# Best care practices in anesthesiology: Development and evaluation of an electronic feedback system to improve physician compliance with evidence-based practices

by

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## Abstract

Recently, hospitals, regulatory agencies, and insurers have renewed their focus on improving patient care and safety. Outcomes based measures are being utilized and hospitals are being asked to report on whether patients are being treated according to a standard of care or a best practice guideline.

As peri-operative physicians, anesthesiologists are able to evaluate and, to a great degree, affect the pre-operative, intra-operative, and post-operative course of a patient. However, several barriers exist. Although best practice guidelines exist, current models to risk stratify patients need improvement. Individual anesthesiologists currently have no uniform way to measure patient outcomes, either in an institutional or provider specific manner, and many treat patients based on anecdotal experience rather than on evidence based medicine.

We addressed these issues through development of an electronic feedback system. The demonstration system targeted the problem of postoperative nausea and vomiting (PONV) in the ambulatory surgery patient population. Because performance of existing PONV risk prediction models was poor and could not be used for educational purposes, we created a new PONV risk prediction model and compared it against existing models. The new, improved risk prediction model was incorporated into an electronic system that gathered patient outcomes data related to best care practice and then fed back the information to care providers.

After implementation of the electronic feedback system, we evaluated its efficacy in improving compliance with best care practices.

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# 1 Introduction

Recently, there has been a renewed focus on improving patient care and safety. Patients, the government, and HMOs are asking that healthcare resources be used more efficiently to provide better quality care and care that is safer. As proof of improvement in care, outcomes based measures are being utilized and the concept of a "balanced performance score card" has emerged; that is, a report indicating that a hospital or physician is treating patients according to a standard of care or a best practice guideline known to have a positive effect on patient quality and efficiency of care.

As peri-operative physicians, anesthesiologists intensively monitor multiple parameters related to the well-being of their patients. Because they are responsible for almost all decisions regarding administration of peri-operative medicines, they are in the unique position of being able to evaluate and, to a great degree, affect the pre-operative, intra-operative, and post-operative course of a patient. However, individual anesthesiologists currently have no uniform way to measure patient outcomes, either in an institutional or provider specific manner, and many treat patients based on anecdotal experience rather than on evidence based medicine (Cabana, et al., 1999). We hypothesize that a peri-operative patient outcomes feedback system may help satisfy these deficiencies. Such a system would identify practices that result in best patient outcomes and provide useful feedback to care providers about their patients' outcomes and level of satisfaction. If integrated into the educational system, it would also allow modification of provider behavior towards compliance with best practices (Cohen, et al., 1996) (Lobach, et al., 1997) (Shiffman, et al., 1999).

Although a few institutions are monitoring patient outcomes (Sandrick, 1998) and have had good success with these systems (Wachter, 2001), none provides feedback to anesthesiologists in a practice specific manner or in an automated, "real-time" manner. Furthermore, although people have examined behavior modification in other fields of medicine (Stomberg, et al., 2003) (Wachter, 2001), only a handful of studies in the field of anesthesiology exist. A few indicate a positive response to feedback (Cohen, et al., 1996) (Overdyk, et al., 1999) (Rose, et al., 1997); however, these studies do not implement sustainable and cost effective ways of providing feedback.

## 2 Objectives

This study's primary objective was to develop and evaluate a sustainable electronic peri-operative patient outcomes feedback system for its effectiveness in increasing anesthesiologist compliance with best care practices.

Postoperative nausea and vomiting (PONV) control in ambulatory surgery patients has been chosen as the best care practice to implement and evaluate in this demonstration system. PONV has been chosen because it is frequent in the surgical population, has been studied extensively (McQuay, et al., 1998) (Pavlin, 2002) (Møiniche, 2002), and efficacy of multi-modal and risk directed treatment techniques has been demonstrated (McQuay, et al., 1998) (Philip, 2002). Furthermore, a preliminary study in Brigham and Women's Hospital (BWH) day surgery patients indicates that providers seldom use a multi-modal technique for PONV prophylaxis and that treatment is not specific for patient risk factors (Sarin, et al., 2006).

The system we developed had electronic educational materials that include a physician's practices, their patients' outcomes, a tool to predict patient PONV risk, and current literature recommendations. Evaluation of the system was conducted through a prospective study examining physician practicing behavior.

In summary, this demonstration system:

1. monitored provider practice of a multi-modal PONV control regimens
2. monitored the patient outcomes of PONV in the immediate postoperative recovery period and after discharge
3. developed, validated, and utilized a new PONV risk prediction model
4. fed back PONV risk model predictions, physician practices, patient outcomes, and other educational materials to patient's care providers via a secure, confidential electronic system
5. monitored change in provider behavior based on this feedback.

## 3 Background and prior work

Postoperative nausea and vomiting (PONV) and postoperative pain are the top two complications in ambulatory surgery patients. Although both can significantly delay discharge, patients are more concerned about having PONV and are willing to pay up $100 out of pocket to prevent PONV (Gan, et al., 2001). Furthermore, having PONV decreases patient satisfaction immensely and increases the risk of a costly overnight hospitalization by three to four times (Habib, et al., 2004). With the number of ambulatory surgery cases increasing each year, PONV is considered the "big little problem" and much research into this complication has been conducted over the last 30 years. Unfortunately, the incidence has remained around 25-30% despite changes in

anesthetic practices (Palazzo, et al., 1984), possibly due to the multi-factorial nature of PONV. At BWH, a preliminary study indicated that the overall PONV rate was 25%, with the rate being as high as 65% in high risk patient groups (Sarin, et al., 2006).

### 3.1 Best practices for control of postoperative nausea and vomiting

Several regimens have been shown to reduce the incidence of PONV in the ambulatory surgery population. These regimens include avoiding inhalational agents for general anesthesia (GA); providing regional anesthesia (RA) to avoid use of narcotics that are emetogenic; and/or providing prophylactic anti-emetics in an attempt to decrease the probability of PONV (Gan, et al., 2003) (Apfel, et al., 2002). Each of these regimens has been shown to be effective, but not guaranteed to eliminate PONV (Habib, et al., 2004). However, blindly applying these regimens to all ambulatory surgery patients is neither practical nor in the patient's best interests. Providing RA may be associated with increased time of getting the patient ready for surgery as well as serious complications associated with the technique. Avoiding inhalational agents for GA may raise the incidence of intra-operative awareness. Prophylactic use of anti-emetics increases the risk of having medication related side effects (Tramer, 2001) and is not 100% effective in preventing PONV (Domino, et al., 1999). All three factors increase the cost of anesthesia to the patient and the health care system as a whole (Watcha, 2000).

The current strategy for reducing PONV relies on risk stratifying the patient and then tailoring treatment based on the classification. For example, in one system, patients considered to be at extremely high risk are recommended to receive multiple anti-emetics as well as avoidance of GA and narcotics if possible, whereas patients

considered to be at low risk are recommended to receive no prophylaxis and only be treated if PONV develops (Figure 1) (Gan, et al., 2003) (Gan, 2006). The specific best practices used for the electronic feedback system of this project are shown in Table 1 and are based on the above strategy of risk stratifying patients.

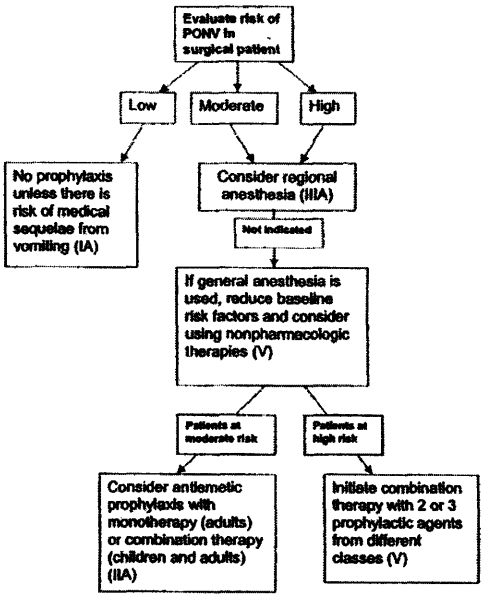



**Figure 1: Guidelines for PONV prophylaxis (Gan, et al., 2003).**

| Risk group | Recommendations |
|---|---|
| Low risk | Zero prophylactic anti-emetics; judicious use of narcotic as defined by fentanyl <=100 mcg IV given at end of case |
| Medium risk | Two prophylactic anti-emetics, but not ondansetron; judicious use of narcotic as defined by fentanyl <= 100 mcg IV given at end of case |
| High risk | Three or more prophylactic anti-emetics; avoidance of nitrous oxide; judicious use of narcotic as defined by fentanyl <= 100 mcg IV given at end of case |
| Extremely high risk | Three or more prophylactic anti-emetics; avoidance of nitrous oxide and inhalational agents; judicious use of narcotic as defined by fentanyl <= 100 mcg IV given at end of case |

**Table 1: Best practices used for electronic feedback system**

## 3.2 Risk models for PONV

Many models have been developed to classify patients into risk groups. Unfortunately, the current models cannot be effectively used for any decision support purposes and are too simple for the educational purposes of this project. Even the "best" models do not have great discriminatory ability in predicting PONV. They cannot be used for decision support beyond risk stratifying patients based on patient history, as they include only non-modifiable factors and rather than factors that the physician can control. Furthermore, they cannot be used to educate anesthesiologists about practices that can potentially reduce a patient's risk of PONV. Although reasons for simplification of the original models were valid (Apfel, et al., 1999) (Apfel, et al., 2002) when the models were first developed, it should now be possible to apply improved yet more complex models to predict PONV risk from information derived from anesthesia management systems that are routinely utilized in the care of patients.

