would die in good health and on schedule (Grice 2001, 37). As far back as the eighteenth century in Britain, physicians interested in anatomy have viewed prisoners’ bodies as suitable candidates for dissection,

creating what Waldby calls a “sacrificial economy” that gives value to prisoners’ bodies after death (Waldby 2000 52). For example, in 1752, the British parliament passed an act for “better Preventing the horrid Crime of Murder,” which allowed judges, in order to deny murderers a grave, to order the corpse’s dissection rather than gibbeting in chains (Richardson 1987 35). For decades after, physicians and lawmakers discussed the merits of extending this practice to other convicted criminals. These practices not only fit with the moral economy of eighteenth and early nineteenth century punishment, they also appealed to physicians seeking supplies of bodies, particularly bodies not obtained from grave robbers (Richardson 1987, 275). This history made NLM officials uneasy, said Michael Ackerman, the NLM’s project director. “So we sat down and examined ethics and law. Is this really the last will and testament of the deceased? What do we know about (possible) coercion? We went to ethics people; we talked to Texas authorities. Everyone assured us this was not grave robbing. This was according to the law” (quoted in Hopper 2002). Though Ackerman conflates the ethics of using Jernigan’s body with the legality of using Jernigan’s body, the legality of making this body visible evidently was clearly enough established to allow Colorado anatomists to use his body.<sup>38</sup>

In addition to Jernigan, at least one early candidate for the process was a death-row inmate. With this first candidate, investigators observed that the method of execution might itself cause problems:

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<sup>38</sup> Several of my informants expressed discomfort at the fact that Jernigan did not know that he would become the Visible Human Male. They suggested that there is a difference between organs used for donation and cadaver dissection, which keep the body anonymous and disconnected from the living donor, and the Visible Human Project, which publicly disseminates images of Jernigan, some of them recognizable.

Previous experience with willed cadavers who had died by court-ordered lethal injection had revealed that such remains may undergo massive deterioration within 24 hours of death. The cause of this change is unknown but may be a result of massive membrane depolarization resulting from chemicals employed in the lethal-injection mix (Spitzer 1996, 119).

As an NLM reviewer put it, the injection mix rapidly “exploded all the cells.” To keep the body in a condition as close to life as possible, researchers knew they would have to slow the body’s deterioration. This created another dilemma: as noted above, embalming changes tissue color. Thus, anatomists decided to embalm the body as little as necessary to prevent it from deteriorating before they completed imaging and freezing the body. By slowing the body’s deterioration, embalming slows its relation to the passage of time. Until the advent of silicon bodies that do not decay, embalming was the best technology available to give researchers time to learn the body’s secrets.

As stated above, Jernigan’s body, now labeled “6022,” arrived in Colorado just eight hours after death. At that point, his body was one of two candidates to become the Visible Human Male. Twelve hours after death, researchers at the University of Colorado made a first set of x-rays. They then prepared the body for imaging by gluing two thin tubes filled with a copper sulfate solution from head to foot using Liquid Nails, a glue designed for attaching fake fingernails. The tubes served as registration guides to help researchers align images, but they add an odd effect to digital constructions of the bodies’ exteriors: they look like seams. They moved the body to the imaging center at the University of Colorado’s University Hospital. Magnetic resonance imaging began eighteen hours after death and ended less than four hours later. Because of the small magnet sizes in MRI machines at the time, the body had to be squeezed to fit into the

machine and the resulting images do not align with CT scans or with cross-sections. After MRI imaging, researchers positioned Jernigan's body inside a plywood box lined with two layers of plastic. They sprayed Alpha Cradle between the layers and, fifteen minutes later, the foam solidified, locking the body in place. Just over twenty-two hours after death, CT scanning began. The contract called for scans to be done at 1-millimeter intervals, but continual measurements of gas accumulation in Jernigan's body indicated that it was beginning to deteriorate. To speed the process, CT scans were done every millimeter in the head and neck, every three millimeters in the thorax, and every five millimeters in the legs. Researchers stopped CT imaging just above the knees, wrapping up 25.5 hours after death. Time was of the essence in this phase of the material body's preparation.

Jernigan's body and that of the other candidate were placed in a specially constructed freezer, where they froze to  $-70$  degrees Celsius in a few days. Meanwhile, the scans were sent to the NLM selection committee, which had to find the most normal body. Or, as the library's technologies director explained to me:

When we got three or so cadavers like this, it went to a committee that the NLM chose of radiologists and anatomists to look at these pictures and to tell us which one would be normal enough to actually become the Visible Man or the Visible Woman. Because we were looking for normal pictures. Everybody dies for a reason. The question was, according to the assembled radiologists and anatomists looking at the CT scan, with which one was the thing that killed them so slight that most people wouldn't notice it and it would look like normal anatomy.

What the project manager means by "normal" is that the body should show little physical evidence of disease or cause of death. The body also should reveal few congenital abnormalities or changes resulting from the process of living, such as scars or missing



organs. Executed prisoners' bodies potentially would be good candidates because they would not die from accident or disease: their bodies would be close to normal. As Andrew Payer, an anatomist and then head of the Texas State Anatomical Board, told a reporter, "Most people don't die of 'normality.' They die of disease, old age, post-surgical or trauma" (Hopper, 2002, A1). Researchers wanted a cadaver that would show as few signs of death or disease as possible because the visible humans would depict "normal" anatomy in three dimensions, helping medical students develop mental models of the anatomy (NLM 1990, 11-12). In this sense, the normal body would become a "normative" body, the body that establishes the norm from which all variations would be defined (Canguilhem 1989 126-27). Jernigan's medical records indicated that, "The individual had undergone an appendectomy at age 21 and a left orchiectomy [testical removal] at age 15. Number 14 tooth had been extracted at age 38" (Spitzer 1996, 119). These minor physical anomalies are products of surgical and dental interventions that occurred when Jernigan was alive. They are artifacts of life that mark this body as specific to a real individual's body.

The concept of "normal" in medicine has a long and contentious history (see Canguilhem 1989). The criminal body long has been a focus of anatomical and physiological inquiry, but most typically with the intention of proving criminal abnormality (Gould 1981). Cartwright notes the irony of choosing Jernigan's criminal body as anatomical norm (Cartwright 1998 24). But the irony goes deeper. As noted earlier, in the eighteenth century, murdered criminals were chosen for dissection as part of the public display of punishment (Foucault 1977; Richardson 1987). Yet, with Jernigan's body, visual evidence of the means of death—lethal injection—was less

visible than with candidates who died by other means. Jernigan's body exhibits only non-pathological anomalies from before his death. NLM Project Director Ackerman said, "Medically he died for no reason. In fact, the experts were very puzzled when they first looked at his scans because they couldn't find a cause of death" (Grady 1996). Lethal injection, thus, constructs a body that, after death, can be viewed by experts as a normal, lifelike, non-pathological body. The destruction of life in this way leaves little trace in the body immediately after death, little mark of the punisher's art. This creates a body with greater utility after death. Does lethal injection, then, mark an extreme version of the punisher's retreat from touching the body described by Michael Foucault (1977, 14)? Perhaps. Foucault describes the death penalty as a "limit, a scandal, and a contradiction for a power whose purpose has become the power to regulate and discipline life" (1978, 138). But how then to explain the reuse of this prisoner's body in such an extreme form of visibility? I would suggest that this body, when it became a medical object, moved out of the representational economy of punishment and into the representational economy of medicine's power over the biological body. In other words, this body represents medicine's attempts, even if only in a virtual world, to exceed even death as the limit of bio-power, of bringing even the dead body into the realm of value and utility that Foucault says modern realms of power extended to living bodies (Foucault 1978 145; Waldby 2000).

### **Sectioning**

On September 2, 1993, just a month after his execution, the NLM committee unanimously chose Jernigan's body to become the Visible Human Male. Over the next five months, researchers at the University of Colorado prepared the body for sectioning.

They broke off the Alpha Cradle around the abdomen and “glued” the arms to the abdomen with gelatin colored with blue food coloring. To fit height limitations of the sectioning equipment, they used a specially designed backsaw with a 1.3 millimeter blade to cut the body into four blocks, each less than 20.4 inches high, consisting of legs, ankles, and feet; thighs and knees; abdomen and pelvis; head, neck, and thorax (Spitzer 1996, 124-5). The frozen gelatin held the hands against the body, even after they were severed from the body just below the elbows. Because of loss of tissue due to the saw blade, one can see lines running horizontally through some models of the body. These are empty image files, used to create gaps in reconstructions, showing where tissue is missing. These gaps represent an ironic fidelity to the original body. They are empty files used to denote empty space. They are an acknowledgment that bits of the real body were irrecoverably lost and that any manual or digital interpolation done to fill the gaps would be a post-hoc construction, a form of interpretation. In this computational medium, even absent parts of the body must be constructed; the any-sections-whatever can also be markers of empty space.

Researchers could break the Alpha Cradle off the frozen body and it would remain in the same position as when it was CT scanned. But they wanted to ensure that the cadaver’s position—so painstakingly created for the CT scans and maintained after freezing—would remain the same through sectioning. They created a new type of mold, using more blue gelatin, and an aluminum cast instead of the plywood box. They put the gelatin-encased blocks back in the freezer and dropped the temperature down to –85 degrees Celsius. These “rock-hard” blocks of blue ice with the body embedded inside were stable enough to undergo sectioning (Spitzer 1996, 125).

The team at Colorado designed a device to do the sectioning. It consisted of a milling device, which resembled a rotary sander, with twenty teeth specially hardened to withstand the intense cold. The spinning blade rotated at 300 rpm to grind off each 1-millimeter section. Sectioning began with the legs and feet on March 21, 1994. To create each section, a mill operator passed the mill across the frozen block just once. Operators collected the material removed—an icy slush—and saved it for cremation later. They passed compressed air over the surface of the remaining block to clean it, then used a scalpel to remove any irregularities on the surface. Operators encountered a difficulty when the mill planed off bits of tissue that were unattached to body parts below. This caused some tearing away of tissue, damaging image quality on cross-sections showing the last few millimeters of the bony protrusions on the body's femurs, some bones in the foot, the temporal lobe in the brain, and the cerebellum. Tissue also was lost when operators milled down the last few slices of each large block of frozen cadaver.

When researchers encountered void spaces inside the body, they filled these with blue latex to distinguish these spaces from the tissue below. On many images, these blue spaces show up in sharp contrast to the reds and whites of the rest of the body. Once prepared, the block was cleaned again, wiped with alcohol and masked to prevent glare from the surrounding dry ice. Operators took a digital photograph and examined it to ensure that the block surface was clean. Finally, they took film photographs. Each section took three to 15 minutes. Using this painstaking process, the operators managed to slice about 50 sections per day before the surface of the block became too warm to allow clean sectioning and the block had to be refrozen. Sectioning work on the final block—the head, neck, and thorax—was completed on May 19, 1994. The Colorado team had

created 1,871 photographs of cross sections. The addition of six empty files representing tissue loss due to saw cuts brought the total number of image files to 1,877. The body was ground into frozen dust saved for later cremation. The material body was destroyed. All that remained was its photographic reflection.

The resolution of the digital photographs was one-third millimeter by one-third of a millimeter. Given the 1-millimeter section depth, this meant that voxels, the units used for three-dimensional modeling, were not perfectly cubic, a source of criticism of the male model. But the entire dataset of cross-section photographs filled fifteen gigabytes of computer space, which was nearly unmanageable in 1994. Using 1989 technology, data from the male body would fill an estimated 15,000 floppy disks. The Visible Human Female, introduced in 1995, was sectioned at one-third millimeter (researchers created 5,189 cross-section photographs filling 40 gigabytes of computer space) and at the same photographic resolution, so the voxels would be cubic. The total cost of creating the male and female data sets was \$1.4 million.

Digital reconstructions of Jernigan's body made from these images show three types of artifacts. The images show tattoos of dragons on his right arm and chest. These artifacts mark Jernigan's body as specific to an individual, revealing just a piece of his life history. They show the lack of an appendix, a testicle, and a tooth. These are artifacts of living. They show a large scar on the right femur, the spot where researchers removed blood and injected Formalin into the body. These are artifacts introduced after death, as a result of the body's preparation for sectioning. And they show lines running from head to foot, along the sides of the face, over the torso and down the front of each leg. These are the tubes of copper sulfate glued to the body and used to align cross sections. Full-body

reconstructions also reveal three lines running horizontally, just under the knee, at the upper thigh, and below the nipples. These are the spaces where the backsaw cut through the frozen blocks. Cross-sections show blue patches in places where researchers embedded latex to reveal void spaces in the body. A close inspection of some interior areas, such as the base of the brain, also reveals places where the saw removed too much tissue. All these are artifacts of sectioning. The artifacts produced after death are, literally and figuratively, the scars of this production process, marks that are impossible to disentangle from the method of production of this body. Negative spaces also are constructed using this method: voids filled with latex and empty computer files created to register missing flesh. Laboratory researchers tend to overlook artifacts created in the production of a scientific object, which is something of a necessity since scientific visualization usually involves making visible an object's hidden properties (Lynch 1988 180). This naturalization of the scientific object also obscures the work that goes into producing the object.

### **Making computable bodies**

The cross-section photographs of the Visible Human Male look like cuts of meat against a blue background. An image of the torso, for example, shows each arm as a circular cross-section with the humerus running through the middle, surrounded by well-marbled muscle, and padded by a layer of fat.<sup>39</sup> The oval of the upper chest shows ribs, spinal column, lungs and heart. The right side of the heart (which appears left in the photograph) is filled with clotted blood. A bright blue dot in the center of the heart is a bit of latex that researchers have laid into an existing cavity. The heart nestles between the

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<sup>39</sup> <http://www.nlm.nih.gov/research/visible/image/thorax.jpg>.

two lungs, which are somewhat darker than the surrounding muscles. Three dark spots above the heart show trachea, esophagus, and aorta. The spinal column shows up in the upper portion of the images as a light-red oval of the vertebral body and two bony arms surrounding the white spinal cord inside. Emerging from the spinal column, the ribs and their associated muscles—the body’s internal armor—encircle lungs and heart. All is encased in thick layers of chest and back muscles made powerful from weight-lifting (Hopper 2002) and surrounded by a thick layer of fat, the fifty pounds Jernigan gained in prison (Brown 1999). Images through other parts of the body with smaller or more complex parts look more abstract. Each slice represents what might be called, following Deleuze, any-section-whatever. That is, anatomists used cross-sections for teaching long prior to the visible humans. But anatomists told me those cross-sections were carefully chosen to represent slices through particular, important parts of the anatomy whose spatial structures could be better understood with the help of a cross-section.<sup>40</sup> The visible human data sets capture those privileged sections, but purely within the context of this serialized presentation, as one among many equidistant exposures.

Early on, NLM’s review committee recognized that the project would generate two types of image data: pixel data and object data. The digital photographs are pixel data, a grid of multi-colored points on a two-dimensional field. In this form, although

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<sup>40</sup> Cross-sections can help students develop the spatial skills necessary to develop solid mental models of anatomical layers. For example, during a lecture on the anatomy of the upper arm which I attended at the Stanford University School of Medicine, the anatomist first showed the layers of muscle as they would be encountered in a traditional anatomical dissection starting from the front: biceps brachii, then brachialis muscle both sitting atop the humerus. Then he drew the upper arm in cross section to show those same layers from a perpendicular viewpoint. He recommended that students try drawing body parts with multiple layers in cross section as a means of understanding the anatomy in three dimensions. The exercise was profoundly helpful.

anatomists and others can look at cross-sections and at animations of cross-sections, they cannot view the body according to more traditional anatomical considerations, such as regions and systems. The University of Washington anatomist told me that:

Generally, the visible human is spoken of as a three-D dataset. It is. And you can zoom through all those slices. But I have been doing anatomy for over fifty years and I can't see the anatomy when I go through that. I need to see a liver, like a chunk. And I need to see a muscle.

The anatomist cannot see anatomy as a series of cross-sections. He needs to see organs and systems that follow traditional conventions of anatomical rendering, which separate body parts along tissue borders. The cross-section image of Jernigan's torso described above is an example of two-dimensional pixel data. The cross-sections also can be collated so a viewer can flip through them, rather like turning the pages of a cartoon flip book and seeing the scene change.<sup>41</sup> This creates the effect of zooming through slices—or of zooming through the body—that the anatomist describes. In this case, one tours through the body, moving 1 millimeter at a time as each succeeding photograph flips onto the screen, too quickly to see them flip, so it looks like a movie. The effect most resembles watching a set of red and white oil splotches inside a profile of a body change shape as they swirl on the surface of water. This type of animation also is a form of pixel data: it is computerized data, but is not yet in a form that the computer can interpret to create manipulable, three-dimensional models. And it is not yet in a form that the anatomist can read.

Anatomists and computer experts convert pixel data into “object data” to create three-dimensional models. Object data typically consists of shapes to be modeled that are

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<sup>41</sup> [http://www.nlm.nih.gov/research/visible/mpeg/umd\\_video.mpg](http://www.nlm.nih.gov/research/visible/mpeg/umd_video.mpg).



outlined on successive cross-sections, then stacked, a process that might be likened to building a loaf of bread from its slices. The stacks are knit together computationally to form a mesh of triangles or polygons based on an underlying mathematical formula that the computer can use to calculate a likeness of the object's surface (NLM 1990, 6). Creating object data requires painstaking work by anatomists and computer graphics experts. NLM's review panel predicted that getting pixel data into a form so it could be modeled would take forty to fifty expert worker years at an estimated cost of \$5 million (NLM 1990, 18). The mathematical mesh makes it possible for the computer to manipulate the data. In other words, the mesh makes the body computable.

To make models, expert anatomists must first outline structures on cross-sections, a process known as segmentation. When the visible humans first appeared, all segmentation had to be done by hand. Now, some structures can be outlined by computers, but the outlines must be checked and corrected by hand. Small, indistinct structures still must be segmented entirely by hand. Segmentation is particularly difficult because, when bodies die, veins and arteries collapse. Collapsed vascular structures, when they can be seen at all, often look like nerves. Distinguishing and segmenting veins, arteries, and nerves can be difficult to impossible unless veins and arteries are filled with dye, which causes artifacts where the dye leaks out of the vessels. Because of concerns about leaking, NLM rejected dye for the visible humans.<sup>42</sup> The final step of using

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<sup>42</sup> The National Library of Medicine recognized that distinguishing arteries, veins, and nerves was a particular problem with the visible human data sets and funded a later research project, dubbed Visible Human 2.0 intended to develop methods for injecting dye into veins and arteries and for staining nerves so they could be distinguished from surrounding tissue (*Commerce Business Daily* 2000; Ratiu et. al. 2003). As with many scientific projects, the resistances to visualization created with the visible humans became the drivers of new research.

computer algorithms to knit the segmented drawings together to create truly three-dimensional images is called “surface rendering.” With organs and large muscles, this is relatively easy. When it comes to fine structures, segmentation can become interpretive and controversial. As the University of Washington anatomist says:

Many people would quibble with the segmentation. ... And segmentation alone is not enough. You need to generate the 3-D graphical models of every little bit and then put it together, like Legos, so you are able to take it apart. And that’s the big job of how to do it and do it for the whole visible human, all its tiny little parts.<sup>43</sup>

Three-dimensional modeling has proceeded slowly because the segmentation is slow, controversial, and must be done by anatomists. The apparent objectivity of the photographic data—the mess of difficult-to-discern details—must be interpreted by an expert before being converted into a more useful product. These segmented outlines of cross-sections resemble the photo-diagram pairs Michael Lynch (1988) describes: they filter out all information except the outline of tissue structures, thus giving order to the photograph. But segmented cross-sections differ from printed diagrams because they are only an interim step towards the three-dimensional model. A segmented body part drawn from a single cross section is just an outline in a computer file. These outlines remain unintelligible until knit together with outlines drawn from other cross sections.

In addition to segmenting body parts, a computer algorithm must be created to generate a polygonal mesh that accurately maps onto the body part being modeled. The

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<sup>43</sup> The anatomist has criticized government funding structures that encourage research that uses individual organs or structures as test cases, but tends to treat the integration of all body structures as “development” work undeserving of funding. He says government funding for creation of an integrated, segmented body will be the only way a complete body gets produced. There is some evidence, however, that companies are emerging that will develop full-body segmentation data: for a price.

creation of such algorithms is something of an art form that skilled medical informatics experts, who usually are not anatomists, typically practice. Further, although NLM has put the digital cross-sections into the public domain, segmentation is considered added value and is therefore typically treated as proprietary information. Not only were anatomists disappointed with the difficulty of segmentation, but medical publishers also found the two-dimensional images inadequate and shied away from the work of creating three-dimensional models. Segmentation is the labor-intensive work that has slowed creation of full-body models that are more than demonstrations. Segmentation also gives the lie to much hype in research and news articles related to the visible humans about the ease of manipulation of this computational data.

