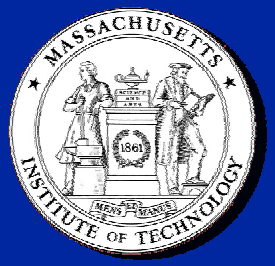
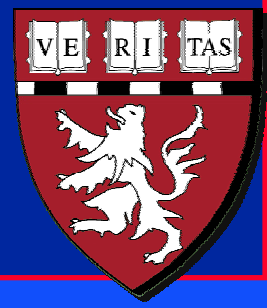


Massachusetts Institute of Technology
Harvard Medical School
Brigham and Women's/Massachusetts General Hosp.
VA Boston Healthcare System



2.79J/3.96J/BE.441/HST522J

BIOMATERIALS FOR JOINT REPLACEMENT

M. Spector, Ph.D. and I.V. Yannas, Ph.D.

http://stellar.mit.edu/S/course/2/fa02/2.79j

TISSUES COMPRISING JOINTS

	Permanent Prosthesis	Regeneration Scaffold
Bone	Yes	Yes
Articular cartilage	No	Yes*
Meniscus	No	Yes*
Ligaments	No	Yes*
Synovium	No	No

* In the process of being developed

JOINT REPLACEMENT PROSTHESES

- Fit
  - Anatomy
- Function
  - Kinematics; Range of Motion
- Fixation
  - Bone cement, bone interdigitation with an irregular surface, bone ingrowth into a porous coating
- Tribology
  - Friction, Wear, and Lubrication
- Other Effects
  - Stress Shielding

Bone Cement
Self-Curing Polymethylmethacrylate

Images removed due to copyright considerations.

Porous Coatings for Bone Ingrowth

Images removed due to copyright considerations.

Porous Coated Tibial Component

Images removed due to copyright considerations.

JOINT REPLACEMENT PROSTHESES

- Fit
  - Anatomy
- Function
  - Kinematics; Range of Motion
- Fixation
- Tribology
  - Friction, Wear, and Lubrication
  - Cell response to particulate wear debris
- Other Effects
  - Stress Shielding

PROGRESSION OF OSTEOLYSIS: "HYLAMER" CUP

Image removed due to copyright considerations.