One of the first models for risk assessment of PONV was developed by Palazzo and Evans. This model was created using logistic regression to identify variables associated with increased PONV in patients undergoing orthopedic surgery (Palazzo, et al., 1993). Since then, models have been created using data from patients undergoing a greater variety of surgical procedures. Of these, the scoring systems of Apfel (Apfel, et al., 1999) and Koivuranta (Koivuranta, et al., 1997) are best known. Both used logistic regression on data from inpatients undergoing a number of different procedures and recorded the outcome of PONV up to 24 hours after surgery. Although the models considered patient history (e.g., sex, history of PONV, history

of motion sickness), intra-operative factors (e.g., medications given, fluids administered) and surgical factors (e.g., type of surgery, duration of surgery), both Apfel and Koivuranta decided to use the top few variables in order to simplify the final models.

a. Original Apfel model (Apfel, et al., 1999):

$$\text{logit}(p) = -2.28 + 1.27 * \text{femalegender} + 0.65 * (\text{PONVHx or MSHx}) + 0.72 * (1 - \text{smokingHx}) + 0.78 * \text{postopNarcUse}$$

b. Koivuranta model (Koivuranta, et al., 1997):

$$\text{logit}(p) = -2.21 + 0.93 * \text{femalegender} + 0.82 * \text{PONVHx} + 0.59 * \text{MSHx} + 0.61 * (1 - \text{smokingHx}) + 0.75 * \text{durationof surgeryover60min}$$

c. Simplified Apfel risk score (Apfel, et al., 1999):

- Predictors are female gender, history of PONV or motion sickness, smoking history, postoperative narcotic use

| Number predictors present | Risk (%) |
|---|---|
| 0 | 10 |
| 1 | 20 |
| 2 | 40 |
| 3 | 60 |
| 4 | 80 |

d. Sinclair model (Sinclair, et al., 1999):

$$\text{logit}(p) = -5.97 - 0.14 * \text{Age} - 1.03 * \text{Sex} - 0.42 * \text{SmokingHx} + 1.14 * \text{PONVHx} + 0.46 * \text{Duration} + 2.36 * \text{GA} + 1.48 * \text{ENT} + 1.77 * \text{Ophthalm} + 1.90 * \text{Plastic} + 1.20 * \text{GynNonDC} + 1.04 * \text{OrthKnee} + 1.78 * \text{OrthShoulder} + 0.94 * \text{OrthOther}$$

**Figure 2: Models published that predict risk of PONV**

Apfel's final model (Figure 2a) only included three patient history factors and postoperative narcotic use in order to predict PONV. Koivuranta's model (Figure 2b) used the same factors except it replaced postoperative narcotic use with duration of surgery over 60 min (Koivuranta, et al., 1997). This simplification of the models was justified by the fact that final score's accuracy, as measured by the Area Under the Curve, was not significantly affected and was considered to be more clinically

applicable (Apfel, et al., 2002). Apfel developed a simplified PONV risk score based on these four predictors and the predicted risk of PONV for the simplified Apfel risk score is shown in Figure 2c (Van den Bosch, et al., 2005). Because these models were based on data from inpatients and not applicable to ambulatory surgery patients, Sinclair analyzed data from over 17,000 ambulatory surgery patients. He published a model (Figure 2d) that noted that the type of surgery, type of anesthesia, and certain patient history factors were important in predicting PONV (Sinclair, et al., 1999).

Discrimination of the Apfel and Koivuranta models have been evaluated in outside centers. In the derivation center, AUCs were 0.75 and 0.72, respectively, using independent test sets. In validation datasets at other centers, the AUCs have ranged from 0.63-0.68 for Apfel's model, and 0.66-0.70 for Koivuranta's model (Van den Bosch, et al., 2005) (Apfel, et al., 2002). Sinclair's model has not been validated in an external center but showed an AUC of 0.78 in the study's test set (Sinclair, et al., 1999).

### 3.3 Compliance with recommended PONV practices

Although PONV has been studied extensively and guidelines have been published in the literature, compliance with recommended practices by anesthesiologists is low. Pilot data from BWH indicate overall compliance with recommended practices is less than 50% and that compliance with recommended best practices in high risk patient groups is less than 10%. When surveyed, anesthesiologist provide several reasons for non-compliance. For one, they feel that they do not have the time to follow-up on all of their patients to see what their outcomes were or to provide some of the more aggressive preventative treatments. They may only follow-up on a select group of patients and this may result in a "selection bias." Furthermore, because of a lack of recorded data, many physicians feel that *their* patients do not have bad outcomes. Other physicians provide *all* patients with aggressive treatment, without regard to risks or costs associated with the treatment.

A few institutions are monitoring patient outcomes (Sandrick, 1998) and have had good success with feedback systems (Wachter, 2001) (Stomberg, et al., 2003). Most examine behavior modification in other fields of medicine and only a handful of studies in the field of anesthesiology exist. A few in this field indicate a positive response to feedback (Wachter, 2001) (Cohen, et al., 1996) (Overdyk, et al., 1999) (Pierre, et al., 2004). However, these studies do not implement sustainable and cost effective ways of providing feedback over long periods.

Cohen first examined if feedback can affect anesthesiologists' practice patterns. The group provided individualized feedback and education to anesthesiologists with regards to PONV control practices over a two year period with a control group

receiving no feedback. The individualized feedback included information on number of promoted measures with which they complied and the individual's PONV rate. The group noticed an increase in compliance with PONV control practices during the study period but, unfortunately did not examine for continued compliance after feedback was stopped (Cohen, et al., 1996). Overdyk also examined PONV control practices in anesthesiologists. His study posted monthly bar charts comparing incidence of PONV, number of patients receiving practices, and patient satisfaction between attendings. Educational literature was also posted. Feedback and literature were discussed during staff meetings each month. The study noted more appropriate prescribing of prophylactic medications and decrease in medication cost without any increase in PONV or decrease in patient satisfaction (Overdyk, et al., 1999).

These studies provided paper based feedback that is costly to create, disseminate, and requires continued effort to maintain. They did not elucidate strategies to provide feedback to anesthesiologists in a practice specific manner, in an automated, "real-time" manner that is sustainable over time.

To the best of our knowledge, no study has evaluated the impact of automated electronic feedback to anesthesiologists and effects on change in practice compliance.

# 4 Design & Implementation

## 4.1 Overview

In order to meet the goals of this project, the following informatics infrastructure was put into place:

1. A clinical database and web based front end that allows entry of clinical data found in the patient record by a care provider or a research assistant.
2. A departmental research database that transforms clinical data into data that are easier to use for research purposes.
3. Web based electronic feedback components that can be used by physicians to analyze their own practices and patient outcomes.

At BWH, patient charts are in paper format. To maximize collection of research data, most information recorded on a paper chart was transferred to this specialized research database. These data include various patient history factors, type and mode of intubation, medications given (including inhalational agents, carrier gas flow rates, and vasopressors), and complications in O.R. Recovery room data collected include pain scores recorded every 20 minutes, outcomes of nausea/vomiting recorded every 20 minutes, analgesic and anti-emetic medications given, times in each phase of recovery, and time to discharge. These data are collected on ambulatory surgery patients undergoing breast biopsies, diagnostic laparoscopy, laparoscopic procedures, or herniorraphy. Surgery start and end times are provided electronically by Partners Information Systems and combined with the above data. Descriptions of all data collected are listed in Table 2.

Clinical data are entered into the system at the point of care using a tablet PC. The data are stored in a local database; at the end of the day, this local database is synchronized with a database on a remote server. On the remote server, clinical data are transformed and copied into the research database.

From this data, PONV risk models specific to BWH and ambulatory surgery patients have been created and internally validated. These models are used as part of the electronic system to provide physicians feedback on how their decisions might affect PONV risk.

After the physician treats five new patients, an HTML e-mail containing physician practices and patient outcomes is generated and sent to the physician. These data, as well as detailed statistics, literature, and the PONV calculator created from the risk models, are also available to physicians via a secure web site. All activity is logged, including whether an e-mail has been read and how much time the physician has spent on each part of the web site.

This electronic feedback system uses web based technologies to maximize availability. The front end to the system is any HTML compliant web browser with Javascript. The back end server technology uses the Adobe ColdFusion application server programming language that dynamically generates HTML. The Apache web server is used to serve the HTML created to clients. Postgresql is used as the database server to store all data.

| Group | Data Element | Valid Responses | Comments |
|---|---|---|---|
| Demographics and Case Information | Name | | From Partners I/S |
| | MRN | | From Partners I/S |
| | DOB (age) | | From Partners I/S |
| | Sex | M, F | From Partners I/S |
| | Operation / type of surgery | | From Partners I/S |
| | Surgical service | | From Partners I/S |
| | Anesthesia attending | | From Partners I/S |
| | Anesthesia resident | | From Partners I/S |
| | | | |
| History | Home medications | | List of relevant medications |
| | History of PONV | Yes, no, unknown | |
| | History of motion sickness | Yes, no, unknown | |
| | Smoking history | Yes, no, unknown | |
| | ASA Class | I, II, III, IV | |
| | | | |
| Preoperative | Medications | | List with dosage |
| | | | |
| Intraoperative | Medications | List with dose & time of administration | Include inhalation agent; include N2O, air, O2 with flows |
| | Type of anesthetic | GA, MAC, RA, unknown | |
| | If GA, type of airway | Mask, LMA, ETT, unknown | |
| | If GA, type of induction | IV, inhalational, unknown | |
| | If GA, induction agent | Propofol, STP, sevoflurane, other, unknown | |
| | If GA, maintenance agent | IV, sevoflurane, desflurane, isoflurane, unknown | |
| | | | |
| | Local anesthetic used by surgeon | Name and amount, none, unknown | |
| | Fluids administered | Type and volume | |
| | Estimated Blood Loss (EBL) | | |
| | Duration of surgery | | From Partners I/S |
| | | | |
| Phase 1 Recovery and Phase 2 Recovery | Medications | | List with dosage |
| | Incisional pain | 0-10 | Every 20 minutes |
| | Nausea | 0-10 | Every 20 minutes |
| | Vomiting | Yes, no, unknown | Every 20 minutes |
| | Time of arrival | | |
| | | | |
| Overall Recovery | Time in Phase 1 | | Calculated |
| | Time in Phase 2 | | Calculated |
| | Overall recovery time | | Calculated |

**Table 2: Data collected from patient chart for research purposes**

## 4.2 Database Development

### 4.2.1 Overview

Postgresql is used to store all data required for the application. Postgresql is a free, multi-environment and well developed SQL relational database. Two databases were designed – the first to store clinical data and the second to store processed research data.

### 4.2.2 Clinical database

Clinical data are stored in a schema containing seven tables. These tables are normalized to comply with relational database standards and therefore do not store the same data in multiple locations nor store derived data. All tables are linked via foreign keys and all have primary keys. The schema is shown in Figure 3; tables in the database are listed in Table 3.