CT and MRI images are inherently in the form of two-dimensional cross-sections, though programs are emerging to convert them to three-dimensional models. One goal of visible human project managers was to create a data set that would foster development both of technologies for converting two-dimensional images to three dimensions and of applications that would help students learn to mentally convert two dimensions to three dimensions, a skill particularly important for radiologists and surgeons. The University of Washington anatomist says radiologists still must learn three-dimensional anatomy:

The radiologists look at things in sections because that is what the current technology gives them. You train yourself especially when you go into radiology to be able to extend that two-dimensional view to a three-dimensional view. Or you learn to get the information that you want clinically for that particular patient from whatever slice. If you learn your anatomy on those slices, what are you going to do when you put your hands on the tummy of a patient? You can't slice up the patient. You've got to see the liver as a 3D brick. And it's a very challenging task mentally to try to see that liver in the section that you now see in the visible human section. And it is a target to generate 3D models of the visible human data. ... You see, we are getting on for seven, eight years and we still don't have many 3D models. The 3D models are still there just

for show. You see? We have a liver and we have a heart and we have a lung, but we don't have all the little muscles and all the little nerves that make a whole.

The anatomist wants researchers to create three-dimensional anatomies that look like a dissected cadaver might, with discrete solids that can be removed and examined. The traditional, anatomical view developed over centuries of anatomical research and practice. This way of looking teaches students to distinguish among types of tissue, as well as among tissue boundaries. Gross anatomy courses teach students a mental organization of the body into regions and systems. These regions and systems do not necessarily represent the body's "natural" form. Surgeons, for example, expose, retract, and clamp body parts extensively, simply so they can see what they are working on. Anatomical drawings "show naturally separated organs; in the patient-body this state must first be produced by isolating them with a knife. Surgeons call this 'exposition' or 'making anatomy' (*Anatomie herstellen*)" (Hirschauer 1991 301). Creating models from digital cross-sections resembles a graphic form of the exposition Hirschauer describes. Scalpels and retractors in the operating room or anatomy laboratory are replaced by Photoshop pointers and lassos on the screen. The work of extracting structures from the visible human data sets serves as a reminder that the traditional structural organization of the body, though it follows some of the body's tissue contours, also follows the visual conventions of biomedicine. The anatomical body is made, not born.

### **Animating the anatomical body**

Since the Visible Human Male's debut in 1994, the NLM has granted more than 1,000 free licenses (intended solely to track who adopts the datasets) to use the Visible Human datasets to researchers, artists, educators and others. Dozens of commercially

produced CD-ROMs containing cross-section images are easily available. The cross-section images have been used for a variety of applications, including teaching cross-sectional anatomy, simulating car crashes to develop safer vehicle designs, and in at least one Hollywood film to construct a science fiction body from cross-sections. Three-dimensional models and more sophisticated programs have emerged slowly. The UW anatomist says most models made from the data lack the in-depth representations of small structures that would make them comparable to a cadaver for teaching structure. But many models have enough detail to be used as teaching tools. Among the richest in color and detail are the Voxel Man models produced by Institute for Medical Informatics at the University of Hamburg, Germany.<sup>44</sup> One example shows the Visible Human Male torso. The right half consists of the torso rendered in great detail, including the texture of the stitches in Jernigan's right thigh, a tattoo of a dragon on the right side of his chest, and a marble-like hand resting on the lower abdomen. The left half reveals in vivid reds and blues the major arteries and veins in the thorax. The upper half of the left chest also shows the heart and lungs, while the lower half reveals only veins, arteries, nerves and the spinal column. Such presentations of layers of the body's exterior and interior can be created simply by selecting which bits of segmented data to present in any given space. These kinds of models can help students envision spatial relations between the body's interior and exterior and between radiological sections and fleshy bodies. These digital incarnations remain firmly within the medical context of their origin.

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<sup>44</sup> [http://www.uke.uni-hamburg.de/zentren/experimentelle\\_medizin/informatik/galerie/io.en.html](http://www.uke.uni-hamburg.de/zentren/experimentelle_medizin/informatik/galerie/io.en.html). Accessed September 15, 2003.

More striking are animations that make Jernigan move. The most clinical of these show various bones and muscles, such as a presentation at the 2002 Medicine Meets Virtual Reality conference, a conference in the emerging field of virtual reality in medicine, which showed an animation of the visible human jaw in motion. These animations are research projects intended to address the difficult problem of modeling human motion. Most such animations make the body move by initiating motion from the bones, a far easier physics problem than the combination of extension and flexion found in muscular initiation of motion. The modeling goal, then, is to develop models that more accurately depict motion. A difficulty with these animations, however, is that even a model that seems to realistically depict lifelike motion needs a purpose. An engineer watching these animations at MMVR with me noted that the animation itself is very difficult to read and would be much improved if it also depicted the force vectors of the muscles involved. Realism for its own sake does not necessarily create useful models; researchers must add epistemological value to generate teaching or research tools.

The flashiest animations I have seen were produced by the Center for Advanced Information Processing at Rutgers University. One Rutgers animated clip, titled “Rocky 3000,” shows a skinless visible man who jumps rope, runs, does pushups, and shadow boxes to musical accompaniment. Another depicts a skinless visible man running over rocky terrain that might be Iraq or might be the moon; as the man runs, a tank turns and blows him into four pieces.<sup>45</sup> As with the jaw animation, motion is initiated from the skeleton and these animations provide no physiological information: the body moves, but muscles do not flex or extend. Rather, the Rutgers animations morph Jernigan’s digital

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<sup>45</sup> [http://www.caip.rutgers.edu/vizlab\\_group\\_files/CURRENT/index.html](http://www.caip.rutgers.edu/vizlab_group_files/CURRENT/index.html).

body with the synthetic violence of video games. Into what imaginaries of bodies, then, are the visible humans entering? I would suggest that four aspects of the Visible Human Male make these horrifying displays possible. First, removing the skin removes precisely those identifying marks that make this digital body specific to a real person; these are the marks that give Jernigan an identity and a history. Skin is how we know each others' bodies (Good 1994, 72). Second, the Visible Human Male's status as "standard body" intended to provide a data set to test various applications signals its status as generic computational "content," no different from any other publicly available data set that graphic artists and animators use to "test drive" their algorithms. Third, the nature of freely available representations—mobile inscriptions—is to move. The ability of digital bodies to be "re-presented outside their original and local context and inserted into other contexts" is both their purpose and their significance (Rheinberger 1997, 106). Finally, Jernigan's status as a socially marginalized criminal perhaps gives tacit permission for this kind of display. How would this animation be different if it carried Jernigan's face? Or that of Tomb Raider character Lara Croft? Or Saddam Hussein?

### **A cadaver in your pocket**

In this section, I describe how images from the Visible Human Project and technologies using the data sets have altered the body's space, time, and opacity in medical education and practice. Applications emerging from research centers around the country that use the Visible Human Male as a teaching tool change not only the nature of anatomy teaching, but also the social world of medical students and researchers in ways that mirror other changes occurring in medical education (see Knorr Cetina 2000). These include a drive toward more remote and technologically mediated means of imaging and

treating the body, such as advanced imaging techniques, minimally invasive surgery, and remote tele-operated or robotic surgeries (Satava 1995; Katz 1999). In this new world of medical education, the visible humans are a test case and a teaching tool in a new medical world in which space, time, and practice all are changing.

One implication of the development of informatic bodies is their mobility. The digital Jernigan, the Visible Human Male, can exist on infinite computers. It can move as fast as the fastest network connection, often at gigabit speeds. In a traditional anatomy classroom or laboratory, the visible human body can be compared against a dissected cadaver. This might help students to recognize pathology in their cadavers. But more advanced uses are developing. Prototypes of tools for browsing the visible humans allow them to be accessed on mobile tools, such as handheld computers, from anywhere, creating the possibility that medical students eventually will carry their cadavers in their pockets. This fits with initiatives in many medical schools to better integrate anatomical and clinical training. Such integration takes various forms, but it relates to cuts in anatomy classroom and laboratory time, as described above. In many of these curriculum changes, some traditional anatomy teaching is replaced with teaching of clinical cases and, sometimes, more time for students in clinics. Under this format, students spend less time learning the names of parts and more time learning how to solve clinical problems. Technologies designed to facilitate this new mode of teaching also prepare students for a medical world in which they will be able to pull up an individual patient's radiological results and patient records from anywhere in the hospital or from any other location. This new mobility of the teaching body facilitates a shift in anatomy teaching from anatomy as



a first-year language and culture class for medical students to anatomy as a reference for clinicians, representing a change in the proximity of teaching body to clinical body.

A second important impact of virtual bodies is on the body's opacity. The original visible human bodies—like all material bodies—were opaque. Thus, they were frozen and sectioned—destroyed in short—to obtain cross-sectional photographs. These cross sections perfectly align with the CT scans taken of the bodies. The rationale behind correlating CT with photographic anatomy is to help medical students and others learn to extrapolate from the shadows of CT images to the colors of the living body (NLM Regents 1990). That is, the correlated CT and photographic images can help students learn to read and interpret radiological images. Further, graphic models made from the photographic images can help students learn to mentally translate from two-dimensional images to three-dimensional anatomy. This trick of mental translation is part of the radiologist's art and a difficult skill to master. Researchers imagine that this type of correlation of images with bodies will increasingly occur in operating rooms, where surgeons might use augmented reality goggles which lay an image, such as a schematic or x-ray, over the surgical field. Or, in minimally invasive surgeries, in which the surgeon threads a camera and instrument into the body and watches the procedure on a monitor, images of the real and the CT or MRI body could simply be combined. Thus, these techniques morph the opaque and fleshy body with the transparent body. This is the concept of a surgeon's x-ray vision as described above (Satava 1995), and it represents a change in the body's opacity. Correlating real and digital bodies also changes the body's space in relation to the images.

A third, and more radical implication of virtual medicine is a change in the body's time. In laboratories around the world, researchers have begun to use visible human data to build three-dimensional models from CT and MRI images. These visible human models now are primarily used for teaching. Increasingly, high-quality, three-dimensional models of actual patients are used to resolve clinical questions that are difficult to answer using traditional two-dimensional images. Surgical simulation researchers also are creating tools to allow doctors to practice surgeries. They imagine that surgeons eventually will use these tools to practice a procedure *in silico* before trying it *in vivo*. The concept of "reversible surgery" is emerging from technologies that allow anatomy students to reversibly dissect a CT-based cadaver. These technologies are based on the idea that a student or surgeon can reset and start again as often as needed to learn the anatomy or master the technique. A material body—dead or alive—moves forward in time. Changes made to that body—in the anatomy lab or operating room—cannot be undone. If the scalpel slips, there is no going back. The reversible body strengthens the ethic of practice at the core of surgical training. This is an ethic emerging from studies showing that the more surgeons practice individual techniques, the fewer errors they make (Kohn, Corrigan et al. 2000; Mishra 2003). That is, students and surgeons should be able to reset and repeat until they have mastered the anatomy or the technique. In other words, researchers want to make the body's time reversible.

Medical knowledges in present-day hospitals are distributed among various spaces in the hospital, including the pathology laboratory, the operating room, and outpatient clinics (Mol 2002). In each of these spaces, ethnographer Annemarie Mol argues, knowledges of bodies and of diseases are enacted differently through different

practices. Physicians incorporate knowledge from distributed locations in ways that fit their particular needs. The development of bodies in virtual spaces alters the distributed spaces of patient bodies, bringing together knowledges of bodies that might be accessible in the examining room, the pathology laboratory, and the radiologist's office. Virtual spaces conquer the body's time, making the body reversible and allowing the physician to practice a procedure to perfection before the first cut. And virtual space conquers the body's opacity, creating a means of seeing inside bodies, possibly overlaid over the real body, which eventually may give the physician x-ray vision. The visible humans already are providing a practice platform to allow today's medical students to grow into a world in which an information infrastructure build on virtual reality technologies helps doctors treat patients.

### **The 'raw truth'**

My discussion of uses to which the visible human datasets have been put shows that they will lend themselves to an infinity of technological projects, some with a medical purpose, others without. The National Library of Medicine's visible human report called the cross-sectional images, "the 'raw truth' on which all subsequent elaborations can be built" (NLM 1990, 19). Thus, they are the basis from which all research in this area will be derived. In this section, I want to focus on two aspects of the visible humans, both related to their origins in medicine, that make them different from other laboratory objects derived from natural substances. The first relates to their status as model bodies created from real bodies. The second relates to the significance of the history I have drawn here. The story of Jernigan's life, death, and imaging raises important questions: why do the details matter? Why are the artifacts important?

Byron Good describes how medicine constructs persons first through the anatomical and visual “reconstruction of the person appropriate to the medical gaze, identified as a body, a case, a patient, or a cadaver” (1994, 73). The concept of medical gaze is drawn from Foucault (1973), who argues that medical practice shapes a gaze that combines sight, touch, and hearing and seeks to locate in the living the illnesses that would be represented as anatomical lesions that could be found when the body is opened at autopsy. This method of interpreting backwards from the body’s interior in death to its exterior in life is, so Foucault argues, a founding move of modern clinical medicine. This type of perceptual thinking can be seen in expert reviewers’ difficulty extrapolating cause of death from images of Jernigan’s body. But it reveals another critical aspect of medicine: the anatomical model, whether the classical model of organs and systems or the more difficult-to-interpret cross sections of the visible human, always serves as a reference used to treat individual bodies. This is what Hirschauer points to when he says surgeons sculpt in the patient a body that looks like the anatomical atlas in order to see what they are doing. This is also what the physicians I spoke with suggested when they argued that virtual reality in medicine must begin with real bodies. The key point here is that, unlike many laboratory inscriptions, in which the ability to create successive inscriptions represents that science’s power over “nature” (Latour 1987), medicine must always consider its origins in actual human bodies, even though that origin is always already mediated by anatomical and other models, because physicians treat actual human bodies.

This brings me to my second point about case histories in medicine. The case history is a narrative genre that uses the categories of the medical interview—“the chief

complaint, history of present illness, review of symptoms, past medical history, family and social history, and physical exam... as a means of constructing a person as a patient, a document, and a project” (Good 1994, 77). The case history both constructs the patient and constrains what medicine considers appropriate to know about the patient: that is, the patient narrative begins from the strongly held belief that illness is biological and places limits on other knowledge about a patient. This becomes particularly striking in cases when “moral drama” erupts into medical discourse. Good argues that medicine cannot fully contain such dramas, “Physicians and students tack back and forth between engagement in clinical practice and moral reflection” (ibid, 87). Some of this tacking back and forth is evident in the Visible Human Project, for example, in the project director’s concern about the ethics of using Jernigan’s body and his subsequent dismissal of the ethics as a question of legality. The visible humans fit into this space between a technology constructed to aid in teaching students clinical practice and a story rife with moral questions. Without details of the method of production of the Visible Human Man, students and others who study this data cannot construct a medical narrative to describe the artifacts found on these images. Without the details of Jernigan’s life, users will remain unaware of the moral drama of using the body of an executed prisoner, a man who did not know how his body would be used, as a visible test subject to be disseminated over the Internet. This is the lesson of Rutgers skinless animations: The history written onto the skin of the digital visible humans reminds viewers that this medical object was constructed from a real individual, an individual whose insides and outsides tell a story of his life and his digital production, a history that all too easily can be stripped away.

## Chapter 4

### The Anatomy of a Surgical Simulation

'All the energy we spend on motion  
All the circuitry and time  
Is there any way to feel a body  
Through fibre-optic lines?'  
- Cassandra Wilson

Surgical learning traditionally has included intensive and structured training of a surgical resident's skills of seeing, interpreting, and intervening manually in a patient's body. Residents now receive most of their training in the operating room, working on actual patients under the close supervision of an attending surgeon. Since the early 1990s, however, operating room time has been squeezed by changes in hospital economics. Medical students and beginning residents often are relegated to roles as mere observers (Ludmerer 1999), even as a growing body of medical research indicates that constant practice is the key to surgical success rates (Gawande 2002; Mishra 2003). In response, researchers in several universities and private companies have begun to develop virtual reality training systems, modelled on flight simulators, that might one day train medical students outside the operating room, potentially freeing attending surgeons' time and giving students a higher level of aptitude before they work on patients. Surgical simulators also might teach experienced surgeons skills associated with emerging visualization technologies and minimally invasive surgical techniques (Rheingold 1991; Katz 1999). Ideally, simulators would provide visual and physical experiences similar to minimally invasive surgery, teaching the fine motor movements needed to clamp, cut, or

suture virtual tissues, and giving students and surgeons opportunities to practice their skills *in silico* before trying them *in vivo*.

Traditional methods of practicing surgical technique outside the operating room include suturing bananas and other natural objects, practicing on rubber and plastic models, or trying procedures on cadavers. All are used in practice, but they have limitations. Bananas bear some tactile resemblance to skin, but the analogy to surgery ends there. Rubber models are expensive and wear out quickly. Cadavers require the presence of an anatomy laboratory and staff, who must maintain a willed-body donation program, an expense many medical-school administrators want to reduce. A procedure also can only be performed on a cadaver or a rubber model a few times before it falls apart. In addition to these negative reasons to move from physical models to virtual reality, researchers also see several potential positive effects. Unlike a cadaver, a simulation is reversible—the computer can be reset—so students can practice as often as needed to acquire a skill. The computer also can track student progress and, ideally, suggest corrective measures, helping the student master a procedure correctly and potentially reducing operating room errors.<sup>46</sup> Simulator makers also are discussing their technologies with specialty certification boards, which might eventually adopt simulated exams as a means of ensuring student competence.

Medical investigators are building two types of computerized simulator: physical simulators, in which a human patient's body is represented by a mannequin with sensors connected to computers, and virtual reality simulators, in which the patient's body is a

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<sup>46</sup> Simulator researchers have picked up a 1999 report on errors in medicine by the National Institute of Medicine (Kohn, Corrigan et al. 2000) as a strong justification for the repetitive procedural training a simulator can provide. (See also Gawande 2002.)

graphic creation existing entirely in the computer.<sup>47</sup> Mannequin-based simulators are useful for teaching physical skills, such as palpation, particularly when the structures to be palpated cannot be seen, as with pelvic and prostate exams. Though still mostly prototypes, whose expense and technological difficulties make their future uncertain, virtual reality simulators eventually may work well for teaching skills, such as cutting, that would rapidly destroy a mannequin. Virtual reality simulators are most commonly developed for minimally invasive procedures for three reasons: because of the pre-existing relationship of instrument to screen (Satava 1995); because minimally invasive procedures are harder to learn; and because students and residents can practice many skills for open surgery on ordinary objects. Virtual reality simulators also can be networked to distant computers, allowing remote teaching. These simulators still are experimental and have yet to find a place in most medical curricula.<sup>48</sup> The technological challenges also are significant and simulator makers often say their creations still do not 'feel right'.

Building virtual reality simulators for teaching surgical skill and other medical procedures has become an active research area among computer experts, engineers, and physicians interested in medical informatics. To build virtual reality simulators,

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<sup>47</sup> A third type of medical, procedural simulator, called 'augmented reality,' seeks to put virtual structures and actual hands and tools in the same space, usually through the use of special screens and/or glasses. Augmented reality systems are not part of this discussion. The premise of surgical simulation most closely resembles that of flight simulations, in which students practice physical and cognitive skills, sometimes following simulated scenarios. Other simulations, of economic processes for example, are primarily mathematical constructs that sometimes represent numbers graphically, but lack physical feedback.

<sup>48</sup> The social challenges of incorporating simulators into traditional medical school curricula may be a challenge as great or greater than the technological challenges of building simulators; these social challenges include such questions as how to restructure curricula and students' time to accommodate simulation exercises.



researchers have had to break down and reformulate knowledge about patients' bodies and surgeons' actions in previously unexplored ways. These new knowledges of bodies become important when computers become surgical teaching tools, making the computer a crucial non-human actor in this research arena (Latour 1993; Haraway 1997). In this paper, I dissect the research that went into creation of a surgical simulator developed by an interdisciplinary medical informatics laboratory at Stanford University School of Medicine to teach minimally invasive gynaecological procedures, such as the removal of a lump in the uterine wall.

Surgery is embodied action, action that creates particular physical relationships between patients and surgeons.<sup>49</sup> The patient body's materiality—its specificity, its pathologies, its interactions with other bodies—is what interests the surgeon. The very origin of the word 'surgery' in the Greek '*cheir*' (hand) and '*ergon*' (work) suggests that surgical learning must include training of a surgeon's hands, though this neglects the extent to which the surgeon's entire body participates in surgery. For a simulator to represent the experience of surgery, the user must see the body on the screen and feel its responses to surgical actions. The computer must facilitate a visual and kinesthetic interaction between the surgeon-user's body and the virtual patient's body, representing the user's actions and the model body's reactions as graphic and 'haptic' feedback.<sup>50</sup> Haptics is tactile and kinesthetic feedback. In computer device research, haptically enabled

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<sup>49</sup> I do not wish to suggest that vision is disembodied. Rather, vision is sensory and, therefore, prior to action, even when it is as profoundly part of that action as the kind of hand-eye coordination a surgeon employs.