Why Artificial Joints Fail

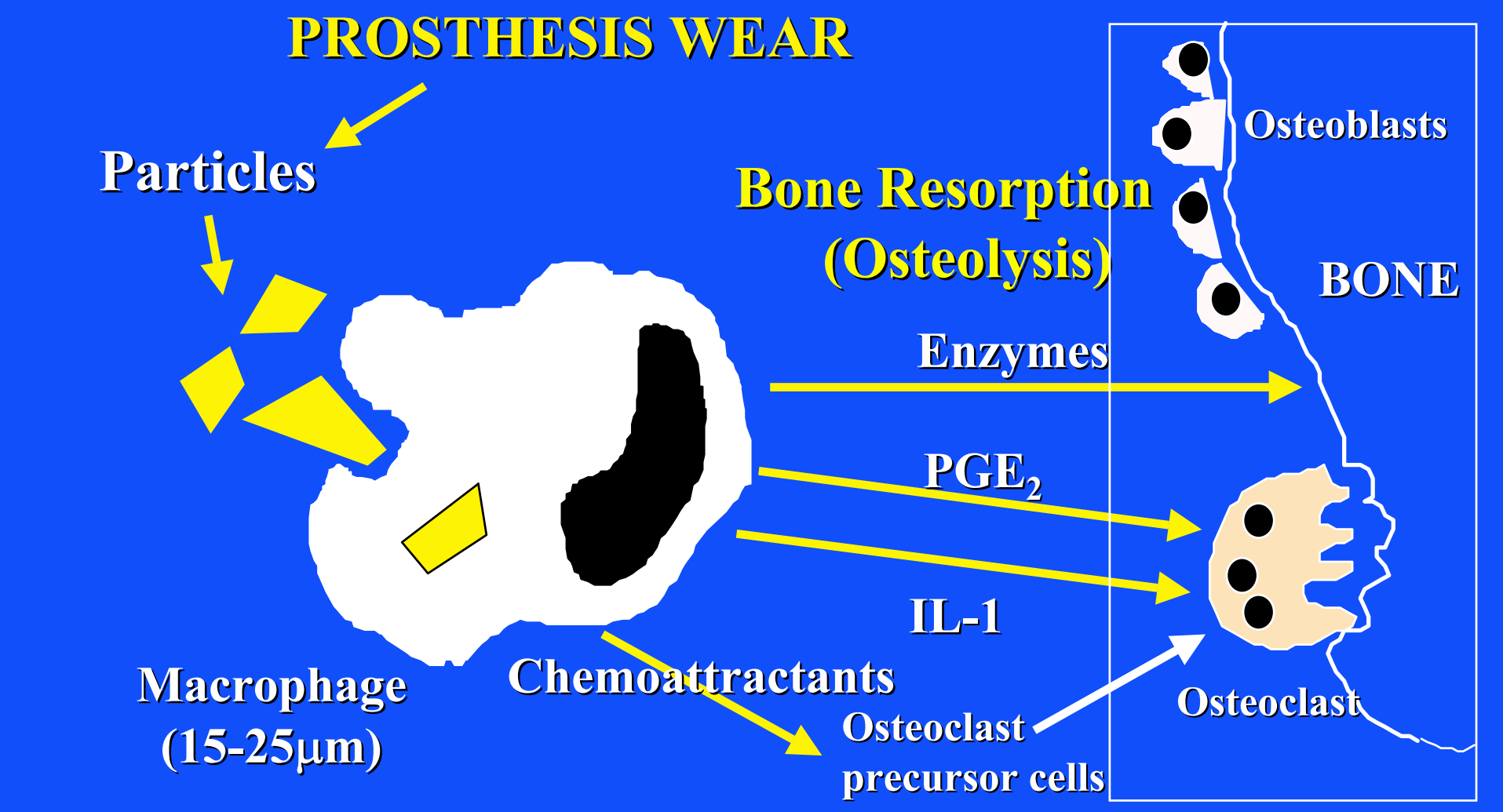
Image removed due to copyright considerations

Spice, Byron. “Particle Disease Seen As Plague on Total Joint Replacement” Pittsburgh Post-Gazette.

J. Charnley, 1979

Photo removed due to copyright considerations

MACROPHAGE RESPONSE TO PARTICLES



POLYETHYLENE WEAR PARTICLES

H. McKellop, 1994 Hip Society

The number of particles generated by a hip prosthesis

7×10^{11} particles/yr.

700,000 particles/step

NUMBER OF INHALED PARTICLES

Avg. particle burden of urban atmosphere:

10^5 particles/liter

Respired volume in man = 1 liter/min.

Therefore, 10^5 particles are inhaled/min.

10% of the inhaled particles are deposited in the lungs.

Therefore, 10^4 particles are deposited in the lungs per min.

5×10^9 particles/yr.

Titanium Wear Debris

Images removed due to copyright considerations

Co-Cr Particles

CELL RESPONSE TO METAL PARTICLES

- Macrophages *in vitro*
- Particles of Ti alloy not toxic; Co-Cr highly toxic
- Ti induced more release of PGE_2 than Co-Cr
- Exp. to Ti increased the release of PGE_2, IL-1, TNF, and IL-6; exp. to Co-Cr decreased release of PGE_2 and IL-6 and had little effect on IL-1 and TNF
- "release of Ti....worse than....Co-Cr"

D.R. Haynes, *et al.*,
JBJS 75-A: 825 (1993)

CELL RESPONSE TO METAL PARTICLES

- Bovine articular chondrocytes
- Co was toxic to cells at all conc.
- At high conc. Cr, Ti, and Ti alloy were toxic
- At high conc. all metals decreased enzyme activity
- PGE_2 increased with conc., except for Ti alloy

W.J. Maloney, et al.,
J. Appl. Biomat. 5: 109 (1994)

BIOLOGICAL RESPONSE TO METAL PARTICLES AND IONS

Summary

- Metal particles and ions are released from TJR prostheses; the amounts can be reduced by careful design and manufacturing.
- Cellular response to metal particles has some of the same elements as the response to particles of other materials.
- No indication yet that metal particles and ions are responsible for profound adverse responses.