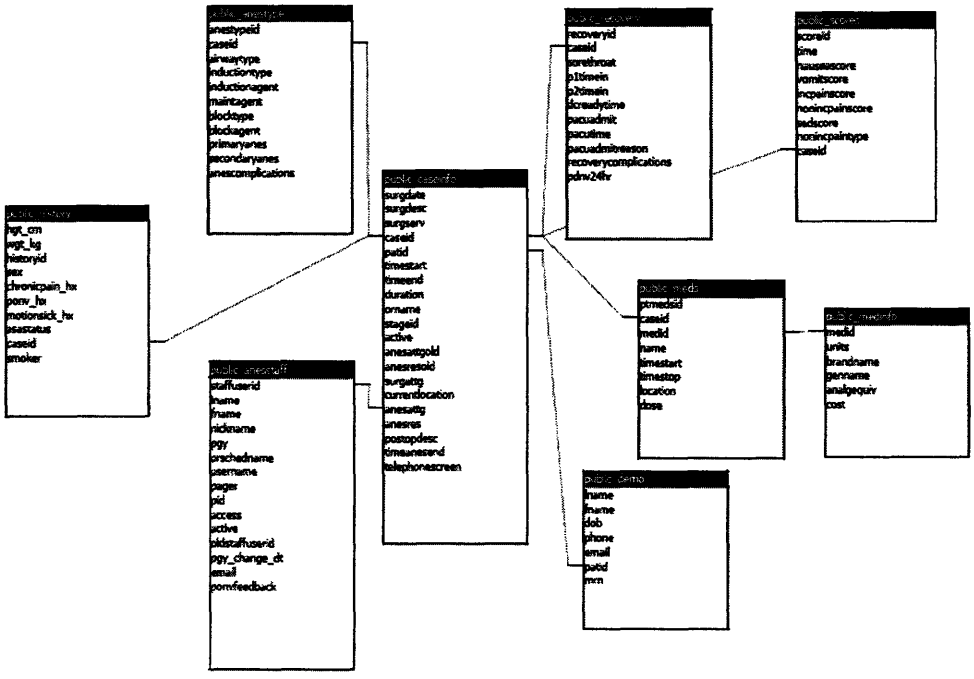



**Figure 3: Schema of clinical database and relationships between tables. See text for more detailed description.**

| Table Name | Description |
|---|---|
| caseinfo | Primary table containing case information |
| demo | Patient demographics |
| history | Patient history |
| anestype | Type of anesthesia performed for case |
| recovery | Recovery room course for case |
| meds | Medications administered to patient preoperatively, intraoperatively, or postoperatively |
| scores | Pain, nausea, and vomiting scores postoperatively |
| medinfo | Supporting table, linked to table "meds" to identify medications |
| anesstaff | Supporting table, linked to table "caseinfo" to identify anesthesia staff associated with case |

**Table 3: Tables in clinical database. See text for more detailed description.**

The two primary tables are "caseinfo" and "patinfo". Table "caseinfo" stores data related to the actual case, such as date of surgery, surgery description, starting and ending times, anesthesiology staff, etc. The "caseid" is the primary key and a unique id for each case. The "patid" foreign key links this table to table "demo" such that identifying patient information is stored separately of case information. Table "caseinfo" also contains fields to indicate whether a case will be used in the evaluation study or not; the field "active" is modified by a program to eliminate ambulatory cases that are not part of the evaluation study and field "stageid" is used to indicate whether all relevant case information has been captured.

All other tables are linked to table "caseinfo" via the unique foreign key "caseid". Table "anestype" contains information on type of anesthesia performed, such as general anesthesia versus monitored anesthesia care, type of airway used, etc. Table "history" stores data on patient history factors, such as whether the subject has had PONV in past, history of motion sickness, height, weight, etc. Table "meds" stores all medications the patient receives peri-operatively. The table provides for a record of when a medication is

started and ended, as well as the dose given. Table "recovery" contains fields for data collected in the recovery room, such as when patients arrive to the recovery room, when they are ready for discharge, any complications, etc. Table "scores" contains fields recording nausea/vomiting scores, incisional and non-incisional pain scores, sedation scores, as well as their times. Descriptions of each table are listed in Table 3 and information on the fields they contain are in Table 2.

#### 4.2.3 Research database

The second schema contains data in a format that is more suitable for research purposes; this is done for performance reasons so that statistics can be compiled on-the-fly. Once a day, a ColdFusion program examines the clinical database for updated information and then processes, transforms, and stores the new data in the research database. Two tables are used to store these data. Table "dsudatastaffid" stores associations between cases ("caseid") and the provider ("staffuserid"), as well the number case for that provider ("staffcasenum"). These data were used to determine how many cases a staff member had done by a given date and to determine when a staff member had completed an additional five cases such that an e-mail could be sent. Table "dsudata" stores processed information, such as the computed field "avgpainscorephase1," which is the time weighted average of a patient's pain scores in phase 1 of recovery. The table "log" kept track of various events, including how much time a user spent reading the e-mail, when and where the user logged in from, and how much time was spent on a particular section of the website. Data was captured and entered into this table as described in

section 5.5. The diagram of the schema for the research database is shown in Figure 4.

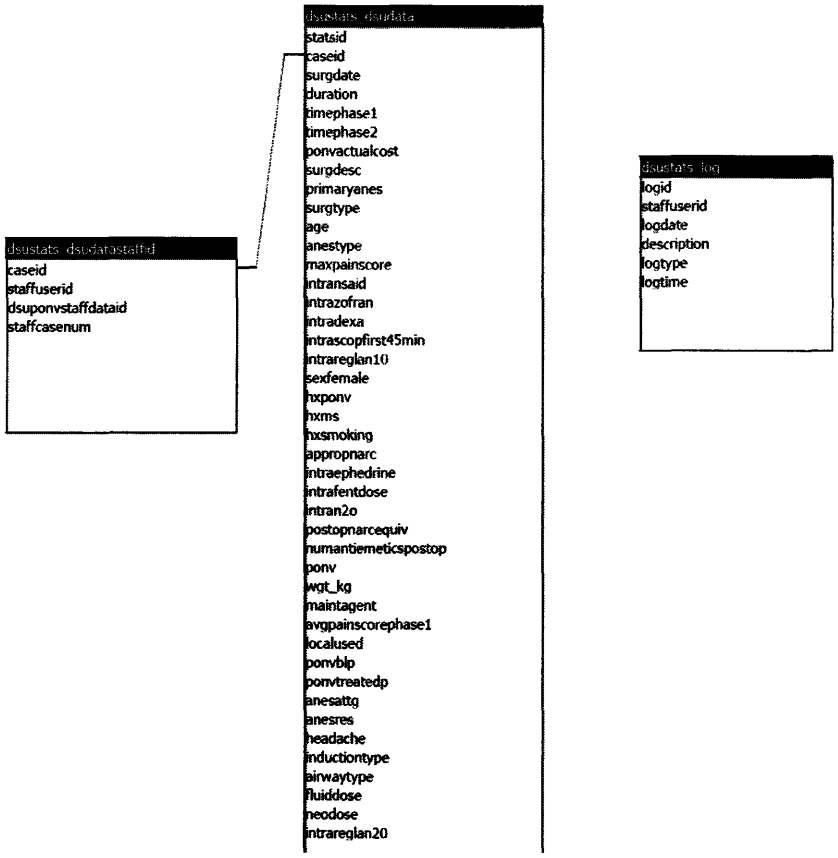



**Figure 4: Schema of research database and relationships between tables. See text for more detailed description.**

## 4.3 Data capture and upload

As indicated before, infrastructure to allow electronic capture of data needed for this project had to be created. This goal was accomplished by creating a system that could be used by the research assistant (or, in the future, by clinicians and nurses) to capture data at point of care in order to maximize the number of data points captured without errors. The system presents the research assistant with the operating room schedule for the day, filtered to show only ambulatory surgery patients who are to be included in the study (Figure 5). Patient MRN, description of surgery, surgeon, and time of surgery are listed for each case; patient names are only displayed when the mouse hovers over the MRN because of patient privacy issues. Cases are grouped by where in the recovery process the patient is in: (1) expected for arrival in the recovery room, (2) in stage 1 of recovery, (3) in stage 2 of recovery, or (4) ready for discharge. This type of grouping allows the user to quickly locate the patient for whom data need to be entered.

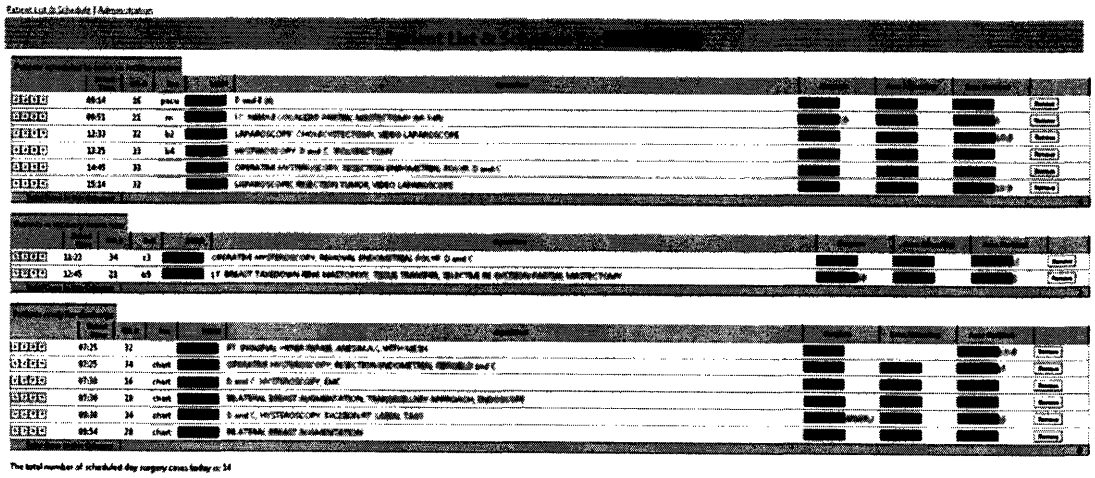


**Figure 5: Research assistant screen showing all cases for which data needs to be collected. Patients were organized by stage of recovery process.**

After selecting the patient by clicking on their MRN or description of surgery, the user is directly taken to the data that needs to be filled out. For example, if the patient is in stage 1 of recovery, the user is automatically taken to the section allowing data to be entered on pain scores and medications given during this stage of recovery. The user can modify data for other sections, such as the recovery room course, by clicking on the appropriate tab that is linked to the section (Figure 6).