<sup>50</sup> Stanford's simulator requires at least three pieces of hardware: a graphics computer to run the simulation, an interface device, and another computer connecting the interface device with the graphics computer. I use 'computer' and 'simulator' interchangeably throughout this essay.

instruments provide physical feedback from a virtual object to the user, creating the sensation of interacting with a material object. Adding haptics to a simulator creates a tight link between sensation and action, a significant research challenge for simulator makers that is neatly captured in singer Cassandra Wilson's question, "Is there any way to feel a body through fibre-optic lines?" (Wilson 1999).

Stanford's simulator incorporates haptic feedback. The addition of haptics to surgical simulation involves three distinct but related research areas: graphic modelling, haptic interface design, and studies of haptic cognition. Each research area requires surgeons, computer experts, engineers, and others to develop new understandings of the model body and the user's body and to incorporate these understandings into computer software and interface devices. The addition of haptics to the simulation reveals, I argue, how the practice of surgery mutually articulates both the model body and the user's body. This point is methodological: Simulator-builders must make explicit connections that are only implicit in their analogues, thus making these relationships more visible. And it is theoretical: analyzing the visual in medicine does not show the mutual construction of bodies in medicine as clearly as analyzing the physical interaction of bodies. Literature on the intersection between social studies of medicine and science and technology studies indicates that looking at technical practice in medicine could reveal the construction of bodies in medical work in new ways (Casper and Berg 1995). This paper begins to show how studying the construction of a medical teaching technology can reveal facets of surgery and surgical teaching that are not readily apparent when observing traditional surgical teaching.

## **Building models, building bodies**

Medical anthropologists and historians describe sight as the privileged sense in biomedicine (Foucault 1973; Good 1994; Kleinman 1995). The visual also is critical to the concept of the physician's abstract diagnostic 'gaze' that collects data from the eyes, ears, and fingers and translates it into information that could be seen if the living patient could be opened up and viewed with the same clarity as at autopsy (Foucault 1973, 164-6). Stefan Hirschauer's masterful essay on the making of bodies in surgery is an appropriate place to begin a discussion about simulating surgical skill. Hirschauer concerns himself with how patients' bodies and surgeons' bodies are produced in the operating room. He describes how such necessary procedures as draping and anaesthesia effect a retreat of the patient's subjectivity from his or her body, 'Wounding somebody becomes wounding some body' (Hirschauer 1991, 299). Drawing a parallel with the patient, Hirschauer also describes the surgeon's physical retreat behind mask, gloves, and gown. He describes surgical exposition as 'making anatomy' (301), meaning the physician creates anatomy as it might appear in a textbook from the messy, indistinct structures of the human body, 'the flesh is dense and compact, stuck together and impenetrable' (300). He makes clear that the abstract anatomical model in the physician's mind and the material patient's body mutually inform each other, a process he calls 'a permanent cross-fading of experience and representation' (310). Hirschauer acknowledges that surgeons acquire two bodies in their education, their own bodies as trained practitioners and the 'ingrained abstract body' of the anatomical atlas (309). But he does not connect development of the surgeon's physical skill to the acquisition of abstract anatomical knowledge.

Byron Good (1994) describes medical students' first explorations of human bodies in the gross anatomy laboratory as primarily visual training. He says anatomy training is visual and the ability to delineate structures comes with weeks of experience and practice. Gross anatomy training is undeniably visual, intended to teach students to discern structures and recognize spatial relationships, but experience and practice in the gross anatomy laboratory consists of weeks of physically dissecting and handling tissues. Students of anatomy and surgery learn visually through atlases, diagrams, and inspections of bodies. They also learn physically, by cutting and separating tissues during dissections and surgeries (Prentice 2002). Anatomists repeatedly told me that a student's physical experience of dissection is a critical component of anatomical learning.<sup>51</sup>

My experience confirms this. After months of observing dissections and handling tissues, I picked up a scalpel and—under the careful supervision of a hand surgeon—performed a mock 'surgical' procedure on a cadaver arm, the transposition of an ulnar nerve, a procedure typically done to relieve pain associated with a pinched nerve in the elbow. I began to understand how much easier distinguishing tissues and remembering names and spatial relations becomes when tactile sensation and visual knowledge come together. Differences among tissues become palpable. Skin slightly resists a scalpel, giving a feel for the skin's fibrousness. The same scalpel slides easily

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<sup>51</sup> The importance of dissection in medical education is hotly debated. Medical school administrations in the United States and Canada have been cutting back teaching time and resources for gross anatomy for several decades. The justifications for this move are many: maintaining a willed body donation program is expensive, gross anatomy is time-consuming, only surgeons really need the in-depth anatomical knowledge provided by gross anatomy, medical students need actual clinical experience earlier. Anatomists are fighting this threat to their discipline with many arguments, including the importance of the training in physical skills and three-dimensional visualization that gross anatomy provides.

through fat. Scissors, used in 'reverse', to separate rather than cut, puncture and spread fascia only with some difficulty. Nerves are hard and slippery. One surgeon likened nerves to pasta cooked until it's 'al dente', soft on the outside with a harder core. Blood vessels, which are hollow tubes that in cadavers often look like nerves, give the sense of two slippery layers gliding against each other when rubbed between gloved fingers. Students begin to make visual and tactile distinctions among anatomical features while dissecting cadavers, but the distinctions grow finer for those who elect surgery as a career.<sup>52</sup> Thus, the embodied, tactile and kinesthetic experience of dissecting helps students develop abstract anatomical knowledge.

Bruno Latour's (forthcoming) concept of articulation provides a good starting point for discussing the connection between the acquisition of physical skill and the acquisition of abstract knowledge. Latour points out the notorious difficulty of describing what a body is. He says the body comes into being through sensory interactions with the world and argues that a good approach to analyzing the body is to define it as an interface that gets increasingly describable as it comes to be affected by more elements. He uses the example of a kit designed by perfume-makers to teach students increasingly fine olfactory distinctions by teaching them first to identify extremely different smells and then to distinguish smaller differences. Following this approach, attending to the body means focusing on what the body becomes aware of. Thus, the sensing body becomes increasingly articulate as the senses learn to register and differentiate objects, a process

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<sup>52</sup> Human gross anatomy is sufficiently complex that an anatomist practicing for five decades described learning new structural features with each dissection. A surgeon practicing for two decades described reviewing the anatomy of regions where she rarely operates. Surgeons and residents in teaching hospitals also constantly review and reinforce their anatomical knowledge when a surgeon quizzes a resident, during surgical planning, and while operating.

Latour describes as learning ‘to be *affected*, meaning “effectuated,” moved, put into motion by other entities, humans or non-humans’ (Latour forthcoming, 1, italics in original). Focusing on articulation prevents the creation of a divide between world and subject, and between physiology and phenomenology. Further, describing the world through the mediation of instruments is no longer something entirely unrelated to teaching the senses, but rather becomes another means of articulating differences in the world. Latour argues against the notion that science and medicine are reductionist: ‘When you enter into contact with hospitals, your ‘rich subjective personality’ is not reduced to a mere pack of objective meat: on the contrary, you are now learning to be affected by masses of agencies hitherto unknown not only to you, but also to the doctors, nurses, administration, biologists and researchers who add to your poor inarticulate body complete sets of new instruments...’ (forthcoming, 20). This is true both of patients and physicians. Viewed from this perspective, much of medical education is a process of articulating two bodies—the patient’s body and the physician’s body—and their interconnections. Latour describes how agencies of instruments and staff articulate the patient’s body in the hospital. I extend his analysis to consider how the patient reciprocally articulates the doctor’s body. The physician’s body is articulated by the patient, by anatomy texts, by professors of anatomy and surgery, by instruments; that is, the physician’s senses, including motor skills, are trained by patients’ bodies and other entities.

Physical skill, such as that of surgeons, often has been described as tacit knowledge. Tacit knowledge is knowledge that cannot be taught solely by verbal means (MacKenzie 1996, 215). Writers about tacit knowledge have focused on how some

physical knowledge can be described (Pinch, Collins et al. 1996), how physical knowledge is transmitted (Polanyi 1966) and on how physical or cultural knowledge can be reproduced (Collins 1985; MacKenzie 1996). The knowledge of smell transmitted by the olfactory kit clearly qualifies as knowledge that cannot be transmitted verbally. Thus, the kit becomes a simulator of sorts, a carefully crafted model instantiating an expert's knowledge of smells in the world. This is an example of what Harry Collins calls 'mimeomorphic' knowledge—complex skill that can be taught with a simulator and does not require particular socialization into a group to be learned (Collins, Vries et al. 1997). Surgical skill is another example of complex physical knowledge that must be learned through practice. Surgeons must acquire a 'muscular gestalt' accompanied by knowledge of anatomy and pathology, as well as problem-solving skills, which Hubert Dreyfus describes as 'the power to respond with a certain type of solution to situations of a certain general form' (Dreyfus 1992, 248-9). Surgeons spend years developing skill they can generalize from one procedure to another and from one body to another. To do so, they must integrate complex knowledge of anatomy, pathology, physical skill, and problem-solving skills. Attending surgeons and years of practice obviously contribute enormously to this development of skill. But what gets less attention is that the act of sculpting anatomical forms from dozens of varied and opaque patient bodies also shapes this learning.

Medical education articulates patient bodies for medical students. Patient bodies are different from the bodies we encounter in everyday life. Medical curricula in most North American medical schools begins with gross anatomy, histology and other sciences of the physiological body. This is a process of articulating a body that is biological, a

body whose mechanisms come into focus and whose subjectivity is carefully circumscribed through representation in charts and case presentations (Good 1994). New medical students experience perceptual shifts that reshape their connection to patient's bodies. One student says, 'I'll find myself in conversation ... I'll all of a sudden start to think about, you know, if I took the scalpel and made a cut [on you] right here, what would that look like' (Good 1994, 73). This statement reveals how the medical student, by learning to dissect, has begun to reconstruct the person as patient. A critical piece of the statement, however, is the student imagining himself or herself physically reconstructing the person by taking up the scalpel and making a cut. This reveals the mutual articulation of patient or cadaver body and physician body: the person's body becomes the biomedical patient body and the student's body becomes the physician's body when the student wields the scalpel in the operating room.

Embodied practices lead to articulation of bodies. Annemarie Mol (2002) describes how different areas of medical practice create somewhat different objects, even when those objects are all the same disease. Her goal is to escape the concept of disease as representation and move toward a concept of disease as an entity that is enacted—brought into being, shaped—in practice, 'Instead of the observer's eyes, the practitioner's hands become the focus point of theorizing' (Mol 2002, 152). Thus, atherosclerosis, Mol's example, is brought into being by patients as pain when walking, by pathologists as a blocked lumen at autopsy, and by surgeons as fat scraped from inside a blood vessel. These atheroscleroses may all exist in one body but, Mol argues, these different practices make the body multiple in practice. The processes of bringing multiple bodies into being is situated and different practices must be coordinated or held apart



through various hospital practices. Mol's concept of bodies being made multiple through varying practices related to bodies helps open up the multiple practices of engineers, computer scientists, and physicians as they create multiple simulated bodies. Articulation suggests multiplicity.

The concept of articulation leads to what I will call the mutual articulation of model body and user body in surgical simulation. The concept of articulation of the body works well when the object is—like the olfactory kit—reasonably stable. Mutual articulation comes into play, I argue, when both the physician's skills and patient's bodies must be articulated. Mutual articulation is implicit in the descriptions I have cited of anatomical and surgical practice. The physician must create the model body from the patient's body even as this sculptural practice defines and reinforces the surgeon's skill. This becomes particularly important when creating models from objects like the human body because broad variations in anatomy and the fleshy opacity of bodies mean the anatomical model must be created anew with each surgery.

The process of building a haptically enabled virtual reality simulator for teaching surgery makes mutual articulation much clearer because simulator researchers must actually build the physical connection between hands and model. And the articulation of bodies does not end with model and user. In simulation-building, bodies must be defined, described, and mathematicized for the computer. Latour suggests that, in science, new articulations may lead to new questions and new inquiries. This is also true of technology-building: each component of the simulator articulates the user's body, and the connection between the model-patients' body and the user's body, in a slightly different way. That is, each component of the simulator grapples with the user's body in a slightly

different way. Surgical simulator builders must articulate the model-patient's body and the user's body in multiple ways. And yet these multiple bodies must also fit together to create an experience resembling the interaction of a surgeon's body with a patient's in a way that articulates the user's body as a surgeon's body. The bodies in this world are multiple, the technologies are multiple, and the researchers needed to build them are multiple. Each device, software, or research study articulates the body in a new way. Builders of haptically enabled simulations must articulate the physics of the surgical procedure—the physical connection between user and model—in very direct ways in relation to each component of the simulation. Surgical simulation, specifically the addition of a haptic interface, makes this mutual articulation highly visible.

### **Materializing the virtual patient**

Simulators add a key ingredient to training outside the operating room: a patient. The virtual patient is a graphic model of an anatomical region or organ, what one researcher at Stanford calls a 'patient-on-demand,' a patient who can be practised upon whenever a student wants, without the inconvenience of waiting until someone gets sick. The simulator's ability to provide a 'patient-on-demand' promises to be one of the most significant social shifts produced by surgical simulation. Currently, medical students and residents must take every opportunity to watch and perform surgeries, whenever they occur, regardless of the hour. Students doing brief rotations may never see some procedures performed or get to practice certain skills. An orthopaedist at SUMMIT explained this rationale for creating a surgical simulator:

I remember very early on, I was probably a second-year resident. And a young boy had come in with a fracture of the radial head and they were going in to do surgery for radial head excision ... And the chief resident said, 'You want to come up and scrub up with me?' And I had so much

other work to do on the ward. ... And I wasn't actually the resident who was supposed to be with him. ... I said, 'Well, you know so-and-so is going to be there with you. He said, 'Are you going to the ward?' I said, 'Yeah I'm going to the ward.' He said, 'If I were you I would actually take the opportunity to come into the OR.' And I was still quite very junior, so I hadn't really gone into the surgical hierarchical system at that time in the training. ... In the second year, you're still not doing much surgery. ... I told him, 'I have to finish those things. Otherwise it will be midnight before I finish.' And he says, 'This may be the only chance you'll get to see this case.' And it struck me then that surgical training is very opportunity driven. And it so happened that I only got to see one more case like that. Many cases came, but they came at a time when I wasn't there.

Simulators may eventually allow students and residents to practice dozens, even hundreds, of procedures as often as necessary to feel competent. This surgical suite in cyberspace is not beholden to the same rules of time, space, or manipulation as the original. The student can practice procedures without worrying about time, operating room protocol, causing harm to a real patient, wearing out a physical model or cadaver, or the whims of potentially mercurial surgeons.

Simulator research at Stanford, and most virtual reality simulator research elsewhere, focuses on minimally invasive procedures. To perform a minimally invasive procedure, a surgeon inserts a camera and instruments through small incisions in the body and performs the entire procedure looking at a monitor that shows surgical action taking place inside the body's interior, a move one surgeon at SUMMIT describes as 'operating on images, not on patients.' Because minimally invasive surgery already occurs 'on-screen,' the move to simulate these procedures is easier than with open surgery. Although efforts exist to simulate open surgery, surgeons often use their hands directly inside the body when doing open surgery, a practice that would more difficult to simulate than surgery with instruments. And minimally invasive surgery involves more kinesthetic than

tactile sense, making the provision of haptic feedback easier. Simulating surgery also takes advantage of a feature of all surgeries: the operating field is separated from the rest of the patient's body, which usually is covered with sterile drapes (Hirschauer 1991, 299). A simulated patient represented as a fragmented body part on a computer monitor may resemble the surgeon's visual experience of the operating field more than might be apparent.

The system requires a user, graphic models of patient body and surgical tools, an interactive device designed to look and act like the surgeon's end of an instrument, a computer to manage the haptic device, and a multi-processor computer to run the simulation. Making the system work requires definition of how these components work together. Materializing tools and bodies in cyberspace requires what are, in effect, three feedback loops that make up the interaction between user and model. The first—or virtual—feedback loop defines the interaction between instrument tips and model body as the model responds to the instruments and, in turn, provides haptic feedback to the user. This is the domain of computer modelling. Researchers—programmers and surgeons—wrestle with the question: how can we create a graphic and physical model that accurately represents the body interacting with the instrument? The second—or mechanical—loop describes the interaction between the user's hand and the instruments as the instruments respond to user and model. This is the domain of mechanical engineering research, which aims to answer the question: how can we ensure that our device works properly—feeding correct haptic information to the virtual world and back to the user's hands? The third—or cognitive—loop connects the user's mind, his or her intent, to the user's hands as the hands receive feedback from the device as the user takes

the next step in the procedure. The cognitive loop represents the domain of haptics research and this question predominates: how does a body learn and what mental models do our tactile and kinesthetic actions help us create? Each of these loops represents a research area among simulation experts. Each requires descriptions of the virtual patient's and the material user's bodies as they interact with the simulation. Though I describe these loops as independent entities and, at SUMMIT, they represent somewhat independent research projects, researchers want to build a simulator from this complex assemblage of hardware, software, and expert knowledge that can represent a visual and physical experience similar enough to performing surgery to help the student learn. Although each component of the simulator defines the relationship between model and user slightly differently, the components attempt to give the user a seamless experience of surgery.

### **Modeling: constructing the virtual patient's body**

SUMMIT's laparoscopic simulator contains a model of the female pelvis made from ninety-five digitized photographs of pelvic cross-sections. The sections came from an anonymous 32-year-old woman who willed her body to Stanford before she died. Anatomists at Stanford froze the pelvis in an upright position, then ground layers off at roughly 2-millimeter intervals. After removing each layer, they took a photograph of the newly exposed cross-section. The retired gynaecologist decided to use the collection of cross-section photographs as the foundation for a virtual reality simulator. He named the collection the Stanford Visible Female, linking it to the National Library of Medicine's better-known Visible Human Male and Visible Human Female, which were created using

similar techniques.<sup>53</sup> He scanned the ninety-five cross-section images into a computer. Then he spent more than a year tracing the structures he wanted to model into files using an early version of PhotoShop, a commercial image-manipulation application: one file for each structure on each cross-sectional image. He describes this process, called segmentation, simply as ‘drawing circles’ around each structure he wanted to model and saving the contents of each ‘circle’ as a ‘mask’ with its own computer file:

I would make a mask and I would put it in the muscle file. And I’d make a mask and I’d put it in the bone file. And then I’d go to the next slice, put the bone in the bone file. Next slice. And so I ended up with all of these files that had individual masks and then we took the software ... and made models from those masks.

The gynaecologist initially segmented only the reproductive system, leaving the six pelvic bones and many muscles as undifferentiated aggregates labelled ‘bone’ and ‘muscle’ respectively. Subsequent iterations differentiated pelvic bones and muscles and added less critical features, such as fat. The gynaecologist segmented the reproductive organs and a collaborating orthopaedist segmented the bones and muscles. They produced 2,200 masks from 95 cross-section slices encompassing the female reproductive system and the surrounding musculo-skeletal system. The division of labour occurred because each physician had a slightly different area of anatomical knowledge. Segmentation includes several of the ‘transformative practices’ Michael Lynch identifies in relation to model-making, including ‘upgrading’ the images by making strong borders between tissue types and ‘defining’ the images by sharpening contrasts (Lynch 1988,

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<sup>53</sup> Visible Human Project information and images can be viewed at [www.nlm.nih.gov/research/visible/visible\\_human.html](http://www.nlm.nih.gov/research/visible/visible_human.html). (see also Cartwright 1997; Cartwright 1998; Waldby 2000; Csordas 2001). Birke (1999) briefly discusses both the Visible Human Project and the Stanford Visible Female.

160-1). But segmentation is not done to make the cross sections readable by human eyes. Rather, anatomists segment cross-sectional images to create outlines readable by computer-modelling programs.

The orthopaedist compares the difference in the two surgeons' anatomical expertise to geographical knowledge of highways and interstates in the Bay Area:

I think it is a question of with what granularity you look at [the body], with what amount of detail. To try to give an analogy, it's like ... a map. If you look at a map, say you're looking at the map of the Bay Area and it's an overall map, and you say, there's [U.S.] 880 and there's [U.S.] 101, and you have a fair idea of the map and that's your basic anatomy. But now if you want to know about Palo Alto, then you need to zoom down. Oh, there's El Camino and there's this and there's this. So now you know a little bit more detail there. It hasn't changed your 880 and 101 knowledge, which is over the Bay Area. ... So, if you're talking about the radial nerve, if someone doesn't have to deal with the radial nerve surgically, they have an idea, OK, the radial nerve comes from there and goes there. But the finer bends and curves only somebody who is dealing with it would know.