Drainage of Particles by the Lymphatics

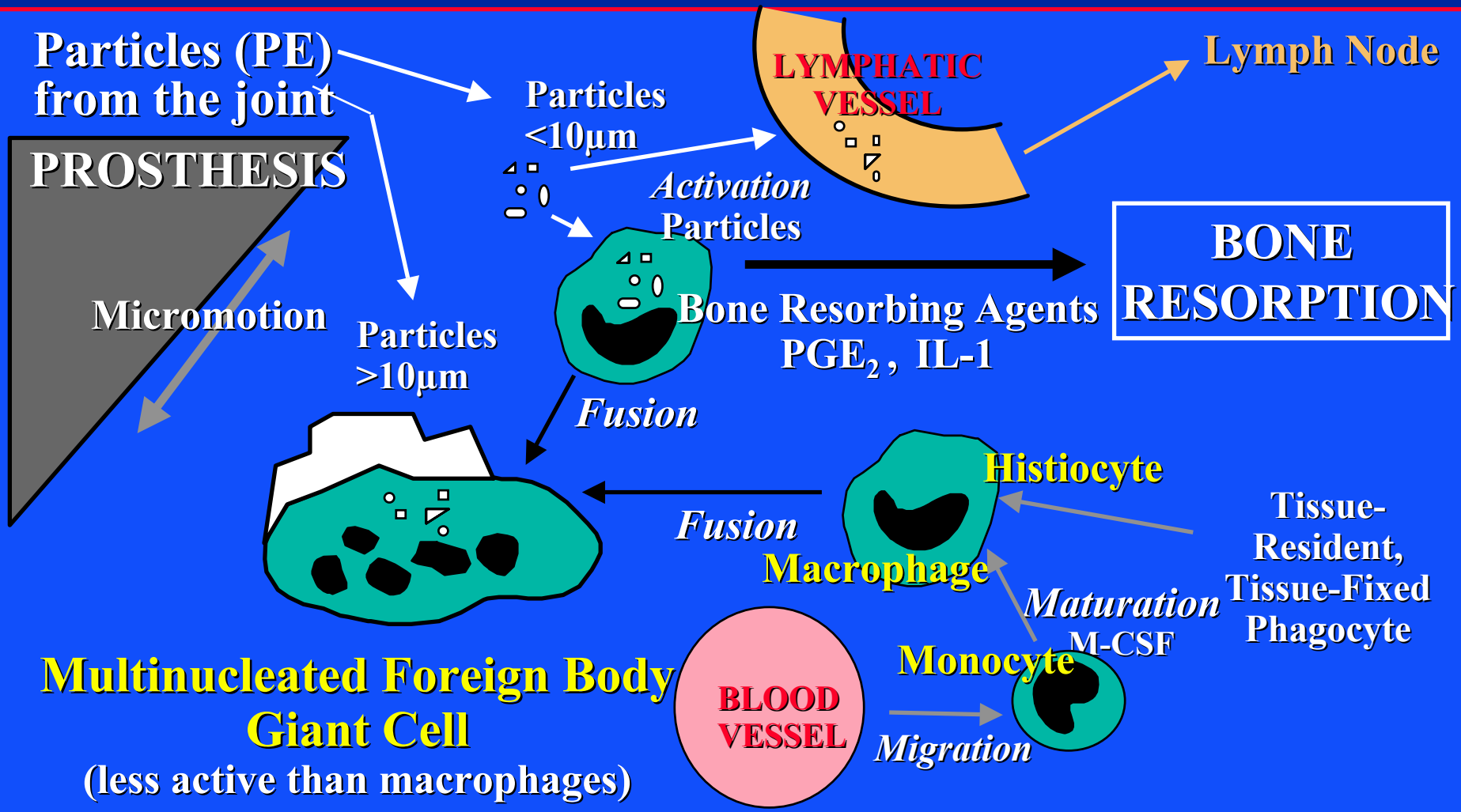
Image removed due to copyright considerations

H. Willert, *et al.*

SMALL PARTICLE DISEASE: LYMPHADENOPATHY

- Enlargement of the node
- Particles drained from tissue by the lymphatic system are phagocytosed by macrophages in the nodes
  - histiocytes derived from cells that line the sinuses of the node and macrophages derived from circulating monocytes
- Sinus histiocytosis
- No adverse clinical sequelae yet noted

MIGRATION OF PARTICLES AND CELLULAR RESPONSES



Lymphadenopathy

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METAL SENSITIVITY IN PATIENTS

- 10-15% of population have dermal sensitivity to metal (14% to Ni)
- Metal ions bind to proteins to form immunogenic complexes
- Metals known as sensitizers:
  - Ni > Co and Cr >>> Ti and V
- 60% of pts. with failed TJRs were metal sensitive vs. 25% with well-functioning implants
  - Did metal sensitivity cause failure or did the failed implant cause metal sensitivity?