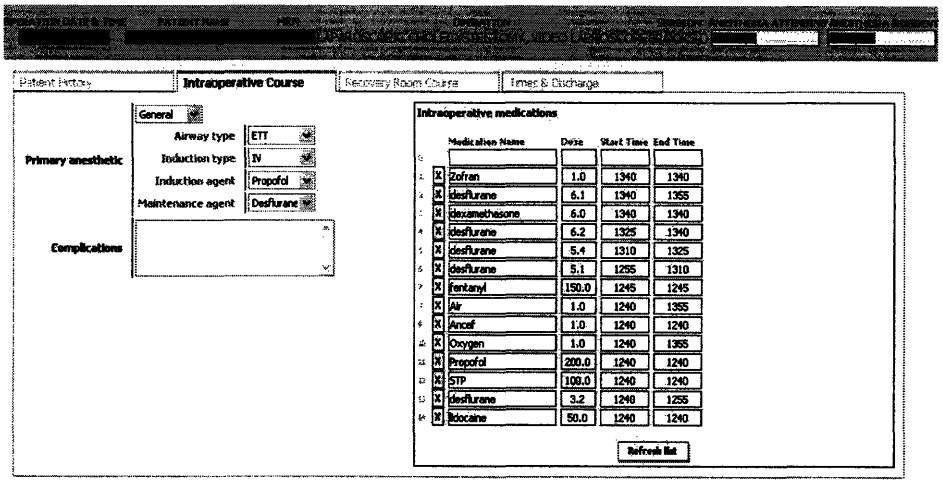



**Figure 6: Web based system created to enter patient chart information into the database. The form to enter information on intra-operative course is shown.**

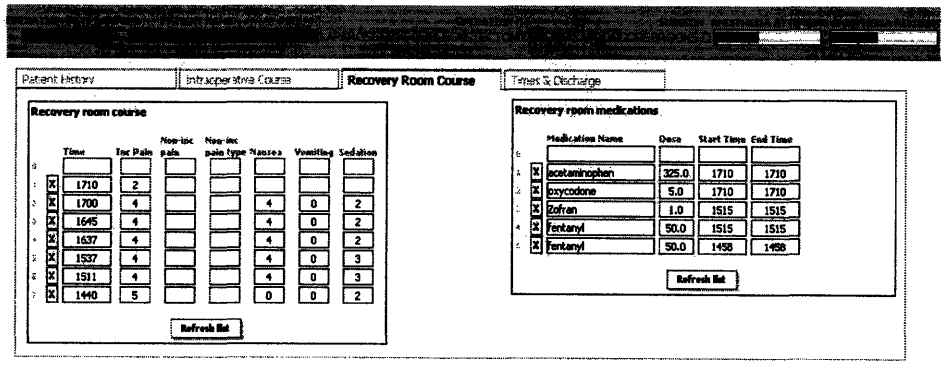



**Figure 7: Form to enter information on recovery room course.**

To ease entry of data, the user is not required to click on multiple confirmation buttons or submit multiple forms. An Asynchronous Javascript And XML (AJAX)

programming methodology is used such that when the user enters a value in an input box, the value is automatically saved when the input box loses focus. The input box border changes from red to green to indicate a successful save of the data in the database. If the server cannot be reached, or data cannot be saved for any reason, an alert box informs the user of the error. An example of an AJAX based form is shown in Figure 7.

As indicated before, the data are uploaded on a daily basis from the tablet PC to the central server. Once uploaded, daily processing of the clinical data occurs and data are transformed for storage in the research database.

## 4.4 Creation and validation of risk models for PONV

### 4.4.1 Overview

Several published risk models were considered for use in the feedback system, but were not used because of their poor performance on preliminary data, as well as the fact that they did not contain certain predictors. For example, no currently published model includes the effects of prophylactic anti-emetics or of different types of general anesthesia on PONV. Therefore, various machine learning techniques were examined for model creation. It was decided that a logistic regression model should be used to create an improved predication model using the BWH data. This type of model has been explored in anesthesiologists' literature and many physicians are familiar with it. Other models, such as Bayesian networks and neural networks, are more difficult to use in a clinical context and may include "black box" functions to come up with a risk prediction score.

### 4.4.2 Statistical software

SAS version 9.1 (Windows platform) was used for logistic regression modeling and analysis.

### 4.4.3 Data source and pre-processing

Data used for development of models were extracted from the research database described above. The binary outcome measure was postoperative nausea/vomiting. Based on extensive literature search and consultation with a local domain expert (Philip, 2006), 17 of the strongest predictors were selected for consideration in the model. Clinical data collected is listed in Table 2. From this clinical data, the following variables were used for model development (Table 4): age (closest decade), female sex, smoking history, history of PONV, history of motion sickness, type of surgery, duration of surgery (in hours), type of anesthesia provided, intraoperative dose of fentanyl (in mcg), use of ondansestron for prophylaxis, use of dexamethasone for prophylaxis, use of scopolamine patch for prophylaxis, use of metoclopramide for prophylaxis (2 different doses used), use of ephedrine IM for prophylaxis, postoperative dose of narcotics in analgesic equivalents, and maximum postoperative pain score.

| Variable | Comments |
|---|---|
| Age | Rounded to closest decade |
| Female sex | |
| Smoking history | Patient current smoker |
| History of PONV | History of PONV with previous surgeries |
| History of motion sickness | |
| Type of surgery | Breast surgery (including breast biopsy and lumpectomy)<br>Breast plastics surgery<br>Laparoscopic cholecystectomy<br>Hernia repairs (inguinal and other hernia)<br>Pelviscopy<br>Hysteroscopy/D&C |
| Duration of surgery | Expected duration of surgery, in hours |
| Type of anesthesia provided | IV induction with inhalational agent and $N_2O$ maintenance<br>IV induction with inhalational agent maintenance (no $N_2O$)<br>Inhalational induction with inhalational agent and $N_2O$ maintenance<br>Inhalational induction with inhalational agent maintenance (no $N_2O$)<br>IV induction and IV maintenance |
| Intraoperative dose of fentanyl | Fentanyl dose used intraoperatively, in mcg |
| Use of ondansetron for prophylaxis | Ondansetron 4 mg IV given prophylactically |
| Use of dexamethasone for prophylaxis | Dexamethasone >6 mg IV given prophylactically |
| Use of scopolamine patch for prophylaxis | |
| Use of metoclopramide = 10 mg IV for prophylaxis | |
| Use of metoclopramide = 20 mg IV for prophylaxis | |
| Use of ephedrine IM for prophylaxis | |
| Postoperative dose of narcotics | In analgesic equivalents |
| Maximum postoperative pain score | Pain score reported by patient on scale of 0-10 |

**Table 4: Variables used for model building.**

The original dataset was examined for invalid or missing values and all patients with any invalid data were eliminated from the model building process. Data were imported into SAS from a CSV file. Categorical variables were reformulated as dummy variables where needed. For example, the categorical variable of surgery type was transformed into dummy variables with the baseline risk being for "hysteroscopy/D&C." Continuous variables were not converted. For example, "duration of surgery" (rounded to nearest 60 minutes) and "age" (rounded to nearest decade) were left as continuous variables. Patient history factors and the outcome variable of PONV were considered binary variables. These transformations resulted in a total of 26 continuous and categorical variables for use in modeling.

### 4.4.4 Model building and analysis

Prior to model building, the data were randomly divided into a ⅔ training set and a ⅓ test set. These two sets were compared to confirm that data had indeed been split randomly and the frequency of the variables' values was not significantly different. The PROC LOGISTIC function in SAS was used to build a logistic regression model using a stepwise algorithm on the training set with the 26 variables. Variables were entered into the model if they met a significance level of $p<0.50$ and were allowed to stay in the model if they met a significance level of $p<0.20$ (Shtatland, et al.). Model building stopped when no additional variables met these criteria.

The experimental model (EM) created was compared against the original Apfel model (OAM), a refitted Apfel model (RAM), the simplified Apfel risk score (SARS), and a refitted Sinclair model (RSM). In order to refit the Apfel and Sinclair models, new beta coefficients were calculated using the variables from the original model using the PROC LOGISTIC function. Each of the models was then run against the test data. To estimate the discriminating power of the models, Receiver Operating Characteristic (ROC) curves were created and the Area Under the Curves (AUC) were calculated using SAS (Figure 13). The ROC curve allows visualization of the relationship of sensitivity and specificity at different probability thresholds. The AUC determines how well patients who had PONV could be distinguished from patients who did not have PONV using the model's risk prediction calculation. An AUC of 1.0 represents perfect discrimination whereas an AUC of 0.5 represents no discrimination (Hanley, et al., 1982).

Pair-wise AUC comparisons were performed to evaluate differences in discrimination between models as described previously (DeLong, et al., 1988) (Hanley, et al., 1983). Here, a non-parametric comparison of the ROC is done.

Calibration curves were also developed to examine the accuracy and goodness of fit of each model. For each model, the predicted number of observations was plotted against the expected number of observations for each of ten risk percentiles created from the test set. For the simplified Apfel model, it was only possible to categorize patients into four bins. A slope of 1 with an intercept of 0 indicates perfect calibration whereas a larger slope indicates an over-estimation of occurrence of PONV by the model. Calibration was further evaluated with Hosmer-Lemeshow goodness of fit $\chi^2$ estimates using deciles (Lemeshow, et al., 1982).

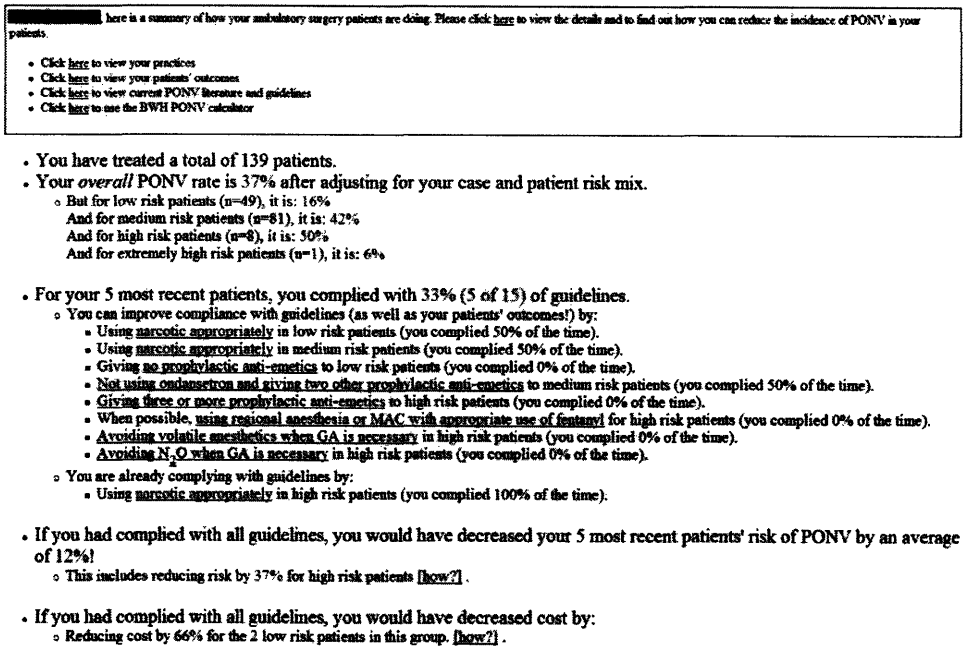
## 4.5 Electronic feedback to physicians

### 4.5.1 Overview

Two components were created to provide electronic feedback to physicians. First, an electronic summary report displayed up-to-date statistics on a physician's practices and patient outcomes as related to PONV control. These individualized summary reports (Figure 8) were automatically e-mailed to the physician every five patients he or she treated.

The next component created was a web site onto which physicians could login to view details of their practices and patient outcomes (Figure 9-Figure 10). Here, they could calculate the PONV risk of hypothetical patient using a

"PONV calculator" (Figure 11). They could also view various "what-if" scenarios to see how change in treatment would affect patient outcome and/or cost. Current guidelines, as well as links to current literature, were posted on this web site.



[redacted] here is a summary of how your ambulatory surgery patients are doing. Please click here to view the details and to find out how you can reduce the incidence of PONV in your patients.