The analogy between anatomical knowledge and a map is quite common, but ignores several complexities inherent in anatomical segmentation. First, cross-sectional images of the body have no labels to guide the surgeons as they segment. Second, though some radiological images, notably CT, are cross-sections, surgeons rarely see actual bodies in cross-section, so interpreting cross-sectional images requires a mental extrapolation in three dimensions from one angle of approach to another, the mental equivalent, perhaps, of trying to read a map of the Bay Area from a diagram of its geological strata.<sup>54</sup> The level of anatomical knowledge required to segment one female pelvis also speaks to the extreme specialization of surgical-anatomical knowledges and to

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<sup>54</sup> One anatomist at Stanford teaches students to check their knowledge of anatomy by attempting to label structures on cross sections. He says the ability to 'rotate' a two-dimensional image by 90 degrees and then label its structures indicates that the student has begun to understand anatomical terminology and the body's three-dimensional structure.

the difficulty of producing a comprehensive model body.<sup>55</sup> The anatomical body, even in a partial area, such as the pelvis, required digital articulation by specialists from two surgical disciplines. This is an example of Mol's body multiple: the female pelvis is a single, albeit complex, anatomical region that is, in practice, a gynaecological pelvis, an orthopaedic pelvis, and more. The orthopaedist's term, 'granularity', can be thought of as the multiplicity of practices that bring this anatomical region into being.

Up to this point, medical experts—the two surgeons—did the work of delineating body parts. The next modelling steps multiplied the body in another realm of practice: the world of computer modelling, a subspecialty of medical informatics. A computer-modelling student took the segmented masks and computationally stacked them, creating models of organs, muscles, bones and other features (as stacked slices of bread create a loaf). To connect cross-sections into a surface model, the student transformed stacked outlines into a 'mesh,' a digital, mathematically generated net that mapped the model's surface. Modelling using this technique takes advantage of a digital photograph's resolution into pixels. Once gynaecologist and orthopaedist outlined the structures to be modelled on the two-dimensional cross-sections, the modelling student wrote computer algorithms—creating a geometry the computer could understand—to connect the outlined pixels across adjacent cross-sections. These connected pixels formed a mesh conforming to each structure's surface, much as a nylon stocking conforms to a foot. Because this

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<sup>55</sup> An anatomist at the University of Washington, who works on computer applications for teaching anatomy, told me that research funding also stands in the way of creating comprehensive anatomical applications. Funding agencies will pay for new applications, usually limited to one area of the body, but claim that applying new computer technologies to an entire body is production work, not research, and ought to be done by the private sector. However, this anatomist claims, and others confirm, most companies have found the labor of creating a comprehensive computer body model not worth the cost.



model is made of both graphic pixels and the mathematical mesh, the model body is simultaneously a graphic and a mathematical representation of a body—a representation that can be viewed and manipulated by a human user in ways the computer can calculate.

The gynaecologist, who spent eighteen months doing the first segmentation of the Stanford female pelvis, described the first time he saw the model uterus created from the masks he drew:

And so when I saw that uterus the first time, the thing that blew me away was not what I expected to see, but what I hadn't expected to see and that is where the utero-sacral ligaments attach to the cervix and support the uterus in the pelvis. There are a couple of little bumps, little sharp points there where those take off that I could see [on the model]. And, of course, that relates a lot to my surgery, which is on those ligaments where endometriosis occurs. So many laparoscopies I did finding endometriosis on those ligaments and in the region of the pelvis that I was so drawn to the image. There they are. And I could see them.

The gynecologist described the process of drawing outlines of structures on cross-section photos as a process of abstracting the human body's complexity and specificity. But when the model came together, the resemblance of model uterus in the computer to an actual uterus gives the gynaecologist a sense of wonder, pleasure, and reassurance that tedious months of drawing circles actually produced a model that looks like a uterus. Hirschauer (1991) describes anatomical exposition in surgery as sculptural practice. This is a process of carving a body resembling an anatomical model out of messy, indistinct flesh. The cross-section photographs the gynaecologist began with are themselves representations of messy flesh, representations that neither computers nor inexperienced medical students can use to practice surgery. By drawing outlines of anatomical structure that could then be computationally stacked to make model body parts, the gynaecologist and the programmer performed a sculptural process analogous to surgical exposition,

which the surgeon's experience confirms: the model looks like bodies he has operated upon. The photographs became a neat, three-dimensional model of a uterus that has already had fat dissected away, in other words, a model that has already received a certain amount of sculpting. The surgeon physically—using a computerized lasso, rather than a scalpel—articulated a model that represented his experience. The model body then affirms for the gynaecologist that this computational procedure worked and has produced a tool he considers adequate for teaching surgical anatomy to simulation users.

The gynaecologist named the newly modelled reproductive systems Lucy 2.0, describing it as the 'digital daughter' of Lucy, the hominid bones found by Stanford researchers in Africa in 1974.<sup>56</sup> This model human body is a laboratory object: it is the image of the original object (in this case a human body), detached from its natural environment, and no longer beholden to the original's temporality (Knorr Cetina 2000, 27). Unlike a living or dead human body, the model body can travel through a computer network, can be pulled apart and put back together, or modified to reflect pathologies, all without causing it harm. The model body becomes an 'immutable mobile,' a recreation in cyberspace of the original with the advantage of 'mobility, stability, and combinability' (Latour 1986, 7). But the model in this state is useful primarily for teaching anatomical

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<sup>56</sup> <http://summit.stanford.edu/ourwork/PROJECTS/LUCY/lucywebsite/fun.html>. Accessed: March 1, 2003. Donna Haraway argues that we must pay attention to the material and the semiotic natures of objects (1991, 200). By naming this model 'Lucy 2.0,' the researchers who created the model brought it into narratives of evolution and reproduction, narratives in which the female often is associated with matter, while the male is associated with form (see Butler 1993). Csordas (2001) describes how the male and female bodies from the National Library of Medicine's Visible Human Project have been described as a digital Adam and Eve. The Stanford model similarly has been baptized with an origin story, but a more evolutionary and Stanford-specific story (Cartwright 1997; Cartwright 1998; Birke 1999; Waldby 2000).

structures.<sup>57</sup> It is visual, but it cannot yet interact with the user as a material body would. It is not yet a patient and it is not yet prepared for surgery because surgery, at its most basic, physical level, involves interactions of bodies and instruments.

Before the model pelvis could become a ‘patient-on-demand’, it first had to become deformable. To make the pelvis respond to surgical action, a programmer added algorithms to the model describing how tissues stretch, separate, or come together—that is, how tissue deforms—when pulled, cut, or sutured. The programmer began with the mesh structure of the surface model and defined the lines connecting points on the mesh as springs. Pulling on any point of the virtual mesh causes the surrounding virtual springs to stretch, ‘deforming’ the model according to well-defined physics equations that describe the resistance of springs. Spring-based deformations are useful for small, relatively slow movements of tissue, as are common in surgery. Stiffer springs lead to tougher-feeling tissues.

To set values for spring stiffness, the gynaecologist and the programmer developed heuristics describing the feel of pelvic tissues. These mathematical descriptions of the feel of pelvic tissues are constructions based on the gynaecologist’s physical memories—what he calls ‘haptic memories’—of the feel of performing surgery on various tissues. The gynaecologist expressed his haptic memories in terms both of his sense of differences among tissues and his sense of the specific feel of a particular

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<sup>57</sup> <http://summit.stanford.edu/ourwork/PROJECTS/LUCY/lucywebsite/infofr.html>. (Accessed March 1, 2003).

tissue.<sup>58</sup> To develop the haptic program, gynaecologist and programmer created algorithms—body objects—that attempt to represent the surgeon’s physical experience in a form the computer can use. To do this, the programmer had to learn something about surgery. He learned the physical differences between structures in a woman’s reproductive system. He also learned some terminology of anatomy and surgery. Most importantly, he found a way to physically describe the gynecologist’s embodied actions. He said he created a description of ‘how the world works’ at a deeper level than typical surgical instructions to cut, clamp, or suture. In effect, the engineer developed a physical model of the movements behind each of those verbs.

Traditionally, tissue stiffness is known only through surgeons’ bodies and might be communicated to a student as a general warning about the potential to harm a delicate tissue, such as the warning that damaging or cutting a nerve during surgery can be a ‘million dollar [malpractice] injury.’ Constructing a quantitative model of a body’s physical response to surgery becomes necessary only when the knowledge moves from body to computer. During a demonstration, the programmer runs into a technical glitch and tries to describe to the gynaecologist how the uterus feels:

Hey, do you want me to reset your uterus there? ... Do you want me to bump up the stiffness so it behaves like muscle? Now it’s behaving like a thin skin. I think that’s something I learned from you [the gynaecologist]: that the uterus is basically like a tough muscle. Now it’s behaving like a thin skin.

The idea of ‘resetting’ a uterus clearly comes from computer science and shows how the conceptual vocabulary from that discipline contributes to defining the body in the world

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<sup>58</sup> The model is an ideal body: it does not take into account variations among patient bodies or in sense of feel experienced by different surgeons, though these are additions that simulator makers say they will incorporate into future iterations.

of anatomical modelling and surgical simulation. Further, the programmer articulates what he has learned from the surgeon about tissue feel. The surgeon's understanding of tissue feel comes from years of practice. The programmer attempts to approximate the surgeon's bodily experience, translating knowledge of a body's feel, which usually remains tacit, into equations describing the stiffness of springs. The virtual model body is put into motion as a function of the movement of springs. This is the type of 'mathematical construct' the group director refers to when she says knowledge that once was primarily experiential must become mathematical when translated into a computational idiom. The feel of the model body's movements becomes articulated in relation to the gynaecologist's experience as it gets translated into algorithms. In turn, the differences in tissue feel incorporated into the model will help articulate the student's body; that is, these differences will help students learn the feel of model bodies, feel that, if all goes well, will allow the transfer of the surgeon's skills from simulated to material bodies. Tissue feel can be described, but only using relative terms, such as 'delicate' and 'tough' (Pinch, Collins et al. 1996). Students can use these descriptions to guide them as relative differences in tissue feel become embodied knowledge. But the computer requires experiential knowledge of difference to be articulated as mathematical values describing those differences. The surgeon constructs differential values, from his experience. Thus, the model's deformability does not, cannot, exist apart from the thing it interacts with, in this case, the surgeon's body as mediated by instruments. Deformability is a quality of model bodies defined exclusively at their interface with other bodies. Values of tissue feel used in deformable models are products of the mutual articulation of bodies.

## **Interacting mechanically: characterizing the user's body**

At this point, programmers had built the possibility of movement into the model body, but it could not yet be put into motion by a user. The next key step in making the surgical simulator was to create an instrument to act upon the body. Because the user activates the instrument, which then acts upon the model body, the instrument becomes, in effect, a bridge from a body in the real world to a model body in the virtual world.<sup>59</sup> A bridge can take the form of several types of device, but ones I have seen share this feature: they all exist both on and off the screen. This existence in both worlds resembles many gaming devices but, as with the physics-based deformable model, medical researchers pay more attention to giving users a realistic feel for surgical interaction and, thus, the coupling of action and reaction is tighter and more rigorously defined. SUMMIT's gynaecology simulator uses the two-handed, or 'bi-manual,' device described earlier, which was designed to mimic the feel and motion of instruments used in laparoscopic surgeries. SUMMIT researchers developed the device jointly with Immersion Corp., a San Jose medical device manufacturer. The device is a heavy, metal box with two protruding handles. Each handle has a scissor-like mechanism at the end that allows the user to manipulate virtual instrument tips. When a user turns the instrument on, graphic representations of surgical instrument tips—the patient ends—appear on the computer screen in the same space as the body model. A multi-processor graphics computer runs the simulation, which uses a method known as 'collision detection' that tells the instrument tips and model body to react when they enter

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<sup>59</sup> I do not use the obvious word 'interface' here, though it is technically correct, because it has visual implications that I want to avoid.

each others' co-ordinate space, that is, when they touch. Outside the computer, the surgeon's ends of the instruments correspond spatially to the instrument ends and the tips move as the handles move, giving the illusion that real handles and virtual tips are continuous. Closing the metal, scissor-like handles in the real world clamps the virtual instrument tips in the virtual world. When the user pulls the handles, virtual tip and tissue move with it, allowing what the gynaecologist calls 'tool-tissue interactions.' The instrument acts in two directions. The interface allows the user to perform actions on the handles that translate into action at the tips that, in turn, act on the model body. The device also transmits back to the user's hands—in real time—the effects of those actions on instrument and model, providing haptic feedback.<sup>60</sup> When I clamped the instrument onto a virtual ovary, for example, I felt a distinct snap as the instrument locked onto it and resistance when I pulled the virtual tissues. In reality, all I pulled was the interface handle; on screen, the instrument tip retracted, pulling the ovary with it.

Within the context of the mechanical feedback loop, the user's body emerges in relation to the haptic device as engineers designed the device and began to study how it operates in practice. A mechanical engineer said engineers and surgeons had lengthy conversations while designing the device to resolve such details as distance between the handles and the range of movement the device should have: 'There was considerable debate from engineers like me who wanted to simplify things by removing some degrees of freedom, but surgeons argued you needed it.' Each new capability makes the device

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<sup>60</sup> Some experiments have been done with haptic interaction between two users in remote locations, but technically this creates a problem separating signals that are feeding forward from users' bodies from signals that are simultaneously feeding back to users' bodies. Human nervous systems have no trouble with this kind of 'signal processing,' but it still is a challenge for machines.

more difficult to manage mechanically and computationally, but surgeons wanted a certain realism or fidelity to surgical experience. Realism requires that the device faithfully mimic not only the feedback of interacting with patients' bodies, a software design challenge, but also the spatial and tactile feel of instruments themselves, a hardware design challenge. Designing a device that correctly interprets the signals it receives from the human user and correctly feeds the haptic response back to the user gives rise to a fascinating problem: characterizing the human user's effect on the system. During an eight-hour meeting of laboratory researchers with an external reviewer, who is an expert in educational technologies, participants tackled the question of how to consider the user's body as it interacts with the device:

**Mechanical engineer:** We will have to do a study that accounts for variability among subjects.

**Laboratory director:** When [our collaborator in Texas] uses Immersion stuff, she's always complaining that she's not getting the kind of frequency response they claim it should have.

**Mechanical engineer:** The dynamic response slows if a human hand is holding the device.

**Laboratory director:** It's like having a sloppy, wet mass holding the thing.

Human bodies, viewed here as research objects, create several difficult problems for investigators. Bodies are variable; that is, not all bodies affect the device the same way. And user's bodies slow the device down, compromising its ability to faithfully transmit the sensations of interacting with the model. The research question becomes how to manage the effects of this 'sloppy, wet mass' (or many, varied sloppy, wet masses) on the device's response. In surgery, the surgeon's body and tools, when they're performing well, are the unproblematic agents of surgical action. This is the essence of embodied tacit knowledge: with years of practice, surgeons learn to use tools as extensions of their



bodies. Technique becomes fully incorporated and, therefore, largely unconscious when all proceeds smoothly (Polanyi 1966). But the effect of the surgeon's—or user's—body on the bi-manual device and the virtual simulation must be characterized mechanically and compensated for in the computerized system, so the interaction of cyberbody and material body feels like an interaction between two material bodies. The user's and the model body's ability to mutually articulate each other depends on programmers', surgeons', and instrument-makers' ability to create a good enough representation of the feel of performing surgery on a live body. This requires articulating the user's body for the instrument and for the programs that control the instrument. Researchers must account for the sloppiness and variabilities of user's bodies so the user can properly articulate the model body and receive useful physical feedback,. This is another example of mutual articulation: the user's body must be articulated for the instrument so it can in turn articulate the feel of doing surgery for the user.

### **Embodied cognition: integrating and translating skill**

The cognitive feedback loop—the work that happens between hand and mind—takes up the question of what we learn through our bodies and how what's transmitted to the body gets interpreted and learned. A physicist turned cognitive scientist does haptics research at Stanford. She has conducted a series of experiments intended to elucidate poorly understood haptic concepts, such as the delineation of edges, which we use to understand our world through tactile and kinesthetic sense. She also is investigating how many times a particular pattern in space must be repeated before the body learns the pattern. She wants to better understand the role of physical learning in surgery and to help

develop more effective devices, including surgical simulators. She sums up the research project as the attempt to characterize ‘somato-conceptual’ intelligence:

Haptic sensations are personal. I cannot tell you exactly what I feel. It’s personal. It’s felt by the touching person only. It’s determined by the touching forces. Each person exerts different forces. There’s a different coefficient of forces for muscle, so we experience different things.

In this researcher’s study of haptic cognition, material bodies become bodies that exert forces on objects and receive forces from those objects. But bodies vary. And varying bodies exert different forces on objects, so experience also varies. According to this concept of haptic learning, physical experience is reduced to a set of forces exerted upon and received by muscle, so experience and learning are determined by the interaction of muscular forces with an object.

Studying the path from physical force to learning presents enormous problems for researchers, so the problem gets redefined in terms of the force transmitted to the hands and the user’s interpretation of that force. During the same external review cited above, researchers tackle the problem of how to understand what’s happening inside the user’s body:

**Haptics researcher:** How do you make it so everybody feels the same thing?

**Reviewer:** It gets metaphysical very quickly. If we all touch the table, do we all feel the same thing?

**Haptics researcher:** It’s a bad question because you can’t answer it.

**Reviewer:** It’s a good question; it just shows you’re not a philosopher.

**Haptics researcher:** Yes, but as a physicist, I understand the question.

**Reviewer:** That’s because physics and philosophy are close together.

...

**Surgeon:** What is felt by the user? What is the force? What is the interpretation of force by the user? Is it possible to measure?

**Haptics researcher:** Different surgeons would make the same interpretation when they feel the same lump.

**Reviewer:** That's as far as you can go. If everybody says it's a ring, you're in good shape.

**Mechanical engineer:** Or 85 percent of them.

**Reviewer:** But if you want to get to their subjective experience, then it's the metaphysical problem. ... You could frame it as a signal to noise problem. You can't guarantee the same experience for everybody. But if you can build enough signal into it so most people give you the same interpretation....

**Laboratory director:** There may be various sources of signal: how do you know what they're telling you?

**Surgeon:** What in the brain it is, you can't measure it.

**Reviewer:** You know right where they are and you know what they're interpreting.

This dialogue reflects a process of defining the surgeon-user's body in a way researchers can manage. They do this by defining the user's body in relation to the device. They begin with broad question: how can they ensure that simulator users all have the same physical experience? They recognize that, if they try to answer the question in terms of subjective experience, it becomes a philosophical issue, not a research question. What a user senses through his or her body—whether studied as forces on muscles or descriptions of experience—is not very accessible to scientific research. If haptic sensing is about forces exerted on users' bodies and the interpretation of those forces, studying the connection between force and interpretation becomes very difficult. The researchers reconsider the user's subjective experience as a question of consistency of interpretation or, in more scientific terms, reproducible results. They realize they cannot know what bodies experience directly, nor whether two people experience the same sensations when touching the same object. They cannot know whether many users' internal experiences of touching an object, such as a lump, are identical, but they know that many surgeons would give the same interpretation of that object. Thus, moving the definition of haptic experience away from metaphysical questions about internal experience—away from the

body's physical and subjective insides—and towards the body's interface with an object, might allow researchers to elicit identical interpretations of that experience.

Defined as a body that interprets a lump, researchers can study what the body knows. As scientists, however, they can go one step further. They can augment the signal from the object to encourage the identity of interpretations. By defining haptic cognition as a relation of signal to noise, they can ensure that the device sends a strong enough message to the user's body that most users give the same response. By observing where on the model the user is working, they begin to understand what signals are strong enough to provide a consistent interpretation. The pathway between the user's body and his or her understanding—the mind-body connection—becomes, in effect, black boxed. It cannot be characterized the way a device might be, or mathematicized, the way a model patient's body might be. Rather, the user's body in haptics research gets defined in terms of the signal the rest of the system sends to the user's body and the fidelity with which the user interprets that signal. The question is no longer what the body is, but how the body interprets action; the ontological body becomes the interpreting body. The challenge thus shifts from trying to interpret what happens inside the user's mind and body toward understanding how to create a model body that surgeons can be sensitive to in identical—or mostly identical—ways. Thus, augmenting the model's signal helps make the interpretations of experience more articulate. The model articulates what the user's body knows, which helps the user articulate what the model is.

### **Discussion: vision, touch, embodiment, knowing**

The simulator is an assemblage of hardware and software, shaped by knowledges from multiple disciplines. Simulator research falls into three areas—modelling and

deformation, interactive device-making, and studies of haptic cognition. Research into each of these areas requires definitions of the model patient's body, the user's body, and how they interact in simulated surgeries. Within each research area, the the physical connection between user and model must be delineated. Simulator makers must make mathematical models of surgical actions that usually remain tacit, such as the movements a surgeon makes when clamping, cutting, or suturing, and the response of tissues to those movements. I have laid out how each of the three research areas articulates the user's body in relation to the simulated model body and vice versa. What remains to be done in this section is to consider the implications of mutual articulation for studying the teaching of manual skill.