Hallab, Merritt, Jacobs, JBJS 83-A:428 (2001)

METAL SENSITIVITY IN PATIENTS

- "May exist as an extreme complication in only a few highly susceptible patients (< 1%), **or** it may be a more common subtle contributor to implant failure."
- "It is likely that cases involving implant-related metal sensitivity have been underreported because of the difficulty of diagnosis."
- Patients who have displayed sensitivity to metal jewelry are at higher risk.

Hallab, Merritt, Jacobs,
JBJS 83-A:428 (2001)

JOINT REPLACEMENT PROSTHESES

- Fit
  - Anatomy
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- Fixation
- Tribology
  - Friction, Wear, and Lubrication
- Other Effects
  - Stress Shielding

Bone (Trabecular) Structure

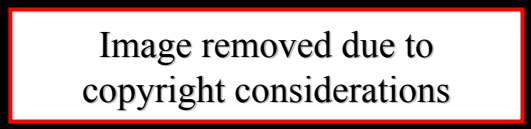
Normal

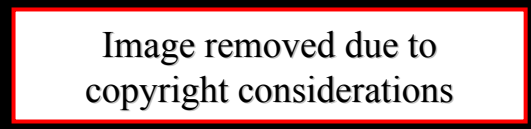
Osteoporotic: Postmenopausal

Images removed due to copyright considerations

Bone Loss Under the Femoral Component of a Total Knee Replacement Prosthesis: Stress Shielding

1 year post-op





Knee Joint

Bone

Art. Cart.

Image removed due to copyright considerations

Meniscus

Ligament

Bone

Total Knee Replacement Prosthesis

Co-Cr Alloy

Bone

Image removed due to copyright considerations

Polyethylene

Bone

TISSUES COMPRISING JOINTS

	Permanent Prosthesis	Regeneration Scaffold
Bone	Yes	Yes
Articular cartilage	No	Yes*
Meniscus	No	Yes*
Ligaments	Failed	Yes*
Synovium	No	No

* In the process of being developed

LIGAMENT DEVICES

Prosthesis

- Does not require an autograft for support
- Sufficient strength for immediate stabilization
- Do not rely on intra-articular healing to augment strength

Augmentation Device

- Acts as mechanical support to reinforce autograft to increase initial strength
- Load sharing with graft tissue to prevent stress shielding

LIGAMENT REPLACEMENT AND AUGMENTATION DEVICES

Issues

- Strength
- Load-deformation
- Insertion site integrity
- Tensioning

LIGAMENT PROSTHESES HISTORICAL PERSPECTIVE

1960	Emery & Rostrup	Teflon tube; fraying in tunnel
1969	Gupta and Brinker	Dacron cord/rubber coat; fragmentation
1973	James, et al.	Proplast; breakage
1977		Polyethylene; breakage
1978	Jenkins	Carbon fibers; fragmentation; migration to lymph nodes

SYNTHETIC LIGAMENTS

Device	Material	Indication
Prostheses		
Gore-Tex	PTFE (Teflon)	Failed intra-art. reconstruction
Stryker	Dacron	Failed intra-art. reconstruction
Augmentation Device		
Kennedy	Polypropylene	Augmentation of autograft ACL

Polyethylene Fiber Braid: Canine Model

Images removed due to copyright considerations

Image removed due to copyright considerations

Olson, Eric J. et al. "The biochemical and histological effects of artificial ligament wear particles: In vitro and in vivo studies." American Journal of Sports Medicine, vol. 16 no. 6 (1988).

LIGAMENT PROSTHESES

- Wear/fraying occurs
- Wear particles of all synthetic ligaments elicit production of inflammatory agents

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