- Click here to view your practices
- Click here to view your patients' outcomes
- Click here to view current PONV literature and guidelines
- Click here to use the BWH PONV calculator

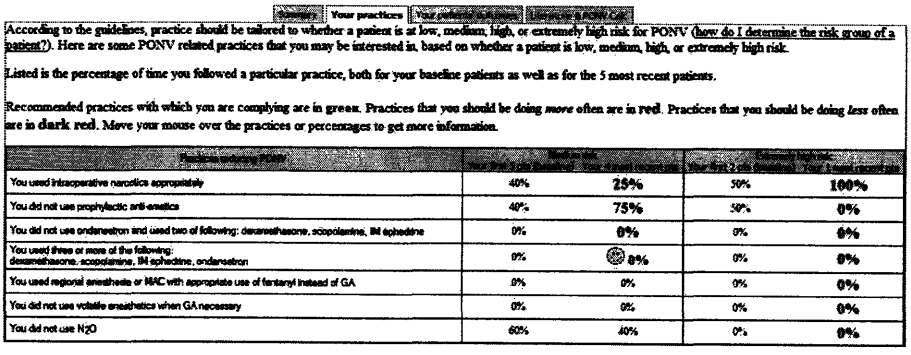
- You have treated a total of 139 patients.
- Your *overall* PONV rate is 37% after adjusting for your case and patient risk mix.
  - But for low risk patients (n=49), it is: 16%
    And for medium risk patients (n=81), it is: 42%
    And for high risk patients (n=8), it is: 50%
    And for extremely high risk patients (n=1), it is: 6%

- For your 5 most recent patients, you complied with 33% (5 of 15) of guidelines.
  - You can improve compliance with guidelines (as well as your patients' outcomes!) by:
    - Using narcotic appropriately in low risk patients (you complied 50% of the time).
    - Using narcotic appropriately in medium risk patients (you complied 50% of the time).
    - Giving no prophylactic anti-emetics to low risk patients (you complied 0% of the time).
    - Not using ondansetron and giving two other prophylactic anti-emetics to medium risk patients (you complied 50% of the time).
    - Giving three or more prophylactic anti-emetics to high risk patients (you complied 0% of the time).
    - When possible, using regional anesthesia or MAC with appropriate use of fentanyl for high risk patients (you complied 0% of the time).
    - Avoiding volatile anesthetics when GA is necessary in high risk patients (you complied 0% of the time).
    - Avoiding $N_2O$ when GA is necessary in high risk patients (you complied 0% of the time).
  - You are already complying with guidelines by:
    - Using narcotic appropriately in high risk patients (you complied 100% of the time).

- If you had complied with all guidelines, you would have decreased your 5 most recent patients' risk of PONV by an average of 12%!
  - This includes reducing risk by 37% for high risk patients [how?].

- If you had complied with all guidelines, you would have decreased cost by:
  - Reducing cost by 66% for the 2 low risk patients in this group. [how?].

**Figure 8: Example of summary report for PONV control that was e-mailed to physician every time he/she completed five new cases.**



Summary | Your practices | Your patients' outcomes | Literature & PONV Calc

According to the guidelines, practice should be tailored to whether a patient is at low, medium, high, or extremely high risk for PONV (how do I determine the risk group of a patient?). Here are some PONV related practices that you may be interested in, based on whether a patient is low, medium, high, or extremely high risk.

Listed is the percentage of time you followed a particular practice, both for your baseline patients as well as for the 5 most recent patients.

Recommended practices with which you are complying are in green. Practices that you should be doing *more* often are in red. Practices that you should be doing *less* often are in dark red. Move your mouse over the practices or percentages to get more information.

| Practices reducing PONV | Baseline | | Recent 5 | |
|---|---|---|---|---|
| You used intraoperative narcotics appropriately | 40% | 25% | 50% | 100% |
| You did not use prophylactic anti-emetics | 40% | 75% | 50% | 0% |
| You did not use ondansetron and used two of following: dexamethasone, scopolamine, IM ephedrine | 0% | 0% | 0% | 0% |
| You used three or more of the following: dexamethasone, scopolamine, IM ephedrine, ondansetron | 0% | 0% | 0% | 0% |
| You used regional anesthesia or MAC with appropriate use of fentanyl instead of GA | 0% | 0% | 0% | 0% |
| You did not use volatile anesthetics when GA necessary | 0% | 0% | 0% | 0% |
| You did not use N2O | 60% | 40% | 0% | 0% |

**Figure 9: Physician's practices. Moving mouse over different cells provided explanations (not shown).**

Surgery | Your practices | Your patients' outcomes | Literature & PONV Calc

| Patient # | Type of surgery | Baseline risk group | Did patient have PONV? | Could you have reduced risk using recommended practice? | Ratio of cost of your treatment to that of recommended practice |
|---|---|---|---|---|---|
| 1 [details] | breastlix | Medium | No | | 0.7 |
| 2 [details] | Unknown | Medium | No | | 0.8 |
| 3 [details] | inghernia | Medium | No | | 0.6 |
| 4 [details] | otherhernia | Medium | No | | 0.4 |
| 5 [details] | breastplastics | XHigh | Yes | Yes, by 53% | 1.1 |
| 6 [details] | breastplastics | Medium | No | | 1.4 |
| 7 [details] | inghernia | Low | No | | 0.9 |
| 8 [details] | vagtape | Low | No | | 1.2 |
| 9 [details] | vagtape | Medium | No | | 0.7 |
| 10 [details] | cholecystectomy | XHigh | Yes | Yes, by 55% | 0.1 |
| 11 [details] | breastlix | Low | No | | 0.8 |

**Figure 10: Outcomes for patients treated by one physician. The physician could view details of the case as well.**

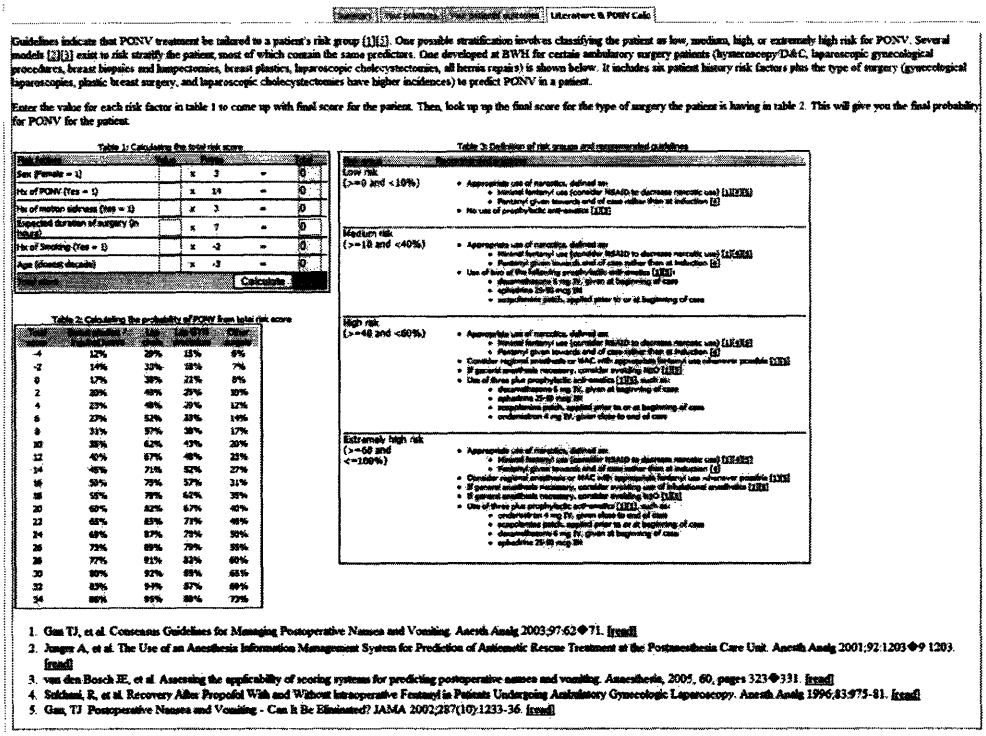



**Figure 11: Online PONV risk calculator and current guidelines. The calculator automatically calculated risk based on patient risk factors as per the BWH PONV risk model. Current guidelines were also listed.**

### 4.5.2 Programming software

Both the summary report and web site were coded in Adobe ColdFusion 7 MX markup language, a server side programming language which dynamically generates HTML. Apache web server was used to serve the web page to a client side web browser. A combination of HTML, Javascript, and AJAX technologies were used, as described below, to log actions on the web site as well as verify that e-mails were read.

### 4.5.3 E-mail report

These reports contained information on the physician's PONV rate and percentile, compliance with proposed recommendations, and anesthetic costs (Figure 8).

Upon opening and closing of the e-mail message, a message was sent to the server log and the amount of time spent reading the message was calculated. This was accomplished by including a hidden link to an image on the web server. Upon opening of the HTML formatted e-mail, the mail client fetched the image from the server via a URL that included a unique token identifying the user. The time this image was accessed and the ID of the user accessing it were logged into the database. Furthermore, clicking on the links in the e-mail message was also recorded and allowed differentiation of whether the user logged in via e-mail link or directly onto the web site.

### 4.5.4 Web site

The web site allowed physicians to view details of their practices and patient outcomes. The web site was divided into multiple tabs or sections. The first section showed the physician his or her practices in a compact table (Figure 9). Moving the mouse over the column headers provided a tooltip containing information about how to determine the risk group of the patient. Moving the mouse over the row headers provided tooltips on each of the different recommended practices. Tooltips on whether the practice should be practiced more or less often appeared when the user placed the mouse over the cell contents.

The next section of the web site showed the physicians their patients' outcomes (Figure 10). It allowed them to view whether they followed the recommended guidelines, if a patient had PONV, and, if he or she did, whether the physician might have reduced the risk by following the recommended guidelines. Furthermore, physicians could view details on patient history factors to learn how to place patients in the appropriate risk group. They could also view various "what-if" scenarios to see how changes in treatment would affect patient outcome and/or cost.

The last section contained a PONV risk calculator and educational material (Figure 11). The anesthesiologist could use the PONV risk calculator to calculate any patient's risk for PONV by entering some patient history factors and her intended anesthetic plan. The calculator used Javascript to calculate a risk score and automatically convert this into a risk probability based on the

type of surgery to be performed. The related guidelines were automatically highlighted when the user calculates a PONV risk. Furthermore, the PONV calculator was displayed such that the anesthesiologist could print the page out and calculate the score manually; in fact, copy of this page and the risk calculator was distributed to all subjects receiving feedback in the study. The section also contained literature on PONV and the recommended guidelines. PDF copies of several review articles were available through links on the web page.

All activity on the web site was logged and date/time stamped. Javascript was used to send a message to the server each time the user logged in or out or when the user moved from one section to another. This allows tracking of the number of times the user used the web site, whether they logged in from the e-mail or accessed the web site directly, and calculation of the amount of time the user spent reading each section. Similarly, each use of the PONV risk calculator was logged, as well as each access to a PDF article.