The deformable model's utility as a teaching tool is limited without values representing haptic feel. Thus, the representation of the gynaecologist's physical experience that gets incorporated into the model shapes how the model will react to the user and how the model will shape the user's experience. The model body's resistance to surgical instruments is defined in relation to the gynaecologist's embodied memories and the resulting algorithms describing the model's resistance will, in turn, shape the user's body. The haptic interface must compensate for the fleshiness of the user's body well enough that the mutual shaping of model and user will provide a meaningful learning experience for beginning surgeons. To do this, researchers will study many bodies, so they can incorporate a model of their variations into the device. And haptics research attempts to define what parts of physical interaction are meaningful for learning by studying what happens at the interface of body and model. Among other methods, this can be done by altering signals the model sends to the user to elicit particular

interpretations. The model's ability to articulate the user's body will be measured in terms of users' interpretations. At each stage of this research, the user's body is articulated in relation to the simulation system and vice versa.

Haptics—designing and incorporating an interface that feeds sensory information to the user's hands—makes the mutual articulation of the user's and the model's bodies more apparent because the connection between the hands and the model must be carefully constructed. Technologically and physiologically, the link between the object's effects on the user and the resulting action is much tighter with touch than vision. A haptics researcher best describes how touch differs from other senses:

Touch and force sensations convey information about the environment by that enabling action. Successful bodily acting requires 'touch and feel' information from the environment simply because, unlike any other sense, haptics (touch and kinesthetics) is not only a sensory channel to receive information, but also a channel for expressiveness through actions. The hands are both sensors and actuators, using sensory information to control their acts (Reiner n.d., 2)

The dual nature of hands—they are sensors and actuators—connects actor to object much more directly than vision, smell, or hearing. Hands simultaneously perceive an object and act directly on it. The effects of touch can be measured as effects on the object. Simulator researchers at Stanford realize this: they know that a poorly designed model of tissue feel or a poorly designed interface may fail to provide the kind of generalizable skill Dreyfus describes (op. cit.). Conversely, they can boost the signal sent to the hands to make interpretation easier. With a simulated model body, researchers can study directly what forces a student exerts when dissecting tissues. They also know they can observe exactly what part of the model reacts to the body's actions, making the study of the connection

between model and cognition more direct. Because hands themselves contain the means of both sensation and action, they embody mutual articulation in a way that forces researchers to place tight constraints on the connection between sensing and acting. The reviewer in the dialogue cited above makes the critical point about touch and cognition, 'You know right where they are and you know what they're interpreting.' The hand, as a perceptual instrument that is both sensor and actuator can make studying the interpretations that result from these perceptions and actions easier to study. Simulator researchers, if they can make haptically enabled simulators work properly, can frame the student's tactile learning. This framing of surgical experience is vital to the development of a surgeon's multi-sensory medical gaze, that is, to the incorporation of bodily knowledges that creates the surgeon's body. With hands, how sensation, action, and interpretation intertwine can be studied at the interface with an object, as the ability of the user to articulate the model body through anatomical sculpting and the ability of the model to articulate the user's body in terms of surgical skill.

The concept of mutual articulation for understanding surgical simulation addresses a problem that arises when discussing simulation. Latour's concept of articulation specifically attempts to avoid a world of subjects and objects in which the subject houses an internal representation of the object whose accuracy must be verified (Latour, *op. cit.*). The notion of abstract anatomical knowledge and the surgeon's ability to sculpt the body to resemble an anatomical model tends to reproduce this concept of a representation of human anatomy housed somewhere inside the surgeon (typically imagined as inside his or her mind). Considering the creation of anatomical knowledge as the development of physical skill that comes with years of practice allows one to consider

not the accuracy of an internal visual model, such as may or may not exist, but simply the surgeon's ability to produce such anatomy in the patient's body. Thus, anatomical knowledge can be thought of at the interface between a surgeon's hands and a patient's body, as it exists in practice. Whether taught by a simulator or by another surgeon, the surgeon's knowledge becomes his or her ability to sculpt the anatomical model from highly variable patient bodies. Simulation reveals that the patient's body plays a role in that shaping.

With a simulated 'patient-on-demand,' students may have many more opportunities to practice surgical procedures when they want, as often as they want, and on as many types of pathologies as can be programmed into the simulator. Haptics will change the nature of the interactions from viewing and perhaps acting upon the body with a mouse to *feeling* the cyberbody react and, perhaps eventually, act. The incarnation of bodies in cyberspace that can provide haptic feedback will make these interactions bodily in ways unlike earlier computer technologies, undoubtedly with implications for other fields in which haptic interactions are important. Haptics research, as a field that studies how hands learn, can reveal how bodies mutually shape each other. Additionally, information gathered from research into modelling, deformation, mechanical haptic interfaces and haptic cognition will contribute not only to simulator research, but also to the development of future medical and surgical technologies, such as radiological modelling, surgical planning, remote surgery, and surgical robotics.

At each point in the creation of the surgical simulation described here, researchers pooled various disciplinary knowledges of anatomy, surgery, computation, education, cognition and engineering to develop an object (a model, a software program, a device)



that has a particular relationship to the user's body. At each point, then, researchers are working to create interpretations of what human bodies are in relation to these objects, that is to articulate the body in new ways. As I argue, these technological knowledges of human bodies are multiple, but not unconstrained. The simulator must be relevant for the medical student. It must work as a teaching tool. The simulator must not only know patients' and users' bodies as they relate in surgery, it must also help incorporate knowledge of those relations—surgical skill—into the student's body.

## **Chapter 5**

### **Learning Surgery: The social in the technical**

#### **Introduction**

It is Tuesday, surgery day, and the hand surgeon has been operating since 7 a.m. It's now early afternoon. The current patient—the third or fourth today—is a young man who broke an arm years before. While healing, the bones in his forearm, the ulna and the radius, fused together near the elbow, eliminating his ability to rotate the radius over the ulna, the motion of palming a basketball or cupping a bowl of cereal. The x-ray showed the bones as shadows, one across the other: they are too close together. The young man convulses a few times going under anesthesia, which is somewhat uncommon. But once under, he does not twitch, as the anesthesiologist's machines monitor his heart rate and blood pressure and make certain he receives enough oxygen. The anesthesiologist places a tourniquet around the man's upper arm and a machine constricts it to stop blood flow into the arm. Once the tourniquet is on, the surgeons will have just over an hour to work on the exsanguinated arm before they must restore blood flow. Surgeon, resident, and nurses assemble a traction device and hang the man's left arm from it. Once the arm is hanging, the next step is to poke a hole in the arm to put the instruments in. This is usually easy, but the surgeon struggles with it. She keeps meeting resistance inside the arm and saying, "This is not good." Finally, she gets a port into the arm and inserts a tiny camera through it. She puts another hole into the other side of the elbow, trying to insert a probe into the elbow to give her a pointer to navigate by. With the camera inserted into one side of the elbow and the pointer in the other, she looks across the patient to a computer monitor depicting the camera's view to try to peer into the elbow. She moves

the instruments around, trying to get a comprehensible view of the radius and the elbow joint, a view obstructed by the extensive scarring. While moving the instruments, she keeps her gaze on the monitor, and keeps up a running commentary with a hand surgery fellow, a new addition to the service. I stand behind the instrument table, well away from the surgical field. I marvel at the surgeon's ability to manipulate instruments on both sides of the elbow while watching the action on the monitor, a set of actions requiring kinesthetic skills similar perhaps to those of driving a car with a stick shift, except that the large movements of driving are primarily forward and backward. In this case, the surgeon's hands make micro adjustments in two different directions while her eyes focus on the monitor.

The arthroscopic exam reveals fused bones and massive scarring. The head of the radius has extensive arthritis and is badly misshapen, so the surgeon decides to remove it. With the arthroscopy done, the team drapes the arm again and the surgeon watches while the fellow makes an incision in the elbow, following the path of the existing scar. After exposing the damaged bones, the fellow uses a saw to cut out the radial head, then he pries the fused bones apart, periodically reaching into the space between the bones to ensure that he has cut far enough and that he has made the bony area as smooth as he can. Surgeon and fellow regularly rotate the forearm, a motion that produces an audible and unpleasant crunch of bone against bone. To alleviate this, the surgeon decides to use a piece of the triceps to bolster the annular ligament, creating a sling for the radius so it will slide more easily against the ulna. This is a modified version of a pre-existing procedure, which the surgeon had imagined prior to surgery might hold the damaged bones apart. The fellow removes a small slip of muscle—just slightly thicker than a piece of

yarn—and wraps it around the radius. Placing the muscular sling requires some fiddling, but once in place, the sling holds, and the bones stop grinding when rotated. This seems to make surgeon and fellow relax a bit. With the muscle sling in place, fellow and surgeon close the wound and heavily bandage the arm.

I wrote these observations in my fieldnotes immediately after watching the surgery:

I was struck watching much of this that there had to be a sense, by feel, of what the bones ought to feel like, even through two pairs of gloves. Three things became really evident from watching this time: first was all the complicated kinesthetics of arthroscopy, where the attention is, and the action, and how much watching it seems to be like watching someone pat their tummy and rub their head. Second, was all the touch stuff involved in working on this elbow. There was also the kinesthetic sense related to trying to get the arthroscopic tools in: it was wrong and [the surgeon] knew it and knew it wasn't a good sign. Third was, again, the vast difference between even the chief resident and the fellow. This fellow was very self-assured. He knew what he was doing and it was a much more collegial, less hierarchical kind of interaction. It's the interaction I remember with the previous fellow, and with [a colleague] in the dissecting room: [the surgeon] still is the boss, but the roles are closer.

This description captures several of the concerns of this chapter, including the complex kinesthetics of surgery, the social relations of surgery, and the judgments and extrapolations surgeons make both from experience and from written procedural reports. Performing surgery requires complex, physically embodied skills, deep knowledge of anatomy, surgical procedures, clinical judgment, and the ability to extrapolate from one procedure to another. In academic hospitals, surgery also requires social skills to judge the competence and preparedness of team members to perform difficult procedures.

In this chapter, I examine surgery and surgical teaching in detail to interrogate what parts of situated surgical teaching can be simulated and what parts cannot. I look at the interplay of tacit knowledge, bodily knowledge, and social knowledge contained in surgical interaction and how such knowledge might change with the advent of surgical simulators, such as the one described in the previous chapter, in medical education. I will show that teaching surgery involves bringing a student into a unique subculture of medicine, first by defamiliarizing the student with his or her body, then by installing new schemes of perception and thought—embodied practices—by encouraging the development of surgical attitudes of decisiveness and confidence. Both technical and social knowledge are reproduced through this form of teaching skill. Simulators attempt to capture and transmit some of a surgeon’s physical skill in a form that can be taught outside the operating room. I will describe how the milieu of surgery, from operating room spaces to surgical costume, all work to instill surgical culture into the operating room’s inhabitants (except patients). Then I will provide two cases of surgical teaching in which the teaching of technical skill also carries social lessons. Finally, I will conclude with some thoughts about how surgical simulation might alter this highly structured form of teaching. Simulators eventually will teach some of the bodily skills of surgery, but part of what is transmitted in the physical act of surgery, I argue, is social knowledge that cannot be simulated. What I reveal using surgical teaching examples is that, simple, physical actions convey complex social information, information that a simulator is unlikely to replicate.

Medical students typically do not enter an operating room until some time between the end of their first year and their third year of medical school.<sup>61</sup> By this time, they typically have spent from a few weeks to a semester studying gross anatomy, which introduces them to working with human bodies. Students also have learned about medicine's hierarchical culture through explicit and implicit lessons in courses and, more importantly, clinical rotations. They have begun to adopt a physician's stance toward the body, viewing it as biological and, for the most part, mechanical (Good 1994). They also have begun to adopt some manners of more senior students, residents, and physicians. Through embodied practice, they have entered the culture of medicine.

Students who opt to pursue surgery learn the physical, technical skills of surgery by watching master surgeons and through years of increasingly more technical and complex practice. Surgical teaching involves not only the transmission of skill, but also intense socialization into surgery's hierarchical subculture and learning environment. Surgeons working at SUMMIT regularly stressed that surgical teaching follows an apprenticeship system and all regularly spoke of their mentors and the lessons they learned from them (often with great admiration, occasionally with grudging respect) (see also Bosk 1979; Good 1994). Surgery involves a set of embodied skills passed from one surgeon to another through visual demonstration and carefully monitored and guided

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<sup>61</sup> Medical schools throughout the United States, Canada and Australia have begun to explore so-called "problem-based" approaches to teaching medicine, particularly following Harvard Medical School's "New Pathway" curriculum changes in the mid-1080s (B. Good 1994; M. Good 1995). Problem-based approaches take many forms, but typically involve bringing more clinical education into the earlier years of medical teaching. While I was doing fieldwork, in 2001 and 2002, the Stanford University School of Medicine was following a more traditional approach to medical education, an approach that required two years of pre-clinical education, followed by clinical rotations, and then internships.

practice. Residents must integrate physical skill, knowledge of procedures and anatomical knowledge. Although simulators, such as the one described in the previous chapter, primarily teach physical skill, they could reinforce procedural and anatomical knowledge in various ways, such as providing labels or incorporating quizzes. Or a simulator could simply give the student an experiential “feel” for various procedures. Most simulators I have seen provide experiential feel and, sometimes, “add value” by offering views of the procedure, such as an overall “map” view or a side view, that would be unavailable during surgery.

A simulator might form an important component of a teaching system designed to integrate anatomical, procedural, clinical, and technical knowledge. But using one does not require this knowledge: I was able to perform a virtual ovariectomy on a simulator with little more than rudimentary knowledge of female pelvic anatomy. But my experience observing teaching surgeries indicated that many aspects of the teaching interaction and operating room context reinforce the surgical knowledge and vice versa. Rather than the continual reinforcement of surgical knowledge that occurs in the operating room, a simulator extracts one component—physical skill—from the surgical context and allows students to practice their skills whenever and as often as they want.

### **Producing and reproducing surgical behavior**

Building an analogy between conduct and speech, Bourdieu (1977) argues that the meanings contained in both conduct and speech depend as much on context and situation of use as on content and says the content of communications depends entirely on the

social relations of the agents involved (see also Lynch 1994).<sup>62</sup> Bourdieu urges anthropologists to focus on the structures of an environment that build particular organizing principles, habits, ways of being, which he calls “dispositions” into the minds and bodies of cultural actors (op. cit. 72). He describes the social world as the site that creates dispositions, which he calls “meaning-made-body” (op. cit. 75). Bourdieu says education, when not institutionalized as autonomous practice (as surgical education is not autonomous practice), leads to teaching based on the imitation of actions (op. cit. 87). Learning occurs through apprenticeship, but social lessons to be learned also are structured and reflected throughout the culture, in games, in observations, and in rituals (op. cit. 88). This includes the layout of spaces, and the functioning of “made” products, from objects to art and myths. Bourdieu describes how institutions that remake social actors focus great attention on clothing, posture, and attitude because these elements serve as continual reminders, at the subconscious, bodily level, of the institutions’ principles. According to Bourdieu, culture is reflected in the spaces and objects of that culture and that much of this knowledge becomes incorporated in bodily habits. This analysis fits medical education, particularly surgical education, in which the student’s means of understanding and interacting with human bodies is broken down and

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<sup>62</sup> Joan Cassell (1998) also uses Bourdieu’s concepts about embodiment to discuss surgeons, though she discusses the embodied ways male surgeons react to female surgeons. The difference between considering the embodied teachings of medical and surgical culture and the embodied differences related to gender point to the need for theories that account for subjects who are embodied in multiple worlds. Donna Haraway’s theory of “partial perspectives” (1991, 190) and Sherry Turkle’s idea of “cycling through” identities (1995, 12) both provide a useful corrective the notion of a unitary self created within a single cultural habitus. Surgeons can be male or female, North American or otherwise. If trained in a North American medical school, they are likely to have adopted embodied characteristics of North American surgeons, but also to have embodied characteristics true of other parts of their lives.



reconstituted as understanding and interactions with patients' bodies. The human body becomes a new kind of entity within medical culture: the patient. Medical schools and clinical faculty accomplish this restructuring of the human body in part by breaking down and reconstituting the medical student's body as the student learns to open dead bodies with a scalpel, view cells through a microscope, and consider the developmental stages of human heart and lungs: that is, through practice (see Mol 2002 for a discussion of the connection between practice and knowledge). The social lessons of medicine begin to be instilled in students probably from their pre-medical years, but certainly from their first weeks of medical school. Students who enter the operating room already have adopted some of the schemes of perception and thought befitting a physician. If they choose to pursue surgery, they will adopt the particular stances of the surgical subculture. Many aspects of surgical practice act to produce and reproduce this subculture.

Anthropological and sociological discussions of medical and surgical culture acknowledge how profoundly medical education shapes the practitioner. Byron Good (1994) has said that the world of medicine is as unfamiliar a cultural terrain as he has ever encountered. He says medical education requires the formation of a worldview that removes the student from his or her ordinary ways of viewing and interacting with bodies, building a strong sense of the body and its ailments as biologically based, a construction of the body that constrains social factors as considerations in diagnosis. Mary Jo Good (1995) says developing a sense of competence is largely a result of mastering social roles, rather than technical skills. She describes students' experiences of early clinical practice as leading to "an astonishingly steep learning curve" (op. cit. 130). She describes the physician's sense of competence as emerging from narratives

“performed” in interactions with attending physicians, residents, nurses, and others. She says feelings of competence are less dependent on a fund of knowledge than on interactions with a team (op. cit. 146). Pearl Katz (1999) describes much operating-room procedure as scientifically based ritual that demarcates surgical spaces, boundaries, and roles (for a dissenting opinion, see Collins 1994). She describes how surgical residents are urged to be decisive and are denigrated as “internists” if they prefer to withhold a rapid diagnosis (Katz 1999, 37). She describes the stereotypical image of surgeons as solitary, confident, masculine performers who value action over contemplation and intervention over caution. Similarly, Joan Cassell describes the surgeons she studies as “arrogant, macho, daring” (1998, 6). These analyses all provide important observations about the culture of physicians and surgeons and how it is instilled in new medical students. However, they speak to largely discursive aspects of how a physician or surgeon becomes enculturated. None describes how surgeons become acculturated through physical practice.

Several treatments of the learning of physical skill—in surgery and other fields—are relevant here. Stefan Hirschauer (1991) describes surgical learning as acquiring surgical skill and acquiring knowledge of the anatomical body. He says residents combine anatomical knowledge of the abstract body with knowing how to create the abstract body in the flesh (op. cit. 310). Physical skill and social knowledge learned through practice rather than explicit teaching has been described as “tacit knowledge,” a term coined by Michael Polanyi (1966), who explains that to understand a skill as another practices it is to know how to practice that skill yourself. Donald MacKenzie uses motor skills, specifically learning to ride a bicycle, as his paradigmatic

example of “knowledge that has not been (and perhaps cannot be) formulated completely explicitly and therefore cannot effectively be stored or transferred entirely by impersonal means” (MacKenzie 1996, 215). In the context of veterinary surgery, Pinch and others (1996) describe some aspects of physical skill, such as the difficulty of performing a particular physical action, that can be communicated in words. Harry Collins (1985) distinguishes between “algorithmical knowledge,” which can be taught through procedural scripts and other explicit means and “enculturational knowledge” that must be taught through residence within a group. Collins and others (1997) later update this using the concept of “mimeomorphic” action, which are actions that can be repeated identically and captured within a set of space-time coordinates (by motion capture, for example). Mimeomorphic actions can be taught taught by a simulator. This is in contrast to “polimorphic” action, which generalizes across contexts, is social, and has meanings that depend on context. Polimorphic action requires complex socialization and cannot be simulated. Collins’ treatment implies a distinction between tacit social knowledge and physical skill. In medicine, tacit social knowledge is typically called medicine’s “hidden curriculum.” Physicians and others have long understood that much of medical learning involves the teaching of social relations in medicine, including stances toward patients, other physicians, and staff, partly through explicit teaching, but also largely through modeling desired behaviors. Using Collins’ terms, this kind of knowledge clearly is polimorphic, requiring complex social interactions. I focus on actions that are imagined to be purely physical and the social lessons these actions contain.

Bourdieu’s approach suggests the potential benefits of bringing together the broad cultural shaping of surgeons with narrower notions of embodied skill. This cultural

training of medical students prepares them to receive social meanings when they perform actions that can indeed be repeated identically, captured in space-time coordinates, and physically taught by a simulator. I argue that, within traditional surgical teaching, social knowledge gets transmitted with technical knowledge. A student inculcated in medical thought and perception is prepared to receive the social lessons of technical training in surgery. An attending surgeon teaching a medical student makes tacit use of a student's cultural preparation to receive the social lessons of surgery. The attending surgeon uses the student's body to teach not only the technical skills of surgery, but also the social lessons of being a medical student and, later, a surgeon.