#### 4.5.5 Evaluation

Evaluation of the electronic feedback components was conducted using a before-after study design with a concurrent control group. An eight-month evaluation phase was subdivided into three stages. The first stage involved collecting data on PONV control practices and outcomes for four months, without any feedback to any providers, on patients undergoing breast biopsies, diagnostic laparoscopy, laparoscopic procedures, or herniorraphy, as described before. These data provided a baseline of provider practices as well

as patient outcomes. Prior to the second stage, each subject was randomized to an intervention or control group. For four months, individualized feedback on (a) practitioner's practices, and (b) outcomes for all patients was provided to the experimental group via the electronic feedback system described before. The control group received no feedback. Once assigned to a group, the subject remained in that group for the duration of the study.

Attending level BWH anesthesiologists treating ambulatory surgery patients were identified from the Dept. of Anesthesiology staff lists for potential inclusion in the study. No remuneration was provided. There was no age restriction on subject enrollment and there was no inclusion or exclusion of specific groups.

A research assistant collected all data on physician practices and patient outcomes in real time from the medical record, i.e. anesthesia pre-operative and intra-operative records, as well as post-operative nursing records. If information was not complete, the assistant obtained the information from either the physician or the nurse.

Only subjects who treated more than 40 patients during each stage of the study were included in the analyses of provider behavior, as per a power analysis done prior to study implementation (assuming a 25% absolute change in behavior profile, alpha = 0.05, beta = 0.10).

Outcomes measured were (a) the number of times a physician accessed the web site, (b) the amount of time spent on each section of the site, (c) the number of articles downloaded from the web site, and (d) the number of times the online PONV calculator was used.

Physician practices were also examined according to recommended guidelines. The number and type of prophylactic anti-emetics given to low, medium, high, and extremely high risk patients were examined. According to currently accepted guidelines, low risk patients should have been given zero prophylactic anti-emetics; medium risk patients should be given two prophylactic anti-emetics, but not ondansetron; high risk and extremely high risk patients should be given three or more prophylactic anti-emetics. The average fentanyl dose used was also examined: less than 100 mcg fentanyl should have been given to high and extremely high risk patients. Also, $N_2O$ should have been avoided in high and extremely high risk patients and and inhalational agents avoided in extremely high risk patients.

The percentage of each subject's patients receiving appropriate therapy, as determined by the patient's PONV risk stratification noted above was calculated. This was averaged by the number of subjects in the group. An unpaired t-test was done on the group percentage to look for any significant change in average behavior pre- and post-intervention. The rate of use of these different profiles, stratified by PONV risk status, was compared using a $\chi^2$ test in order to determine if there was a behavior change between the time periods.

Subjects were also asked to complete a survey regarding the level of feedback they were receiving about their patients, whether they wanted more feedback, if they felt they would change their behavior based on this feedback, and tested their knowledge about current PONV risk models (Figure 12). All answers were on a 5 point Likert scale with five equal to "all of the time" and zero equal to "never." They were also asked to estimate their rates of PONV. Subjects completed this survey twice, once at the beginning of the study and once at the end of the study.

Follow up interviews were conducted at the end of study with all participants to query their views on the electronic feedback provided, the web site, and reasons for changes or no changes in their practices.

The following questions refer to feedback about outcomes.

| | All of the time | Most of the time | Fair amount of the time | Rarely | Never | Don't know (DK) |
|---|---|---|---|---|---|---|
| 1. How often do you receive feedback about your ambulatory surgery patients? | 5 | 4 | 3 | 2 | 1 | DK |
| 2. How often do you receive feedback from... | | | | | | |
| a. Patients | 5 | 4 | 3 | 2 | 1 | DK |
| b. Nurses | 5 | 4 | 3 | 2 | 1 | DK |
| c. Other anesthesiologists | 5 | 4 | 3 | 2 | 1 | DK |
| d. Computer systems (BICS, LMR, other) | 5 | 4 | 3 | 2 | 1 | DK |
| 3. How much do you change your practice after receiving this feedback? | 5 | 4 | 3 | 2 | 1 | DK |
| 4. How often would you *like to* receive feedback from... | | | | | | |
| e. Patients | 5 | 4 | 3 | 2 | 1 | DK |
| f. Nurses | 5 | 4 | 3 | 2 | 1 | DK |
| g. Other anesthesiologists | 5 | 4 | 3 | 2 | 1 | DK |
| h. Computer systems (BICS, LMR, other) | 5 | 4 | 3 | 2 | 1 | DK |
| 5. How much would you change your practice if you received *more* feedback about how patients are doing in the recovery room? | 5 | 4 | 3 | 2 | 1 | DK |

| | Very significant | A lot of change | Some change | Very little change | Not at all | Don't know (DK) |
|---|---|---|---|---|---|---|
| 1. How much change have you noticed in anesthesiologists' practices over the last six months (with regards to ambulatory surgery practices)? | 5 | 4 | 3 | 2 | 1 | DK |

The following questions refer to the recovery process.

| | | |
|---|---|---|
| 1. What do you think is the PONV rate (%) for *your* ambulatory surgery patients for... | hysteroscopy/D&C | |
| | laparoscopic gynecological procedures | |
| | breast biopsies and lumpectomies | |
| | laparoscopic cholecystectomies | |
| | hernia repairs | |
| 2. What do you think is the PONV rate (%) for all anesthesiologists' ambulatory surgery patients for... | hysteroscopy/D&C | |
| | laparoscopic gynecological procedures | |
| | breast biopsies and lumpectomies | |
| | laparoscopic cholecystectomies | |
| | hernia repairs | |

**Figure 12: Anesthesiologist survey.**

# 5 Results

## 5.1 PONV risk models

Data from 2498 patients were used in the model building and testing process. The distribution of patient, anesthetic, and surgery characteristics was not significantly different between the training and test sets and is shown in Table 5. The experimental model ended up containing 10 input variables, including four patient history and outcome factors, two surgical factors, and four anesthetic factors. Patient history and outcome factors included: age, history of motion sickness, history of PONV, and maximum pain score postoperatively. Surgical factors included duration of surgery and type of surgery. Types of surgery found to have significant effect on PONV were laparoscopic cholecystectomy and pelviscopy. Anesthetic factors found to have an effect on PONV included: intraoperative fentanyl dose, intraoperative dexamethasone use, intraoperative ondansetron use, and type of anesthetic performed (e.g., IV versus inhalation induction and $N_2O$ use versus no $N_2O$ use). PONV was the binary outcome variable in the model.

The final experimental model, its beta coefficients, and odds ratios are shown in Table 6. The strongest patient history and surgical factors increasing risk are laparoscopic cholecystectomy, history of PONV, pelviscopy, history of motion sickness, and duration of surgery. Anesthetic factors increasing risk included the type of anesthetic utilized, with inhalation induction increasing risk the most. Age and use of prophylactic ondansetron or dexamethasone reduced PONV risk.

The new beta coefficients calculated for the refitted Apfel model (RAM) and for the refitted Sinclair model (RSM) are shown in Table 7 and Table 8.

| Variable | Training set (n=1688) | Test set (n=844) | p value |
|---|---|---|---|
| Duration (hrs) | 2.8±1.0 | 2.8±1.0 | 0.84 |
| Surgery Type (%) | | | 0.45 |
| Hysteroscopy | 26.2 | 26.4 | |
| Breast biopsy/lumpectomy | 25.2 | 24.5 | |
| Pelviscopy/myomectomy | 18.7 | 19.4 | |
| Inguinal and other hernia | 14.8 | 14.8 | |
| Breast plastics | 5.2 | 6.0 | |
| Laparoscopic cholecystectomy | 5.3 | 3.4 | |
| Tubal ligation | 3.1 | 3.9 | |
| Other GYN surgery | 1.5 | 1.4 | |
| | | | |
| Age (decade) | 4.8±1.4 | 4.9±1.3 | 0.36 |
| Sex (% female) | 88.3 | 87.8 | 0.70 |
| Weight (kg) | 69.4±14.3 | 69.3±14.8 | 0.90 |
| History of PONV (%) | 24.6 | 24.5 | 0.95 |
| History of motion sickness (%) | 31.8 | 33.3 | 0.45 |
| Smoker (%) | 10.4 | 11.0 | 0.65 |
| | | | |
| Type of anesthesia (%) | | | 0.06 |
| IV Induction with $N_2O$ | 22.0 | 24.4 | |
| IV Induction without $N_2O$ | 35.1 | 32.0 | |
| Inhalation Induction with $N_2O$ | 12.1 | 11.4 | |
| Inhalation Induction without $N_2O$ | 4.8 | 7.3 | |
| MAC | 24.5 | 23.1 | |
| | | | |
| Intraoperative ondansetron (%) | 47.3 | 49.1 | 0.40 |
| Intraoperative dexamethasone (%) | 40.2 | 39.5 | 0.71 |
| Intraoperative scopolamine (%) | 17.1 | 17.8 | 0.66 |
| Intraoperative metoclopramide =10 mg (%) | 55.1 | 54.3 | 0.69 |
| Intraoperative metoclopramide >10 mg (%) | 2.9 | 3.7 | 0.30 |
| Intraoperative IM ephedrine (%) | 4.6 | 4.2 | 0.59 |
| | | | |
| Intraoperative fentanyl dose (mcg) | 91.3±83.6 | 89.1±80.3 | 0.54 |
| | | | |
| Maximum pain score in phase 1 | 3.3±2.4 | 3.2±2.5 | 0.19 |
| Postoperative narcotics (analgesic equiv) | 0.30±0.38 | 0.32±0.44 | 0.24 |
| Crude PONV rate (%) | 22.5 | 22.0 | 0.81 |
| Postoperative rescue anti-emetics (number) | 0.22±0.61 | 0.21±0.58 | 0.96 |

**Table 5: Distribution of patient, anesthetic, and surgery characteristics between training and test data sets. None of the variables had statistically significant differences between these sets ($p > 0.05$). p-value indicates result of Chi-square test for categorical variables or of t-test for continuous variables.**

| | Beta coefficient | p-value | Odds Ratio Estimate | 95% CI |
|---|---|---|---|---|
| Intercept | -2.0863 | <0.001 | | |
| Age | -0.1804 | 0.0005 | 0.835 | 0.754-0.924 |
| History of PONV | 0.9749 | <0.0001 | 2.651 | 2.007-3.500 |
| History of motion sickness | 0.4259 | 0.002 | 1.531 | 1.174-1.996 |
| Maximum postoperative pain score | 0.1085 | 0.0002 | 1.115 | 1.053-1.180 |
| | | | | |
| Duration of surgery | 0.1803 | 0.01 | 1.198 | 1.045-1.373 |
| Surgery Type (vs "Other") | | | | |
| Laparoscopic cholecystectomy | 1.1613 | <0.0001 | 3.194 | 1.919-5.317 |
| Pelviscopy | 0.4665 | 0.004 | 1.594 | 1.161-2.189 |
| | | | | |
| Intraoperative fentanyl dose | 0.002 | 0.02 | 1.002 | 1.000-1.004 |
| Intraoperative dexamethasone use | -0.2220 | 0.10 | 0.801 | 0.611-1.049 |
| Intraoperative ondansetron use | -0.1972 | 0.18 | 0.821 | 0.615-1.096 |
| Anesthesia type (vs "Other") | | <0.0001 | | |
| IV induction with nitrous oxide use | 0.2924 | 0.09 | 1.340 | 0.951-1.887 |
| Inhalation induction with nitrous oxide use | 0.8725 | <0.0001 | 2.393 | 1.547-3.700 |
| Inhalation induction without nitrous oxide use | 0.9497 | 0.001 | 2.585 | 1.450-4.607 |
| MAC | -0.8049 | 0.002 | 0.447 | 0.270-0.739 |

**Table 6: Final experimental model (EM) created using logistic regression. 95% CI = 95% Confidence Interval.**

| | Original beta coefficient | New beta coefficient | p-value | Odds Ratio Estimate | 95% CI |
|---|---|---|---|---|---|
| Intercept | -2.28 | -2.78 | <0.0001 | | |
| Female sex | 1.27 | 0.67 | 0.03 | 1.950 | 1.059-3.590 |
| History of PONV *or* motion sickness | 0.65 | 0.93 | <0.0001 | 2.531 | 1.801-3.558 |
| Non-smoker | 0.72 | -0.014 | 0.96 | 1.015 | 0.596-1.726 |
| Postoperative narcotic use | 0.78 | 0.73 | <0.0001 | 2.072 | 1.438-2.988 |

**Table 7: Beta coefficients and odds ratios for refitted Apfel model. 95% CI = 95% Confidence Interval.**

| | Original beta coefficient | New beta coefficient | p-value | Odds Ratio Estimate | 95% CI |
|---|---|---|---|---|---|
| Intercept | -5.97 | -2.32 | <0.0001 | | |
| Male sex | -1.03 | -0.15 | 0.67 | 0.864 | 0.438-1.701 |
| History of PONV | 1.14 | 0.91 | <0.0001 | 2.480 | 1.703-3.610 |
| Smoker | -0.42 | -0.002 | 0.99 | 0.997 | 0.578-1.722 |
| Age | -0.14 | -0.22 | 0.002 | 0.801 | 0.697-0.922 |
| Duration of surgery | 0.46 | 0.25 | 0.007 | 1.280 | 1.071-1.531 |
| Primary anesthesia = GA | 2.36 | 1.28 | <0.0001 | 3.583 | 1.941-6.613 |
| Breast plastics | 1.90 | -0.085 | 0.82 | 0.918 | 0.449-1.877 |
| Gyn surgery, but not D&C | 1.20 | 0.20 | 0.32 | 1.220 | 0.822-1.811 |

**Table 8: Beta coefficients and odds ratios for refitted Sinclair model. 95% CI = 95% Confidence Interval.**

Results of the experimental model's (EM) performance as compared to the original Apfel model (OAM), refitted Apfel model (RAM), the simplified Apfel risk score (SARS), and the refitted Sinclair model (RSM) on the validation data set are shown in Table 9. AUC for the EM was 0.760, for the OAM was 0.676, for the RAM was 0.659, for the SARS was 0.667, and for the RSM was 0.718. ROC curves for each model are shown in Figure 13.

Pair-wise discrimination comparison of models is shown in Table 10. Statistically significant differences ($p<0.05$) in AUC were noted between the EM and all other models, RAM & RSM, and SARS & RSM.

Calibration, as indicated by goodness of fit by the Hosmer-Lemeshow $\chi^2$ test, is shown in Table 9. All models, except the OAM, appeared to have good calibration for BWH ambulatory surgery data as indicated by a p value of greater than 0.05.

| Model | AUC for test set | 95% CI for AUC | HL $\chi^2$ | HL (p) |
|---|---|---|---|---|
| Experimental Model (EM) | 0.760 | 0.723-0.797 | 8.8 | 0.36 |
| Original Apfel Model (OAM) | 0.676 | 0.633-0.718 | 43.6 | <0.0001 |
| Refitted Apfel Model (RAM) | 0.659 | 0.617-0.701 | 5.1 | 0.53 |
| Simplified Apfel Risk Score (SARS) | 0.667 | 0.626-0.707 | 3.0 | 0.22 |
| Refitted Sinclair Model (RSM) | 0.718 | 0.678-0.759 | 7.8 | 0.46 |

**Table 9: Summary of discrimination and calibration performance for each model. AUC = Area Under Receiver Operating Characteristic Curve. 95% CI = 95% Confidence Interval. HL $\chi^2$ = Hosmer-Lemeshow Chi-Square. HL (p) = Hosmer-Lemeshow probability > Chi-Square value.**

| Model | Experimental Model (EM) | | Original Apfel Model (OAM) | | Refitted Apfel Model (RAM) | | Refitted Sinclair Model (RSM) | |
|---|---|---|---|---|---|---|---|---|
| | diff | p | diff | p | diff | p | diff | p |
| Experimental Model (EM) | | | | | | | | |
| Original Apfel Model (OAM) | 0.084 | 0.0001 | | | | | | |
| Refitted Apfel Model (RAM) | 0.101 | <0.0001 | 0.017 | 0.32 | | | | |
| Simplified Apfel Risk Score (SARS) | 0.093 | <0.0001 | 0.009 | 0.16 | -0.008 | 0.55 | | |
| Refitted Sinclair Model (RSM) | 0.041 | 0.002 | -0.043 | 0.08 | -0.059 | 0.01 | -0.052 | 0.03 |

**Table 10: Pair-wise discrimination comparison of models. diff = AUC difference. p = p value of difference.**

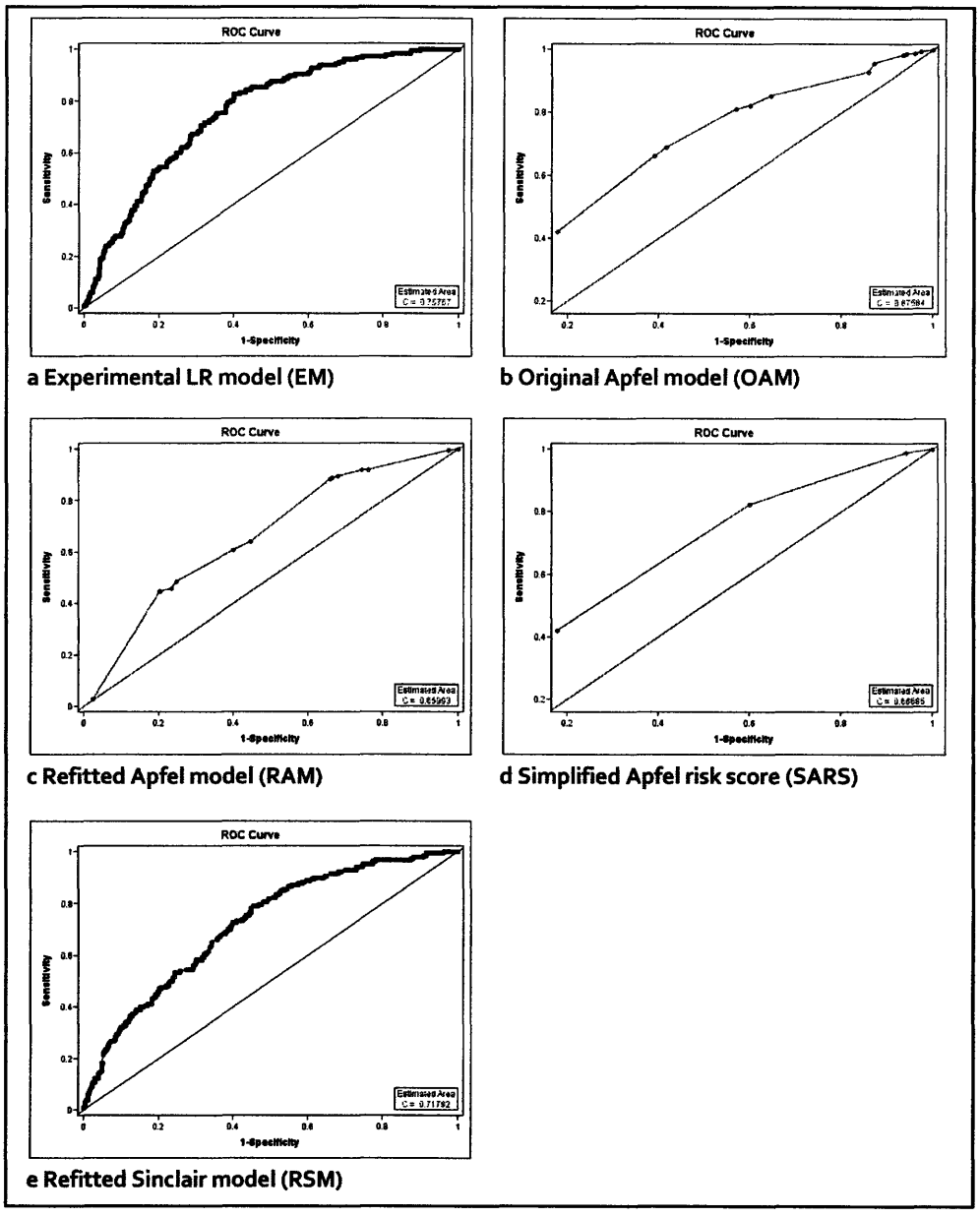



**Figure 13: ROC curves for various models evaluated on the test dataset.**

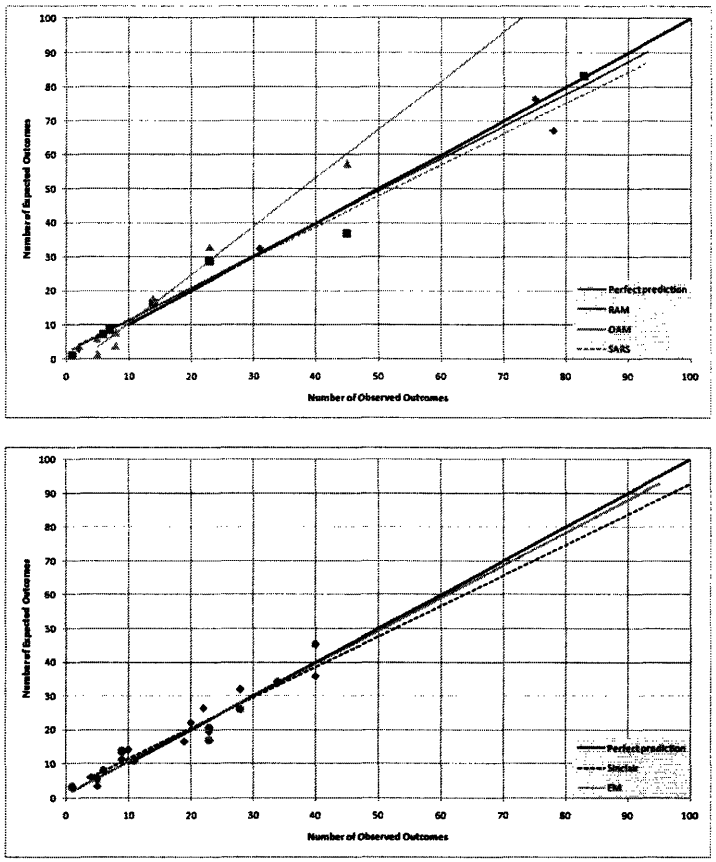



**Figure 14: Calibration curves for models evaluated on the test dataset.**

## 5.2 Study of electronic feedback to physicians

Nine attending level anesthesiologists were enrolled in the study. Of these, five received feedback and four were in the control group that did not receive any feedback. Data on 474 ambulatory surgery patients the nine physicians treated were also collected over the course of eight months.