### **Observing surgeries**

I watched a hand surgeon perform roughly twenty procedures over five days of observation. The procedures ranged in complexity from relatively simple suturing of a cut tendon, which takes little more than twenty minutes, to long, complex surgeries, such as the removal of a mass intertwined with nerves in the palm. On several occasions, I observed the surgeon's brief discussions with a patient before or after surgery and learned to recognize a patient's look of pre-operative apprehension. Patients are not the primary focus of this chapter (though they are everywhere present in real or simulated form). During these procedures, the surgeon worked with medical students, junior and senior residents, and a senior fellow. I also watched her work in Stanford's anatomy laboratory, dissecting several arms with the help of another hand surgeon and a retired hand surgeon.<sup>63</sup> Thus, I had an opportunity to watch this surgeon work with students, residents,

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<sup>63</sup> Fellows are surgeons who have completed their residencies and spend a final year working in their chosen specialty before entering practice on their own. Thus, they are fully qualified surgeons.

fellows, peers, and one highly respected senior colleague. Teaching interactions also ranged in complexity, from showing a medical student on a two-week rotation how to cut the loose ends of newly tied stitches to allowing a fellow to perform most of a procedure, an interaction between colleagues, rather than teacher and subordinate.<sup>64</sup>

As a non-medical visitor, I was not allowed to “scrub” on a case, meaning I was prohibited from entering the surgical field or participating. The surgeon often introduced me to residents and occasionally to nurses, either as an anthropologist or as someone researching surgical simulation. People I met only once or twice spent some time trying to place me. The name sticker usually showed my affiliation merely as “SUMMIT” in block letters and some asked me if I came from Summit Hospital in Oakland. Others asked if I was a nurse. Once operating room staff established that I did not fit any traditional medical roles, I was usually treated as a relatively ignorant medical student, albeit one observing with permission and approval from the attending surgeon, which granted me a certain status as nurses and anesthesiologists helped me find good places in the room to view the surgery. I was also, however, regularly reminded to keep away from the sterile instrument table, sometimes when I was not close. At times, I was treated with some condescension by nurses, a hazing experience that’s common for medical students and often worse for women (Cassell 1998).

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<sup>64</sup> One of the first coffee discussions I organized at Stanford focused on an article in *The New Yorker* that described surgical and medical teaching as students and residents getting brief introductions and then being allowed to sink or swim on their own (Gawande 2002). The article generated a great deal of anger among the four surgeons—retired and practicing—in the group at SUMMIT, who argued that teaching, at least in their experience at Stanford, involved the very careful supervision of students and residents. In my observations of surgical teaching, I never saw even the most senior residents or fellows working on a patient without supervision.

My observations consisted of watching, as closely as possible while remaining outside the sterile field and out of the way of the sterile table, various machines, and nurses. The amount of equipment in the room dictated how close I could get to the operating field (while remaining eighteen inches or more from the sterile field). Most of the time, I was able to watch over the seated surgeon's shoulder, a perspective that allowed me to hear much of the murmured talk between surgeon and resident as they bowed their heads together over the incision. Several times, I tied surgical gowns, which surgeons do not tie themselves once they are scrubbed, and was asked to help grab supplies for the surgeon when a nurse was unavailable. I also regularly took photographs for the surgeon's use of the surgical field or of pathological specimens. I marveled at how easily the surgeon enlisted me into the role of a very junior medical student.

I could ask the surgeon questions at certain times during a procedure, but I usually limited these to technical or anatomical questions, saving larger questions for later. This relative lack of talk in the operating room was useful for focusing my attention on observing physical interactions. I also conducted interviews and discussions with this surgeon, a medical student who worked with her, and others outside the operating room. These included one-on-one interviews with surgeons, interviews with two surgeons simultaneously, and larger discussions, usually fueled by coffee and cookies, with up to five practicing and retired surgeons and members of the group at SUMMIT, as well as guests. These discussions usually took place around an article or a question related to medicine, medical education, or specifically, surgical education. They provided a unique opportunity to hear surgeons discuss their field with one another and with interested lay people.

## **Disciplined spaces**

Medical anthropologists and sociologists have termed medicine a “totalizing’ institutional setting” (Good 1994, 82), focusing on the how scrutiny by higher-ups creates a climate of surveillance and scrutiny that compels medical students to adopt approved practices and concerns. I want to further this argument by point out that spaces, times, costumes, and bodily discipline all reinforce the social hierarchy of the operating room, a hierarchy that places surgeons at the center and all others at the periphery, a system that gradually moves the surgical resident into full participation at center of the action (see also Lave and Wenger 1991).

Space, time, costume, and conduct in the surgical suites at Stanford all function to focus attention on the surgical procedure.<sup>65</sup> The ambulatory surgery center at Stanford Medical Center is on the hospital’s second floor. From the “staff only” signs on the double-door entryway to the blue cloth drapes that cover the patient and leave only the operating field visible, the surgical center at Stanford Medical Center focuses the attention of physicians, nurses, students, and guests ever more narrowly on the operating field. Inside the double doors is a corridor connected to the operating rooms, men’s and women’s dressing rooms, and to a small lunch room. Everyone entering the area from the outside must retire to a dressing room to replace street clothes with surgical scrub shirts and pants, which are neatly laundered, folded, and stacked on shelves by size. Once dressed in scrubs, everyone must don shoe coverings and head coverings before passing through another set of double doors that leads to the operating suites themselves. The

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<sup>65</sup> Hirschauer says drapes provide a “situational focus” on the operative site (1991, 297-98) I agree, but want to extend the focusing effect to the operating room and its surroundings.

operating area is a grid of wide, low corridors surrounding the operating rooms proper, which are set up in clusters of four surgical suites. The area buzzes with activity as surgeons, residents, nurses, orderlies and others circulate. The corridors have non-skid tape on the floor. Gurneys, machines, racks of supplies, and plastic trashbags filled with medical waste line both sides. The corridors appear somewhat chaotic and jammed, but orderlies keep the clutter neatly to the side to allow gurneys to pass through. The corridors also have sinks well-stocked with surgical masks and supplies for sterile scrubbing. Surrounding this grid of operating suites are a pre-operative area containing small bays where anesthesiologists and nurses start IV's and administer medications, a waiting area for patient families, and a post-operative area where nurses monitor groggy patients. The spaces of the operating area allow the efficient movement of patients and surgeons from pre-op to operating room to post-op. The many small operating rooms are the heart of the surgical center where space and time further condense, intensifying the enforcement of surgical rules.

Once a visitor in sterile garb passes through the doors leading to operating area, he or she makes a first transition into a sterile space. This space is more carefully controlled than the outer hallway, lockers, and lunchroom. Visitors must check in at a control desk staffed by nurses. Clothing requirements are strictly enforced as I learned on my second day observing surgeries. I was unaccompanied and remembered to change into scrubs and shoe coverings, but forgot to put on a head covering. The moment I stepped through the second set doors, a surgeon barked at me to put a head cover on, a harsh lesson, but one I never forgot. The scrubs and coverings are the first stage in creating a sterile space for operating, but they also serve to homogenize visitors:



everyone wears the uniform of surgery. The uniform is transforming: I remember looking in the mirror the first time I donned surgical scrubs and smiling at my reflected image, thinking about how quickly the clothing had somehow made me “medical.” With scrubs, individuals are socially transformed into their professional roles as doctors, nurses, technicians, orderlies, and others. Donning scrubs effects a shift in operating room personnel’s “ontological status” (Young 1997, 94). Some who regularly work in the operating rooms re-establish their individuality—and, by extension, that they belong to *this* operating room—by wearing a pair of their own shoes (I recognized one nurse after several months absence from the operating room because of her shiny, silver Doc Marten boots) or head coverings in distinctive prints, such as bright jungle head caps or flowered “Easter” bonnets.

Everyone in the operating rooms—except patients—wears scrubs, head covers, and shoe coverings (or dedicated shoes). Surgical masks are required inside the operating room proper, but not in the hallways. As with the example of my failure to don a head covering, operating room personnel strictly enforce this protocol. I watched a nurse scowl at a physician who started to enter an operating room without a mask while a procedure was in progress. The moment he saw her face, he backed out of the room and put on a mask: no words were needed. Masks are required in the operating room only after nurses wheel the sterile instrument table into the room and “open” it by uncovering the instrument trays. At this point, masks are enforced anywhere near the operating table, but requirements are looser at the room’s edges. I once watched a nurse growl at an unmasked senior resident, “Hey, we’re open in here,” meaning the sterile instruments table had been uncovered. The resident clownishly rolled his eyes, pulled his scrub shirt

up over his mouth, and began to dance apishly toward the nurse. This clowning marked the resident's relatively senior place in the surgical hierarchy and his ability during this relatively relaxed moment—at least jokingly—to defy the nurse (Goffman 1961, 114). Such joking stopped whenever a patient was wheeled into the room.

The operating room itself has various zones of sterility. The outer edges of the operating room hold a computer with Internet access for quick reviews of the surgical literature or, more often, quick email checks. The area also holds some personal items belonging to operating room staff and a low shelf with the patient's record and other paperwork. This area is not sterile, but masks are enforced when an operation is under way. Sterility is more strictly enforced closer to the patient and the table covered with sterile instruments. Surgeons and scrub nurses wear sterile gowns and gloves. Circulating nurses, visitors, and others not wearing sterile gowns must stay clear of table and patient. They must also stay clear of surgeons' and nurses' sterile front sides, especially their hands. The operating field is the area surrounding the incision for about eighteen inches on all sides. Here, no one who has not scrubbed may stray. Clothing in the operating room first separates inhabitants from the rest of the world, then separates those allowed into the operating room, and finally separates those allowed in the sterile field from everyone else. These separations are another way operating room protocol directs focus to the sterile operating area.

When the operating room is ready, surgeon and resident wander into the room and, often, begin discussing the case. Patients, who usually enter the pre-operative area under their own power, only enter the main surgical corridors on gurneys that, with an accompanying intravenous line, marks the beginning of the patient's transformation into

a “technically amplified” human being (Hirschauer 1991, 291). Attendants wheel the patient into the operating room and help the patient off the gurney onto the operating table. Nurses and residents use blankets and bolsters and straps to ensure that the patient is comfortable and secure on the table. The patient is awake at this point and, often, the surgeon will speak a few words of reassurance before the patient goes under anesthesia. While the anesthesia takes effect, the nurses place blue paper drapes over the patient’s body, leaving the operative area exposed. They also will set up a draped barrier between the patient’s face and the operative area, typically by clipping the drape to an IV pole and stretching it across the patient’s body. This serves two functions: the primary function is to maintain sterility of the operating area. The drape also serves, when the procedure takes place under local anesthesia, to prevent the patient from seeing what’s happening (for an extended debate on draping, see Collins 1994; Collins 1994; Fox 1994; Hirschauer 1994; Lynch 1994).<sup>66</sup> The drape parcels the patient’s body into operative site and anesthesia sites, which some observers have likened to separating the patient’s objective body from his or her subjective body (Patterson and Madaras 1983; Hirschauer 1991; Young 1997; Katz 1999). About this time, the operating room settles into at least three overlapping islands of activity: an anesthesiologist at the patient’s head monitors the patient’s life signs. In the surgeries I watched, an anesthesia resident often watched and asked questions or administered anesthesia and intubated the patient under a senior anesthesiologist’s guidance. The surgeon, resident or fellow, the occasional medical

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<sup>66</sup> Surgeon Richard Selzer describes trying to cover the operating area when he realized that a patient under local anesthesia could see the insides of his own abdomen, his liver, bowel, and running blood in the reflection of the operating room lamp: “...he has already *seen*; that which no man should; he has trespassed” (Selzer 1974, 25).

student, and the scrub nurse form the second island. The scrub nurse overlaps between the surgeon's island and the circulating nurse, who creates an opening to the outside world.

Time also functions as a means of focusing attention on the operating area. During the time prior to a surgery or between surgeries, orderlies scrub the operating room. Nurses and attendants bring in the instrument table and any needed machinery. This break between surgeries is relatively relaxed. During this setup phase, the surgeon often is absent or on the telephone or checking email. The surgeon, though undoubtedly managing the details of a busy life, also seems to studiously ignore this setup, which may give everyone a break from the rigorous control she will exercise later. Sometimes, during this period, scrub nurses, residents, and surgeon can be found in the break room chatting, snacking or scanning that day's newspaper. This is also a time when the anesthesiologist, who usually is busy preparing the patient, can consult with the surgeon about the patient's overall health or the choice of anesthesia. During my observations, surgical schedules often fell behind, which caused the surgeon to press everyone, especially anesthesiologists, to hurry a patient into the operating room. Though the surgeon sometimes succeeded in moving the proceedings along just a bit, I had the sense that the larger surgical machine tended to move at its own pace much of the time. While the procedure was under way, the mood varied from intense concentration to something more lighthearted, but it generally lifted considerably when the team prepared to close the wound and bandage the arm (see Goffman 1961, 124). When time was tight, I occasionally watched surgeon and resident each stitch portions of the wound in an astonishingly complex, high-speed choreography.

Further focusing of action on the surgical field occurs at two points before a hand surgery begins. The first, if the patient will receive a general anesthetic, focusing occurs when the patient goes under anesthesia. The anesthesiologist writes down the time when the anesthetic drip begins and the patient goes under, which is less a “slipping” into unconsciousness than a sudden drop, at least in my experience. This marks the beginning of surgical time, time that must be used wisely because patients recover more quickly when they spend less time under anesthesia. In hand surgeries, a second time-focusing step occurs when the tourniquet constricts blood flow to the arm. By this point, surgeon and resident have scrubbed and they tightly wrap the patient’s hand and arm in clingy bandages to push blood out of the arm before the tourniquet blocks blood flow altogether, a moment marked by an announcement from the anesthesiologist, “tourniquet is up.” From this point on, the surgeon has just over an hour to complete the procedure, so time becomes precious.

Some simulator makers, particularly those interested in training anesthesiologists, have attempted to replicate entire operating rooms, including staff, replacing the patient with a wired mannequin. But much simulator training involves “part-task trainers” that teach a particular skill—or piece of that skill—outside the operating room. What role, though, does this highly structured environment play in priming a medical student for the social lessons of surgery? Cassell says surgery differs from other medical specialties in its relation to time: surgery is an event, a performance, rather than a process of healing (Cassell 1991, 35). I argue that the focusing effects of surgical times, spaces, and costumes all reinforce surgery’s similarities to a performance, heightening the dramatic effects of opening a patient’s body. The simulator removes students from the operating

suite, which is a “space of enclosure,” a Foucaultian disciplinary environment whose effects on space, time, and production are “greater than the sum of its component forces” (Deleuze 1992, 1). The effects of simulator training will require study as they become more prominent in medical education. But they reflect a wider trend towards minimally invasive, remote, and robotic surgeries that move the surgeon’s hands out of the patient’s body and, with remote and robotic surgeries, out of the operating room altogether, suggesting that the relations of time and space within surgical spaces of enclosure already are changing.

### **Disciplining bodies**

The operating room is thus a much more open space than the sterile area around the patient. Anesthesiologists and visitors enter and leave the room. Circulating nurses enter and leave the room, spelling each other or wandering in to consult with each other or to grab some piece of equipment. The area around the operating field usually is tightly packed with surgeon, resident, possibly a medical student, a scrub nurse, the instrument table, and sometimes other machinery, such as a fluoroscope or fetal heart-rate monitor, that can be wheeled in as needed. Nurses and surgeons strictly enforce sterility within this area. Anyone who will be in the operating field must sterilize themselves by scrubbing their hands and forearms and donning a sterile gown and gloves. Scrubbing is an important operating room ritual and surgeons will describe their participation in a case by saying they “scrubbed in” (Cassell 1991, 46; Katz 1999, 185). Scrubbing marks who gets to act in surgery and who must watch. As a visitor, I was repeatedly reminded by nurses to avoid brushing against the sterile instrument table and, once, when I approached to

take a photograph of the operative field, the resident jerked his arm away in horror when I came close to brushing against it. Surgeons and residents do not leave the patient's side.

Once the patient enters the room, the circulating nurse and sometimes the resident and an orderly position the patient and a nurse cleans the operating area on the patient's body. With all these components in place, the surgeon and resident, fellow, or medical student leave the room to scrub. Scrubbing requires a series of steps: Surgeons start by cleaning under their fingernails with a specially packaged pick. They then use a brush and soap to thoroughly scrub from fingers to elbows. Once scrubbed and rinsed, surgeons and others hold their hands above their elbows so water rolls towards their elbows and away from their hands. They turn the sink off with their knee, using a handle provided for this purpose. From this point on, hands cannot touch anything except a sterile towel and the insides of a pair of gloves. The hand surgeon steeples her fingertips together in front of her as she returns to the operating room, a gesture that undoubtedly keeps her hands and fingers firmly under control, but that also emphasizes the ritual, almost prayerful, aspect of this critical pre-surgical moment.<sup>67</sup> The enforcement of sterility rules appears to be second nature to experienced surgeons and nurses, but it takes time and practice to learn. This largely technical lesson also has a social component. I watched a young medical student—who spent the summer assisting in surgeries one day a week—wrestle with it on several occasions, even after several months of practice. He was repeatedly reminded by surgeons, residents, and nurses to watch how he positioned his hands and what he touched. He had a tendency to back away from the sterile field, which the

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<sup>67</sup> (For an interesting debate about symbolic meanings of surgical procedure, including scrubbing, see Cassell 1991; Hirschauer 1991; Collins 1994; Hirschauer 1994).

surgeon explained to him posed a greater danger of contamination than staying close. He also clearly struggled to remember to keep his hands above waist level and sometimes seemed uncertain about what to do with them. I never saw either a resident, surgeon, or nurse struggle to maintain sterility. This disciplining of body and hands is among the difficult early lessons of surgery. Some parts of embodied, technical skill can be explained (1996). And the verbal reminders help students maintain sterility until it becomes second nature; that is, until it becomes embodied. Scrubbing and maintaining sterility are technical skills. They are also among the first and most ritualistic lessons of surgical training. They locate new students at the bottom of the surgical hierarchy and defamiliarize them with their bodies by placing them in unfamiliar surroundings with unfamiliar rules.

While nurses washed and draped the patient, the surgeon nearly always discussed the procedure with the resident, often drawing the anatomy or the angle of cutting on a drape or directly on the patient's body with a sterile pen. The drawing and discussing moments I observed functioned as focusing moments: surgeon's and resident's concentration locked onto the operating field and, from this point on, rarely left it. Once the procedure began, the surgeon never left the operating room and rarely left the surgical field. Occasionally, she stepped away to look more closely at an x-ray or MRI hanging on the wall. When she crosses the operating room, she folded her arms tightly across her mid-section and walked across the room gingerly, avoiding contact with all people and objects that might contaminate her. Circulating nurses left and returned to the operating room and scrub nurses were replaced. But I never saw surgeon or resident leave the patient's side during a procedure, a kind of symbolic acknowledgement that, at least



during the time of the surgery, surgeon and patient both are locked into the surgical system and both might suffer, though unequally.

The surgeon also acts as an advocate for the patient's body. The one time I saw the hand surgeon lose her temper was when a nurse failed, for the second week in a row, to erect a traction device for the patient's arm before the tourniquet went up, starting the clock. This delay gave the surgeon less time to operate and might have pushed her to hurry more than necessary. The surgeon also describes her work to patients as "borrowing their arm," as though it is a part they can detach from themselves. Once, when a patient under local anesthesia became uncomfortable towards the end of a procedure and began to pull his arm away, the surgeon, who remained very calm during this potentially dangerous moment, gently spoke to the patient, saying pulling away is not a good idea, that she was almost done, and "I've got your arm for a little while longer. You'll get it back soon."

The word "surgery" evolved from the Greek "cheir," meaning "hand," and "ergon," meaning "work." (Webster, s.v. "surgery") and surgeons have long been denigrated as medicine's manual laborers, the physicians who get their hands dirty as barbers or butchers (see Lawrence 1998). Surgeons commonly describe good surgeons as having "good hands." But this trope perhaps understates the extent to which the surgeon's entire body becomes part of the operating equation. As I have discussed, surgeons' scrubbing and dressing rituals prepare their bodies for surgery, even as a patient's body is being prepared (Hirschauer 1991; Katz 1999). Surgical work also uses the surgeon's entire body. Patients must prepare themselves physically for surgery, typically by avoiding food

and drink the night before. Surgeons, too, discipline their bodies from the inside. The hand surgeon avoids caffeinated coffee on surgery days, though she is quite fond of it, because it increases the tremor in her hand. Tremor is a natural physiological occurrence that surgeons are exceptionally aware of and that one surgeon explained to me is a major driver behind the development of robotic surgery (see also Ditlea 2000). Surgeons also find many ways, such as bracing themselves on the patient, to keep their arms and hands steady.

The hand surgeon describes her work less as an invasion into the patient's body than as becoming part of the patient's body. She uses the metaphor of Heisenberg's uncertainty principle, on the basis of which physicists argue that objects can never be definitively separated from observers—observers become part of the system under study.<sup>68</sup> With surgery, simply the act of opening a body alters the body. “You're part of the equation,” the surgeon says. During a group discussion at Stanford, the hand surgeon describes how she drills a screw into a bone, how she handles the drill, and makes certain the screw goes far enough, but not too far. She calls this careful modulation of movements in surgery “controlled violence,” saying that, when performing many procedures, her kinesthetic sense helps her feel when an instrument has reached just far enough. She can also see the instrument's point of arrival when a resident wields the instrument. The surgeon, who sits next to me during the group discussion, demonstrates as though operating on my leg. She braces her entire left forearm against my thigh and shows how she would guide the drill using both hands:

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<sup>68</sup> My thanks to Professor David I. Kaiser for helping clarify this point.

I make the residents become part of the patient. I use the expression, “Be part of the experiment.” So if I’m drilling on Rachel, ... and I’ve got the drill in my right hand, I brace my right hand on the hand which is in contact with her, so I get a sense of space.

The surgeon’s forearm becomes part of the hypothetical space—my leg—that she is working on. As she says, the surgeon becomes part of the patient. But the hand doing the guiding is not simply a mechanical stop, the kind of device found attached to a carpenter’s table. Rather, it also gives her a mental sense of space and steadies her hand and body. It guides her hand and, proprioceptively, gives her a sense of the boundaries of the patient’s body, which is in contact with her forearm. She describes feeling the procedure through kinesthetic feedback on the hand holding the drill—the sensations of the screw passing through a bone’s hard outer cortex, through its softer interior, and through the cortex on the other side, a sensation that the surgeon confirms resembles drilling through a hollow door. As the surgeon describes the procedure, she knows the patient’s body—and gauges the procedure’s progress—through her own body.<sup>69</sup>

As this surgeon’s description of drilling indicates, surgeons must connect physical sensation with an internalized image of anatomy, a connection that a student or resident might make more rapidly by practicing on a simulator. As the hand surgeon says:

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<sup>69</sup> I should make something clear. Using a drill this way is an open surgical procedure—the surgeon opens the skin, retracts muscles, and exposes the bone before drilling. Most simulators are for minimally invasive procedures, in which the surgeon threads a camera and instruments into small holes in the patient’s body. The camera shows surgical actions on a monitor. This is a crucial distinction that I don’t want to ignore. But, as in the drilling example, the kinesthetics of minimally invasive surgery are extremely complex because they require a surgeon to manipulate camera and instruments while watching the effects of their manipulations on a computer monitor outside the operating field. Tactile feedback in minimally invasive surgery is much less than in open surgery.

That's part of our goal for [simulating] surgical procedures: you take some of the mystery out of it. You educate individuals to develop their 3D mind faster. And I think that's what a lot of endoscopy, arthroscopy—even injections—is: it's visualization of 3D anatomy within a black box, putting your imagination into the black box. So the first time you touch the patient, you know more.

Many traditional surgical teaching tools, including anatomical atlases, procedural manuals, or objects to practice upon abstract one component of technical ability, such as physical skill, procedural knowledge, or knowledge of human anatomy in three dimensions. An ideal simulator would encourage a medical student or resident to integrate these skills before beginning practice on actual patients.

### **The social lessons of teaching surgery: a medical student**

The surgeons I worked with at Stanford regularly described technical skill as “20 percent” of necessary surgical knowledge, falling lower in importance than hard-to-quantify qualities of wisdom, judgment and experience, which medical students and beginning residents do not yet possess. The surgeons at SUMMIT judged students and measured their preparedness to begin doing simple surgical tasks by a set of social criteria, such as how well they fit in with the operating team. The hand surgeon described the development of technical skill as the “composite of exposure and desire”:

I really view it as a package. You don't expect someone very junior to possess good judgment in the context of experience because they don't have it. So I think early on it's attitude. It's eagerness. It's poise in the sense of being able to modulate when is a good time to ask a question, when is it appropriate to be, not confrontational, but challenging, and when it's better to kind of recede in one's role in the hierarchy. And, as far as the technical end, it's eagerness, willingness to learn, willingness to try, and then it's the acquisition of technical skills, relative to experience.

Throughout a student's surgical training, whether it's a few weeks on a surgery rotation, or an eighty-hour a week residency program, attending surgeons judge students' ability to take on more responsibility, to become increasingly part of the surgical team, and ultimately, to perform more complex procedures.<sup>70</sup> As the surgeon makes clear, many of those judgments have much more to do with social skills than technical skills (see Bosk 1979; Good 1995).

This surgeon has nearly two decades of experience in the operating room. As a teacher of medical students, she has learned to break down her actions into constitutive parts to explain them to students. But, in all likelihood, the physical sensations of drilling or other common procedures are relatively transparent to her when all goes smoothly. Polanyi says we rely on a tacit awareness of a set of muscular movements in order to perform a skill: "We are attending *from* these elementary movements *to* the achievement of their joint purpose, and hence are usually unable to specify these elementary acts" (Polanyi 1966, 10). This is a situation Martin Heidegger calls "ready-to-hand" (quoted in Suchman 1987, 53). That is, the equipment tends to disappear or become part of our own bodies when we know what we are doing. For example, I often heard the hand surgeon describe a probe or a pair of scissors as extensions of her fingers. According to Heidegger, the equipment and steps do not become part of us when they're unfamiliar, as with a medical student. So how does a medical student experience the same procedure?

I watch the same surgeon teach a medical student how to use a drill during a complex wrist surgery. The patient is a powerful, athletic man who damaged his left wrist

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<sup>70</sup> Beginning in July 2003, resident work weeks were capped by the Accreditation Council for Graduate Medical Education at eighty hours per week (Associated Press, June 12, 2002). Previously, residents often worked up to one hundred and twenty hours per week.

while lifting weights. A traction device clasps his hand and holds his forearm in the air. An arthroscopic examination of the spaces between the wrist bones shows some arthritis and several torn ligaments that have loosened the strong arch of wrist bones. The arch is a structural feature, analogous to an architectural arch, that allows such weight-bearing activities as handsprings and pushups. The ligaments cannot be repaired. The surgeon decides to shorten the man's ulna—one of the two bones in the forearm—to keep it from acting like a piston banging into the arch of wrist bones and aggravating the injury. Surgeon and resident make a large incision in the man's forearm, use a handheld electric saw to cut out a short length of bone, then join the two ends with a metal plate. They fiddle with the plate to place it properly, then anchor it by drilling four screws through holes in the plate and into the bone.

A medical student holds retractors and helps hold the wrist during most of the procedure. The student has observed and assisted in surgeries for several weeks and the surgeon decides to let him put the final screw in place. The student takes his place next to the patient and flashes me a look that I interpret as pure terror. The resident braces the patient's wrist from one side. The surgeon insists that the student to hold the drill in his left hand instead of his right, even though he is right-handed. It will become clear that the surgeon's decision to make the student use his left hand is a crucial part of the teaching interaction, even though it was dictated entirely by the situation (see Suchman 1987). The surgeon helps him hold and guide the drill. Braced by the surgeon and counterbalanced by the resident, the student successfully places the screw. Surgeon and resident stitch up the incision and bandage the arm.

The drilling lesson was part of an open surgical procedure that did not involve the kinds of minimally invasive work on the screen that most simulators reproduce, though simulations of open procedures do exist. The kinesthetic relationship between hands, instruments, and feedback is similar. Simulators, although they are mostly still experimental, do a pretty good job of modeling situations like drilling. Researchers can create a simulated model body and good approximations of its responses as it interacts with instruments. They can also create reasonably good approximations of haptic feedback. But they are more commonly developed for minimally invasive procedures for three reasons. First, because of the pre-existing relationship of instrument to screen. Second, because minimally invasive procedures are more difficult to learn (Katz 1999, 217). And third, because students and residents can practice many skills for open surgery on ordinary objects. They can suture banana skins, for example, to approximate the feel of suturing human skin. But much more happened in this simple interaction, as a series of later conversations between surgeon and student reveal.

Several days later, the medical student and surgeon talk about the student's experience during a group coffee. The student says placing the screw terrified him, though he put a brave face on it at the time:

**Student:** ... I'm right-handed and [the surgeon] was like, "Use your left hand." And I was thinking, Why?

**Surgeon:** Because he was doing this...

The surgeon holds out her right hand as though holding the drill and twists her body around, so her right hand is on her far left side. Her position makes everyone present laugh because it seems so awkward. The surgeon doesn't tell the student in words that his body was twisted around when the drill was in his right hand. Rather, she demonstrates

with her body and makes a joke of it. The joke demonstrates the student's improper position and itself becomes another teaching moment, indicating that she wanted the student to use his entire body to help keep the screw aligned.

Lucy Suchman, in a discussion of a copier's instructions to users about its operations, shows that the copier has recourse only to information about the success or failure of each step in the process (1987). A surgical simulator would have similar limitations. It could easily specify which hand might be needed for a particular action. But it could not teach the student—implicitly or explicitly—how to align his body. It does not have an awareness of the fully embodied situation.

Even after the surgeon's physical demonstration, the student remains focused on the issue of handedness:

**Student:** I wanted to [use the right hand] because my dominant hand, I felt would be, I really, honestly felt I would have been able to screw it in better, but yet she insisted that I do it with my left.

**Surgeon:** You were getting that hazing. It's mostly in fun, but it's also pushing your boundaries.

**Student:** And it's all for a good purpose, to ultimately do it right, learn it.

The student reveals that using his left hand made him anxious: he believed he could do better with his right. The surgeon indicates that she is pushing him, giving him a challenging introduction to surgical culture. The interaction indicates that the surgeon and the student frame the procedure very differently. The student focuses only on his body—and that body's right-handedness—while the surgeon sees the student's body in relation to the entire operating field and the tight spaces around it. MacKenzie (op. cit, 231) says that, within the community devoted to developing nuclear weapons that he has studied, judgment develops over years of experience within a community and is part of



the tacit knowledge transmitted from expert to student. The attending surgeon has the experience and authority to judge which hand to use. As we will see, the student later begins to understand the reason for the surgeon's decision. In a small way, he starts to learn judgment.

The surgeon says what might seem like a non-sequitur, but which I believe is a crucial part of the interaction: she calls her instructions hazing, but says she is also pushing the student's boundaries. The hazing of medical students by surgeons and staff is a well-documented tactic that reinforces the rigid hierarchies of surgeons and staff in the operating room (Bosk 1979). But pushing the student's physical boundaries has a similar effect. The surgeon pushes the student out of the comfort of his right-handedness and into the anxiety not only of drilling a screw into a patient's arm, but also of doing it with his non-dominant hand. As with learning to scrub and maintain sterility, the surgeon brings the student into a new area of practice, in part, by taking him out of the comfortable familiarities of his own body. The interaction makes clear that the drill is not the only piece of equipment unfamiliar to the student. To torture Heidegger's phrase just a bit, the student's left hand also is "unready-to-hand." Asking the student to use his left hand not only correctly positions his body in relation to drill and patient, it also effects the boundary-pushing the surgeon desires. The situation reinforces, in a subtle, physical way, the student's status as neophyte and the surgeon's status as the person who knows how to operate, the person who has learned to judge the surgical situation and the student's skills. The student's final statement, that it's all for a good purpose, to do it right, and to learn it, shows he understands the dual goal of helping him learn and properly placing the screw in the patient's arm. But no one makes the social lesson explicit. Tacit knowledge

can be physical or social. Tacit physical knowledge is what haptics research is about. And surgeons talk about tacit social lessons as the “hidden curriculum of medicine.” But the two are usually treated separately. This lesson reveals that there are tacit social lessons contained in the physical lessons.

At a later point in the group discussion, the surgeon explains the contextual work that she and the resident did to help the student.

Did you notice what we did with you? I mean you were probably so conscious of what you were doing, but both [the resident] and I were right on you. It’s almost like learning to ride a bike. I was guiding your hand. He was over there. We were giving you all this silent feedback, like giving you the counter-pressure and stuff, so you wouldn’t fail. So that’s the part where it’s that baby step and then you slowly withdraw the support.

The surgeon acknowledges that two frames—hers and the student’s—are at work in this lesson. The student focuses on hand, drill, screw, and bone, and probably is unaware or only peripherally aware of the support he gets—of the larger frame. In contrast, the surgeon watches the student, guides his hands, watches him embed the screw into the bone, and monitors the resident’s counter-pressure. She acknowledges that, like learning to ride a bike, the student can only focus on his own body, whereas she enlists four bodies—the student’s, the patient’s, the resident’s, and her own—to help the student experience proper screw-setting, “to do it right, learn it.” The surgeon is the expert, the person who knows—physically and conceptually—how to set the screw. She makes the student’s hands into another type of instrument, an extension of the drill. His hands are, in effect, wielded by the surgeon. But if the student continues to practice, she will gradually pull back her support until the student wields the drill instead of the surgeon wielding the student. I will discuss the physical guiding that a surgeon does in the next

section. This kind of guiding might be replicable in various ways by a simulator, but it is unlikely that the simulator could judge when to guide the student and when to pull back support; that is, when to let the student err, even a little, and when to provide a corrective (see also Bosk 1979).

Neuroscientist Francisco Varela describes unreadiness to hand as a breakdown saying, “New modes of behaving and the transitions or punctuation between them correspond to microbreakdowns that we experience constantly” (Varela 1992, 328). These microbreakdowns are moments of awareness of the situation and its unfamiliarity, moments when we check for landmarks, remind ourselves of the next step, or become aware of the tool in our hands as something apart from ourselves, something to be handled. It is a moment when each step is very conscious, deliberate, and considered. Knowing how to do something means continually managing all the microbreakdowns the world provides. Clearly, the student experiences a microbreakdown, which is not necessarily a psychological breakdown (though he is nervous). He is painfully aware of the equipment and its unfamiliarity. In surgery a serious breakdown could harm the patient and this is where the surgeon’s frame becomes important. Drilling a screw into a bone and using his left hand are unfamiliar to the student. But neither drilling nor teaching a student to drill is unfamiliar to the surgeon. Within her frame, there is nothing unfamiliar and she expertly manages the student’s microbreakdown.

This is the fundamental difference between surgeon-as-teacher and simulator-as-teacher: the simulator can only embody the student’s frame. With further development work, simulators might be able to guide hands by increasing resistance if the student strays from the correct path, providing a kind of haptic bracing similar to the surgeon’s

bracing. But a simulator's primary measures of success would be whether the student performed correctly and quickly. This kind of teaching becomes a question of trial-and-error: do it enough times, make enough mistakes, and all will fall into place eventually. Within the surgeon's frame, that is, in the operating room, there is little room for trial-and-error. Thus, the surgeon uses her knowledge, her physical skill, and that of the resident, to ensure that the student gets it right.

What does the student learn by placing the screw? In a brief write-up about his summer working with this surgeon, he says he would have benefited more if he had spent more time reviewing anatomy and surgical procedural manuals. He learned how to scrub and began to learn the basics of maintaining a sterile field. But his drilling experience worked on at least two other levels, which he begins to indicate in his write-up:

I was appreciative of the opportunity to hold retractors, cut stitches, and on one occasion, screw a K-wire through a bone, and on another, more precarious opportunity, to use my left (non-dominant) hand to apply a screw through a metal plate and into a bone. [The surgeon] said I should use my left hand because the angle was better, but perhaps it was out of a secretive desire to turn me into a southpaw like her and [another doctor].  
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Somatically, the student experienced the correct feel of drilling during the surgery. His write-up indicates that he understands that using his left hand improved the angle of the drill. But he describes the positioning as being primarily related to hand and drill, remaining within his narrow frame, focusing only on this point of contact and not on the relation of his entire body to the drill or the bodies of surgeon and resident. This is technically correct, but insufficient, as the surgeon's body-twisting mimicry reveals. The student also jokingly misunderstands the left-handed surgeon's intent in asking him to use his left hand, saying she may secretly wish to make him a "southpaw." This joke,

which on one level is a reminder of his anxiety, works on another level (Freud 1963). The surgeon has no particular agenda in relation to the student's handedness, though he will have to become somewhat ambidextrous if he becomes a surgeon. But the student's suggestion that the surgeon wants him to become "like her" reveals an important truth: the entire lesson is structured so the surgeon's knowledge of this procedure gets physically imprinted into the student's body. If he continues in surgery, he will indeed become "like her."

As the student experienced the feel of drilling, the sensations of the screw passing through bone were transmitted to his body. And, supported, braced, and guided by surgeon and resident, he learned the "feel" of doing it correctly. The surgeon also used the student's anxiety to her advantage in the teaching situation. By mobilizing his body and his emotions, she reinforced both the feel of drilling correctly and her own authority in the operating room, her authority as the person who knows when and how to do the procedure and as the person who can mobilize all the resources in the room for treatment. If the student continues in surgery, this lesson will be taught and taught again in subtle and unsubtle ways. The student gets physical and social lessons transmitted into his body just as surely as he transmits the screw into the patient's body.

### **Guiding eye and hand, building confidence**

I turn now to my second case, in which the surgeon guides a new resident through a procedure. The resident is a handsome, athletic man, as many orthopedics residents seem to be. He is new to the hand surgery service. The surgeon describes him, out of his hearing, as very talented, skilled with his hands, but lazy, lacking some knowledge of basic anatomy. The resident has an air of confidence in the operating room that makes

him appear more senior than he is. While waiting for a patient suffering symptoms of carpal tunnel syndrome, the surgeon quizzes him about the symptoms that would indicate surgery to relieve pressure on the carpal tunnel.<sup>71</sup> The resident hesitates, but answers correctly. She asks him what nerve becomes compressed when a patient develops carpal tunnel syndrome. He says, “median nerve.” She says, “that’s very good,” mildly sarcastically and then asks him which branch of the median nerve. He does not know the answer. She assigns him to review the anatomy of the carpal tunnel. This surgeon praises the resident when he is correct and pushes him when he is wrong. I am struck by how different this is from teaching in the humanities and social sciences where factual knowledge is rarely stressed. Quizzing reinforces the importance of factual, anatomical knowledge in this world.

When attendants wheel the patient in, the surgeon speaks to him in ungrammatical, but comfortable Spanish (he speaks no English), making certain that an anesthetizing nerve block put in his arm has taken effect. As he goes under general anesthesia, she absentmindedly strokes his wrist and I cannot decide whether she is comforting him, ensuring that he has no feeling in the wrist, palpating the injury, or simply thinking about the procedure. She tells me he has all the symptoms of carpal tunnel syndrome, but in the wrong location, further back in the wrist, a couple of inches away from the base of his hand. She shows me a swelling on the wrist, but does not speculate about what the swelling is.

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<sup>71</sup> Carpal tunnel syndrome is a form of repetitive strain injury in which overuse causes tissues in the tight space where wrist meets hand to swell, pressing on nerves in the same space.

With the resident looking on, the surgeon draws lines on the man's hand and draws an "x" and a circle on either side of the line at the base of the palm. She instructs him that this is the path of the incision. She discusses the landmarks on the palm and how to find them. She also describes how she learned to do carpal tunnel releases and how the procedure has changed. She lets the resident make an incision in the man's wrist. Evidently, the incision is too shallow and she tells him to cut a bit deeper with the scalpel before using scissors to avoid tearing the tissues. As he opens the wrist, a purple muscle protrudes through the incision. Both resident and surgeon are surprised. "What's that muscle belly doing there?" the resident asks. The surgeon does not reply, but instructs the resident to open the man's palm, which has a tough layer of tissue between skin and the nerves and tendons in the carpal tunnel and is not easy to cut.

As the resident cuts into the base of the man's palm, the attending repeatedly warns him that his scalpel is straying too far "radially," towards the man's thumb. She tells him a story about a hand surgery fellowship she did at "the Brigham," Harvard's Brigham and Women's Hospital in Boston. She says surgeons had a particularly subtle method of giving residents direction: first, they would nod or point. Then they would quietly say, "I think you'd better move," which she says meant, Move now. Anything more urgent and the resident or fellow was in deep trouble. She called this understated mode of giving direction, "Harvard speak." She says her method of instruction is not so subtle.

The muscle is an anatomical anomaly. Most muscles in the forearm are muscular towards the elbow and spread out into long, thin tendons as they approach the wrist (these muscles control most hand movement). The patient's *palmaris longus* muscle is reversed,

with the muscular portion in the wrist and the long tendon stretching toward the elbow. The anomaly is strange enough that the surgeon asks me to use the computer in the room to comb the literature for similar cases both to ascertain previous treatment decisions and on the chance that this one might be publishable. Fortunately for the patient, the muscle is non-critical and often is used as a “spare part”<sup>72</sup> to replace damaged muscles. The patient does not need it. Surgeon and resident remove the muscle, leaving a gaping hole in the man’s wrist where the muscle once was. A thin thread of nerve runs across the gaping hole. The surgeon asks the resident if he has used staples to close a wound while working for her. He says no and she instructs him in her particular method of stapling.

Though this case involved an unusual anatomical anomaly, the teaching interaction was quite straightforward. The teaching moment is a “situated action,” an action that occurs in “the context of particular concrete circumstances” (Suchman 1987, viii). As a situated teaching moment, it contains several layers of pedagogy that are not easily pulled apart. I count at least five different forms of teaching in this interaction. The first form of teaching was explicit quizzing, asking the resident to verbally recite what he knows of wrist anatomy. This kind of quizzing is constant in the early years of medical school and residency. Medical students call it “pimping.”<sup>73</sup> The quizzing has several social effects. Making students perform their knowledge on the spot reinforces the importance of massive amounts of memorized knowledge that a physician must be able

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<sup>72</sup> “Spare parts” is a term I heard regularly in anatomy laboratories and operating rooms to designate redundant or vestigial body parts that surgeons use to replace damaged body parts. The term speaks to the mechanical view of the body common in medicine, particularly surgery (see also Fox and Swazey 1992).

<sup>73</sup> I could never get an explanation of the etymology of this particular use of the word, though it is suggestive of the power dynamic involved.



to call upon at any moment. Quizzing pushes students to study anatomical and procedural knowledge continually and to keep on their toes. Quizzing also reinforces the medical student's or resident's status as lower in the surgical hierarchy than the surgeon, subject to her demands. And it is a leveling force: the surgeon also is reinforcing—through teaching practice—her own knowledge of anatomy and procedure and letting the student know that memorizing and quizzing the facts is not beneath her. Her sarcasm with the resident gives him an unstated social cue. Knowing that the median nerve runs through the carpal tunnel is barely adequate: he needs to do better.

During surgical training, attending surgeons continually quiz medical students and residents about anatomy and procedures, often requiring them to do homework over and above their other time demands. Anatomy knowledge gets re-learned and reinforced throughout a surgeon's career. The hand surgeon told me that she regularly reviews the anatomy of regions where she operates infrequently. But much reinforcement of anatomical knowledge comes through practice, as a gynecologist tells me:

You see, through the experience of practice, you keep reminding yourself, you keep studying. So your first glimpse, your first knowledge, your first database of gross anatomy, gets refreshed. All through medical school you are exposed to different areas of specialty and you also, throughout your practice, keep palpating where the carotid is, for example. And I know where the carotid body is, for example, where the separation is. ... You keep renewing your knowledge of surface anatomy through practice. And you go to Grand Rounds and somebody will show you a picture of a specimen from a surgery or a diagram, it becomes continually renewed and updated.

The gynecologist makes clear that anatomy knowledge becomes cemented through constant practice and repetition, whether during physical exams or during rounds. The abstract knowledge of where the carotid artery is becomes accessible to and reinforced by

his fingertips as he repeatedly seeks it through palpation. What the gynecologist also makes clear is that medical knowing is a lifelong process of learning and updating one's knowledge. A simulator could, of course, quiz students about anatomy and procedure. It could even require this as a pre-condition for practice, but all the social knowledge embedded in quizzing, the reinforcing of a resident's and a surgeon's status, cannot happen with a simulator. Anatomical knowledge comes from formal learning, a set of terms and spatial relations that can be taught with an atlas or model, and through practice, from continual repetition not only of words, but of practice with fingertips. This is true of much of medical, and especially surgical, practice: Anatomical names must be memorized and procedures can be learned from a manual or by a set of verbal instructions. But much of this knowledge gets connected and reinforced—learned by the body—only through practice (see also Bourdieu 1977; Gawande 2002; Mol 2002).

The second form of teaching in this interaction was drawing on the hand, which I watched the surgeon do often with residents. Using a sterile pen, she sometimes draws on a sterile drape, more often directly on the operative site. She describes it as giving her and the resident common ground to work from:

I do draw a lot, particularly for complex procedures. It's for me as much as for them because it sets what their level of understanding is coming into it. If I said, Well, let's just see what they know, that's not really fair to either of us because we would be constantly feeling each other out. If I say, Here's the distal radius; these are the points that we're going after; this is what I'm looking for, it may not be obvious to you. But if you have this in mind, then you've got something to work towards.

As the surgeon explains, she often draws, especially for complex procedures, because the drawing creates common ground for attending surgeon and resident. It means the surgeon does not have to guess what the resident knows and the resident does not have to guess

what the surgeon expects. It gives the resident something to work towards, both locally, during the procedure, and generally, as knowledge the resident will require to become a competent surgeon. The drawing creates a path to follow and a map (see also Bosk 1979, 41). It forms part of both surgeon's and resident's rehearsal of the surgical procedure. It is preparation. A simulator easily could trace a path for a resident to follow. But what the surgeon is doing is more complex. The surgeon is creating an object, the drawing, which externalizes what she knows and what she expects the resident to know. As path and roadmap, the drawing gives the resident an image of what he is expected to do. As a teaching tool, it performs another function: the surgeon does not expect this beginning resident to know how to make an incision in the palm that follows the right landmarks and avoids the danger spots. Thus, turning him loose on this hand would be inappropriate. The drawing is a very simple visualization technology, a "material-semiotic actor" (Haraway 1991, 200). It is a material trace—path and map—on the patient's hand. It is also a semiotic actor, a visual metaphor that reveals the differences between attending and resident. It shows the anatomical, procedural, and practical knowledge that she can externalize with the stroke of a pen. The surgeon expects the resident to understand that he will eventually have to connect procedural knowledge, anatomical knowledge, and surgical technique. Procedural knowledge eventually will form part of the embodied practical knowledge that he is working towards.

The fourth form of teaching contained in this interaction is the story about "Harvard speak." The story indirectly tells the resident the meanings of both the pointing and of the verbal cues. It tells him, again indirectly, to take verbal and physical cues seriously: these are instructions. Story-telling is an important part of the oral culture of

medical teaching (Bosk 1979; Hafferty 1988). It is a means of conveying tacit social information about medical practice and social structures in medicine. Story-telling is critical to teaching medical culture, orienting students and residents to the field and establishing social controls (Hafferty 1988, 345). I heard the hand surgeon tell the story about “Harvard speak” on several occasions. By telling this story, the attending ties herself to two of medicine’s grand institutions—Harvard Medical School and Brigham and Women’s Hospital—and differentiates her teaching style from theirs—she is not as subtle in her directions to residents. The story reiterates her authority as someone taught within a longstanding teaching tradition and someone who has made independent judgments about how to guide subordinates. She also is telling the resident indirectly what he should pay attention to and how serious it is when she actually has to tell him, in words, that he is straying. The story reminds him that straying is dangerous and underscores the need to connect anatomical knowledge with procedural knowledge and with physical practice.

The fifth form that teaching took during this procedure was the admonition not to stray. During a discussion about surgical teaching that occurred after this surgery, the surgeon explains how she guides students non-verbally and verbally:

I do a lot of manual guiding, guiding them with my pointing instrument, my freer. And I’m constantly kind of guiding here and they’re mostly not aware of it because it’s becoming part of the field. But if they start drifting, then I may have to say something if they don’t pick up the visual cue. I’m ... guiding, almost like a pointer. Sometimes it’s pushing the tissue or getting it in the right plane. Sometimes you have to say, No, move your knife over here, if they’re not quite so clued in.

The surgeon says that much of her guiding is non-verbal, using a pointer to subliminally guide the resident’s hands. This is similar to bracing the medical student: she expects that

the student or resident will focus on the task and remain relatively unaware of the guidance. Unlike the bracing of the medical student, however, the resident has more autonomy. Verbal guidance is a last resort and occurs when the resident fails to recognize the visual cue. Thus, the surgeon first uses non-verbal cues to guide the resident. She uses an instrument to urge the resident's hand to stay in the correct path. This is largely a subliminal cue for the resident because the instrument becomes part of the resident's larger perceptual field. The pointer becomes part of the resident's "outer horizon," a concept Hubert Dreyfus borrows from Edmund Husserl to describe contextual information that remains perceptually indeterminate, but that guides perception of the area of focus (Dreyfus 1992, 240-41). Because this non-verbal, contextual pointing does not always work, the surgeon also can use verbal cues.

On a different occasion, a retired surgeon and anatomist explains this tacit guiding:

It's steering. You physically steer the person along. If you talk with people who are learned surgeons, they will say, I had a lot of guys come back to me and say, You know, the first time I did a Dupuytren's Contracture,<sup>74</sup> boy, was it an easy operation. And the next time I did it myself and, you know what, it wasn't so easy. This is because what you do is open a pathway to the surgeon to do what he is supposed to do without saying it. And sometimes you say if you think they might be doing something that will be troublesome or doing a wrong thing, obviously. [You might say], That motor nerve is somewhere else ... and so on. You've got to be a little careful doing it. You don't want to cut that motor nerve, etc. You tell them if you want to keep them out of trouble, but you let them go as long as you can, doing their best without your help. [My former residents] used to tease me. They would say I could do surgery with a dental probe because I used a dental probe to point to things in the operating room and to hold things aside for the surgeon who is doing it. That's how you make things

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<sup>74</sup> Dupuytren's Contracture is a progressive thickening of the fascia in the palm that causes the fingers to contract towards the palm.

easy for the surgeon, to give him beautiful exposure, to show where he is supposed to be.

This surgeon describes this kind of guiding as “steering” the resident,. He says former residents often return to their teachers and tell them the first time they did a procedure under the attending’s supervision, it seemed very easy. Later, without the surgeon’s guidance, the difficulty becomes clear. The key, as this former surgeon says, is to let the resident proceed as long as possible without help. The attending silently helps the resident see where he or she should be working. As this former surgeon says, attendings want to allow a resident or student to proceed as long as possible on his or her own, correcting the resident or student only when necessary.

Following the apprenticeship model of surgical teaching, surgeons typically teach by demonstrating a procedure, then turning it over to residents to try under their guidance. In addition to technical skills, surgeons also learn a particular stance toward patients, pathologies, and treatments. These traits include clinical judgment, as I discussed earlier, but they also include confidence and decisiveness (see also Cassell 1991; Katz 1999). Surgical decisiveness is an extreme form of teaching within the larger culture of medicine, in which doctors are trained to manage uncertainty (Fox 1957; Katz 1984). As the retired surgeon says:

Surgery is a skill that requires decisiveness. Whereas other people can stand around and talk about, Are we going to change the dosage? the surgeon has to do one thing or the other. Either operate or not operate. Take it out or not take it out. Anastomose or not. There are all sorts of decisions that have to be made. And they have to be made on less than perfect evidence and so you gain a lot of skill in doing that over a period of time.

This former surgeon says decisiveness is a required trait of surgeons. Speed matters. Second-guessing is a problem. Steering the resident by physically guiding or pointing in his or her visual field makes the resident feel as though he or she is proceeding unguided. Guiding is largely subliminal, intended to teach the student and resident at a level that is embodied and largely subconscious. This gives the student or resident the illusion of autonomy and of competence, the illusion of possessing a skill he or she does not yet have. As the retired surgeon says, residents come to believe a procedure is easy, in part because the attending surgeon can make it easy. The resident believes he or she has accomplished the procedure largely alone. Non-verbal guiding helps the student or resident when he or she has to attempt the operation unguided. This may help the student or resident develop the confidence and decisiveness needed to practice surgery.

A simulator probably could replicate some form of this guiding, possibly by having a built-in pointer that exists in the visual field or by providing haptic resistance outside the proper path. This has been a topic of conversation among the simulator makers at SUMMIT. Haptic signals can be embedded in a simulator that would provide increasing resistance to the resident's hands if he or she strayed from the correct path, but such haptic guidance might anticipate the student's actions rather than correct it. That is, the attending surgeons find ways to correct straying, such as non-verbal pointing or guiding that, as the retired surgeon says, allow the resident to proceed unguided as long as possible before issuing a corrective. Building a simulator that would know when to allow the student to proceed, when to give visual cues, and when to speak out, a simulator that could gauge precisely how to guide and give the illusion of autonomy would be a much more difficult computational problem. Further, part of surgical learning,

as I have shown, is emulating a master surgeon and working under his or her tutelage. Does the surgeon's gaze, and the fact that he or she is standing by, watchful but only tacitly providing correction, add to the student's confidence? A simulator, even if it successfully models the visual and tactile sensations of surgery, keeps the interaction solely within the student's frame and neglects the social lessons of the operating room. It cannot play on the student's anxieties, nor defamiliarize the student with his own body. It cannot enlist his entire body, nor the bodies of others, to get the procedure right. It may be able to provide non-verbal guidance to the resident's outer horizon, but judging just when to provide that guidance to give the resident the illusion of autonomy may be a different matter. Techniques of the body are only techniques of the body with a simulator. This may account for why residents who try them often say they're boring. They may lack the cultural richness of the real thing. Regardless, simulators may one day provide valuable practice for medical students. They might make up in opportunities for repetition what they lose in fidelity. And they may fit well into changing social, political, and economic goals of academic medicine, such as new emphases on providing objective proof of skill acquisition and on the value of constant practice. Thus, simulators may be coming onto the scene at a moment when medicine is ready for their kind of teaching.

Experiential learning, slowly accumulated over years of medical school, residency, and surgical practice—from watching surgeries to trying small procedures to full-scale operating—is how surgeons traditionally have learned their craft. Simulator makers want to accelerate this process, particularly the earliest lessons of surgery. What happens, then, when students come into the operating room with a stronger grasp of



physical skill? Will students trained on simulators as readily accept a senior surgeon's authority? Will they miss the physical reinforcement of the social lessons of surgery?

As my analysis shows, teaching surgery involves bringing a student into a unique subculture of medicine, first by defamiliarizing the student with her or her body, and then by installing new schemes of perception and thought—new embodied practices. These embodied lessons are not only technical: they contain within them social aspects of surgery that are much less likely to be replicable with training on a simulator.

Successfully integrating simulation into surgical training ought to include the acknowledgment that some components of the lesson—specifically, a student's anxiety, his or her total bodily experience, and tacit social lessons—are part of the embodied experience of surgery that will not be communicated.

## **Conclusion**

### **Engineering Medicine**

Up to this point, I have described in depth how a new interdisciplinary field is forming around the construction of virtual reality models and computerized tools for teaching anatomy and surgery. I have discussed how researchers building these tools are developing representations of bodies that differ from those of traditional medicine, representations that begin from any-section-whatever and treat bodies as colored pixels in the coordinate space of the computer. These bodies without privileged organs, tissues, or systems, then become reimagined as models depicting organs, tissues, and systems, but organs, tissues, and systems that can be manipulated. This research arena, thus, imagines bodies in new ways: as entities that can be described and modeled mathematically, that can be manipulated, and whose relationship to space, time, and opacity can be altered. I have shown how surgeons' bodies, too, must be mathematically described as the physics of surgical action to allow these systems to provide meaningful feedback to a student's eyes and hands. If and when they are incorporated into medicine and medical education, these systems are likely to alter certain social aspects of medical teaching, including a student's relationship to cadavers and to the social structures of the operating room.

There are two primary areas where the technologies, communities, and practices I describe are significant: the first is in the way these technologies bring medical representations of the body into the representational scheme what Henri Bergson describes as "modern science" (Bergson 1998 330). The second is in the ways these representations—materially and semiotically—promise to alter the time, space, and opacity of bodies of medicine.

Henri Bergson describes the differences between the ancient science of the Greeks and “modern” science beginning with Kepler and Galileo as fundamentally a difference in the relationship of events to time—time becomes a variable that is independent of action. The ancients, Bergson writes, saw time in a series of privileged moments that could be captured in a form or an idea, like each “snapshot” of action contained in the Parthenon’s friezes (Bergson 1998 332). Modern science, instead, captures action, motion, or becoming at “any moment whatever,” dividing time in equidistant, but arbitrary, cuts, like the frames of a motion picture. Bergson says our knowledge is “cinematographical” (306), saying both ancients and moderns take mental “snapshots” that make motion immobile. But modern science does away with the privileged instant—the form or idea of an action—in favor of “any moment whatever,” which may capture privileged instants, but only as a chance results of the unfurling of equidistant snapshots (Deleuze 1986 5). In this dissertation, I have shown how the computerization of bodies has altered the privileging of the body’s organs and systems—its spaces—and its one-way passage from life to death or from surgically untouched to surgically altered—its time. This dissertation extends the notion of “any moment whatever” to consider several examples of how the world of virtual reality in medicine shifts the body’s privileged spaces and times. In Chapter 1, I showed how creating computer models of wrist motion required measurement of sizes of parts of the wrist, so the forces of wrist motion can be calculated. This move resolves the wrist into forces and moment arms that can be used to create predictive models of surgical action. This modeling deprivileges the surgeon’s visual and experiential knowledge of anatomy and where a ligament, tendon, or muscle should attach in favor of a mathematical

description of motion. In Chapter 2, I showed how the Foundation Model of anatomy requires filling in the gaps left in anatomical taxonomies. This is a case of every location in the database requiring a field, even if that field is clinically irrelevant. So the taxonomy gets filled with existing names but also with new names—this creates a taxonomical any space whatever. In Chapter 3, I showed how cadaver bodies became represented as any-section-whatever, with the computer requiring explicit representations of all spaces, regardless of importance, even null space. This is an example of the de-privileging of traditional anatomical spaces of organs and systems and the construction of bodies in coordinate space. In Chapter 4, I described how the surgical actions of cutting, suturing, and tying must be resolve into equations that—like the example in Chapter 1, except describing the surgeon’s motion—reproduce the entire arc of motion encompassed by a surgical action, making surgical action into surgical physics. This leads away from the privileging of a surgical action and toward the resolution of surgical action into time steps at any moment whatever.

These moves make human anatomy less a science of taxonomic description or of privileged organs and systems and more an engineering science. But what is the significance of this move if this particular type of representation of bodies is embedded in the computer, invisible to all but the researchers building these programs? The creation of bodies represented as moment arms or force vectors and as any-section-whatever, or any space whatever allows the computer to represent bodies in motion or as bodies after particular surgical action, as a patient-on-demand who can be practiced upon repeatedly and reversibly until a student learns anatomy or until a surgeon knows how to proceed. Virtual bodies thus alter bodies’ time, space, and opacity. A body’s time becomes

reversible—at least in the representational space of modeling. This might allow a surgeon to practice a procedure to perfection. Or it might allow a modeler to predict the future effects, say, stopping or continuing to smoke. A body's spaces become representable as three-dimensional models, allowing modelers to, for example, explore a lump on both sides of a colon wall to help determine—before surgery—whether the lump is cancerous. This is also a change in a body's opacity.

Further, these changes in representations of bodies may change medical practice, but they may also change how doctors conceive of bodies. First, and most simply, physicians might begin to imagine bodies as dynamic systems, something the cadaver fails to do. Further, virtual reality might foster an imaginary of bodies as manipulable. In this sense, virtual reality may become a physician's playground for imagining how to manipulate human structure, a form of play that Francois Dagognet, as quoted by Paul Rabinow, says carries within in as much possibility as ambivalence, "Either one adopts a sort of veneration before the immensity of 'that which is' or one accepts the possibility of manipulation" (Rabinow 1992 249-50). The possibility of manipulation must be imagined before it becomes real: virtual reality is one space where this imagining can occur.

The goal, or "Holy Grail," of virtual reality in medicine is to use medical imaging data from living patients to build models that will be used to plan surgeries, practice them, and predict outcomes. What this means, then, is, like Ian Hacking's representing to intervene, the goal is to move from representing bodies to intervening in bodies. But intervening has a first step and this first step is to change the representation of bodies in time and space. The body becomes coordinate systems, time steps, moment arms.

Is this a good move or bad? Inherently neither. If doctors learn even deeper ways to be unaware of the humanity of their patients, then it might be bad. If they learn more precise ways to treat them—perhaps developing more precise tools for determining the effects of surgical action—then such technologies might be beneficial.

SUMMIT is among the most technologically oriented places I have visited. And yet its staff taught me, and taught me well, that the men and women who treat patients according to biomedical models of illness and injury can be caring, humane, loving individuals.

An example occurred during one of our weekly coffees. We planned to discuss an article by the engineer Andy Groves, who created his own meta model of treatment regimes for prostate cancer because no such thing existed in the medical literature. He describes being appalled at what he viewed as highly subjective decision-making by physicians. I expected our coffee conversation to consider such issues as subjectivity in medicine. One of the participants, however, brought in a famous urologist as a guest, a man who was intimately familiar with the characters in Groves' article. The urologist brought with him two recent papers, both deeply technical considerations of the pros and cons related to testing for prostate specific antigen, a high level of which can be considered an indicator for prostate cancer. The urologist spent more than an hour giving a highly technical monologue about his research and the debate about PSA. At the end of the talk, the urologist told the story of Paul Beeson, an eminent physician who suffered from a lifelong tendency toward occasional, severe urinary tract infections. He described Beeson's lifelong struggle with these painful infections. And finally, he described how the physician eventually found a urologist, a man who few other urologists respected,

who located a congenital deformity that sometimes caused material from his bowels to leak into his urinary tract, causing infections. This was the genesis of the quotation, the urologist said, and in telling this story, he choked up and wiped tears from the corner of his eye. This was not the first time I had seen a physician cry when describing medical successes or failures. Later that day, another surgeon described her father's death from aggressive prostate cancer. And a third surgeon described his own prostate removal. And an educational specialist described her long, painful, and only somewhat successful spinal surgery. I was struck by how suddenly this highly technical conversation turned personal and emotional. And I was profoundly moved by what these physicians and other professionals chose to share of themselves and their lives that day. I realized that no matter how technical medicine becomes, no matter how remote, or mathematicized, or computational, medicine is always, in the end, about life, death, and human suffering.

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