All nine subjects completed surveys at beginning of study. Seven completed surveys at the end of the study; two of the original nine subjects could not be contacted as they were no longer working at the hospital. Pre-intervention, 78% stated that they rarely or never received feedback with an average Likert score of 2.00±0.71. All indicated that they would be willing to change their practice based on feedback. They

wanted this feedback mainly from patients, nurses, and computer systems although they would also accept it from other anesthesiologists. Most anesthesiologists underestimated their patients' rate of PONV. The absolute difference was 21±16% from their actual rate.

Of the five people who received feedback e-mails, four looked at the web site at least once and responded to more than 25% of the e-mails. They always logged in using the link in the e-mail, although they were allowed to log in directly to the web site. Physicians treating more patients logged in more often.

Subjects spent a total of 4.7±2.7 min on website. They spent an average of 0.6±0.7 min viewing their practices and 0.7±0.9 min viewing their patients' outcomes. Subjects spent the most time on viewing literature guidelines and examining the PONV risk calculator; they spent 1.8±2.2 min viewing this section of the web site (Table 11).

| Section | Time spent (min) |
|---|---|
| Physician practices | 0.6±0.7 |
| Patient outcomes | 0.7±0.9 |
| Literature guidelines, PONV risk calculator | 1.8±2.2 |
| Total time | 4.7±2.7 |

**Table 11: Time spent by physicians on web site.**

Post-intervention, 57% stated that they rarely or never received feedback with an increase in the Likert score of 2.43±0.53. Most still wanted more feedback. However, there was no statistically significant difference between pre- and post-intervention responses.

No significant difference in practice change was observed between groups. Absolute differences pre- and post-intervention for each recommended best practice were calculated for the control group and intervention group. For each practice, no significant difference was noted between groups (Table 12).

| Practice | Pre/post change in control group (%) | Pre/post change in intervention group (%) |
|---|---|---|
| No prophylactic anti-emetics (AE) in low risk patients | 12 | 9 |
| 2+ AE, no ondansetron in medium risk patients | 16 | -31 |
| 3+ AE in high risk patients | 4 | 2 |
| 3+ AE in extremely high risk patients | -1 | 0 |
| Fentanyl <= 100 mcg IV in high risk patients | 12 | 10 |
| Fentanyl <= 100 mcg IV in extremely high risk patients | 13 | 10 |
| No $N_2O$ in high risk patients | -19 | -3 |
| No $N_2O$ in extremely high risk patients | -17 | -5 |
| No inhalational agent in extremely high risk patients | 0 | 0 |

**Table 12: Absolute change in number of practices complied with pre- and post- intervention.**

Follow-up interviews querying for subjects' impressions of the electronic feedback, the web site, and their reasons for not changing practice indicated several issues. Many of the subjects thought viewing the web site took too much time and they were too busy to use it on a regular basis. They felt they did not know where to look on the web site to access information they wanted or the web site did not provide them with the information they wanted. Some felt that residents often made decisions when they were not around and, therefore, felt they were not always in control of practice. One subject disagreed with the guidelines.

# 6 Discussion

## 6.1 PONV risk models

Preliminary analysis indicated that published models would not work for purposes of this project. Their performance on data from BWH ambulatory surgery patients was poor. Also, the models could not be used for the education of physicians because they did not contain certain predictors. Therefore, data collected at BWH was used to create a new PONV risk prediction model. This experimental model was tested against several popular models and showed improved performance. A logistic regression model was used even though other methods of machine learning may have resulted in better predictive models. Physicians are familiar with logistic regression models and the concept of "odds ratios" to determine how much of an effect a variable has on the outcome. Furthermore, other models result in "black box" formulas such that they often cannot be used for teaching purposes.

### 6.1.1 Experimental model developed

In our experimental model, history of PONV, history of motion sickness, age, duration of surgery, type of surgery, intraoperative fentanyl dose, intraoperative dexamethasone use, intraoperative ondansetron use, type of anesthetic performed, and maximum pain score postoperatively were determined to be independent predictors of PONV. Inclusion of these variables is consistent with published studies as well as the other models.

One of the strongest predictors of PONV was the patient's history of prior PONV (odds ratio of 2.65). Prior history of motion sickness resulted in a 1.5 increased risk of PONV. An increase in one decade of age resulted in slightly decreased risk of PONV whereas longer duration of surgery increased the risk of PONV.

Female gender did not appear in our model, even though female gender has been well demonstrated as an important predictor of PONV (Cohen, et al., 1994). This may be due to the composition of the data set such that 88% of patients were female. With such a large percentage of female patients, differentiation of risk between male and female patients may be difficult and the risk may be incorporated into the baseline risk.

Several types of surgery found to have significant effect on PONV. Of these, laparoscopic cholecystectomy increased the risk of PONV the greatest, with an odds ratio of 3.2. Pelviscopy also increased risk and this is consistent with literature (Gan, 2006).

Anesthetic factors found to have an effect on PONV included: intraoperative fentanyl dose, type of general anesthetic performed (i.e., IV versus inhalation induction and $N_2O$ use versus no $N_2O$ use), intraoperative dexamethasone use, and intraoperative ondansetron use. Previous models have not differentiated between intraoperative and postoperative doses of narcotics and most have focused on long term narcotics such as morphine. Literature is controversial on whether intraoperative narcotics actually increase risk whereas the most current literature indicates that postoperative narcotic dose does correlate with

increased risk of PONV. Here, although there is a statistically significant increase in PONV risk with intraoperative fentanyl use, an odds ratio of 1.002 indicates that risk is not increased greatly and this may not be clinically significant. Furthermore, our model did not find that postoperative narcotics are associated with increased risk.

Instead, a patient's postoperative pain was shown to be correlated with the PONV risk. Here, the higher the maximum pain score (scale of 0-10, with ten being the worst pain experienced) that a patient reported, the more at risk he/she was for PONV (odds ratio of 1.1). Although some experts have hypothesized that postoperative pain is associated with PONV (Chia, et al., 2002) (Gan, 2006), it has been hard to separate out whether postoperative pain or postoperative narcotic use is the cause of increased PONV. This is because when the patient complains of pain postoperatively, he/she is treated with narcotics.

It is reassuring that the type of anesthetic performed appeared to be associated with PONV risk in our model. Recent studies indicate that exposure to inhalation agent increases PONV risk (Apfel, et al., 2002) and many experts advocate avoidance of inhalation agents for high risk groups (Gan, et al., 2003) (Gan, 2006). In our model, we were able to differentiate between different types of general anesthetic techniques that some have postulated may increase risk but have not proven. For example, our model indicates that an inhalation induction increases risk almost two-fold over an IV induction with propofol. Exposure to nitrous oxide also seems to increase risk, but more for

patients who undergo IV induction rather than inhalation induction. This may be due to the fact that an inhalation induction already increases the risk of PONV. None of the previously published models break down risk by anesthetic technique, something that can be controlled by the anesthesiologist.

As expected, prophylactic intraoperative use of dexamethasone and ondansetron independently reduced risk of PONV. This risk reduction was similar for each medication and is consistent with the 20-25% risk reduction quoted in the literature (Apfel, et al., 2004) (Thomas, et al., 2001). Ours is the first model to incorporate these variables and to demonstrate to physicians the risk reduction resulting from their use after controlling for confounding variables. Prophylactic use of scopolamine did not appear in the model. This may be due to the fact that the outcome of PONV was only recorded for up to time of discharge whereas scopolamine is thought to have more of an effect on post-discharge nausea and vomiting. Use of either metoclopramide 10 mg or metoclopramide IV 20 mg IV was not shown to affect PONV; this result is consistent with literature that numbers needed to treat to prevent one case of PONV with metoclopramide are very high (Henzi, et al., 1999). Intramuscular ephedrine use did not appear in the model either, perhaps due to the fact that only 4.4% of patients received this treatment and its efficacy could not be determined with such low numbers of data points.

History of smoking did not appear in our model, even though it is well proven to be associated with decreased risk of PONV. Like in the case of female gender, this may be due to the patient population studied. Here, only 10.6%

of patients were smokers and, therefore, the risk associated with being a non-smoker may be incorporated into the baseline risk rather than an independent predictor.

### 6.1.2 Discrimination and calibration

The model developed in this project showed statistically significant improved discrimination over the original Apfel model, the refitted Apfel score, the simplified Apfel risk score, and the refitted Sinclair model. The Apfel models, though often advocated for use because of their simplicity, are clearly not applicable to the BWH ambulatory surgery patient population and may not be applicable to other institutions' patients also. It is known that risk prediction models often do not perform as well at institutions other than the one where the model was developed. Performance results from this study of the Apfel models are consistent with results at other validation centers (Apfel, et al., 1999). Another reason for the Apfel models' poor performance may be that the original models were developed using data from inpatients rather than ambulatory surgery patients.

The original Apfel model, the refitted Apfel score, and the simplified Apfel risk score all performed similarly and there was no statistically significant difference between their performance. The original Apfel model had worse calibration than the other two, as was to be expected. The simplified Apfel risk score had good calibration for data at BWH because it classified patients into only four quartiles.

The refitted Sinclair model had both good discrimination and calibration on the BWH data. This can be explained by the fact that it was very similar to the experimental model developed in the types of variables used. However, the experimental model contained more detailed variables and contained predictors that appeared in an aggregated form in the Sinclair model. For example, the Sinclair model differentiates between patients who had general anesthesia and those who did not. Our model also considers the contribution of different techniques used to induce general anesthesia to the overall risk. This may explain why our model provided better discrimination. It also allows our model to be used for teaching purposes by demonstrating the relative risks associated with certain anesthetic techniques.

## 6.2 Electronic feedback to physicians

Prior to intervention, most attending physicians enrolled in the study indicated that they rarely or never received feedback. The rest indicated that they followed up on their patients in the recovery room before the patients were discharged. All indicated that they would like to receive more feedback about their patients' outcomes. They even indicated that they would be willing to change their practice based on this feedback.

Of interest is that anesthesiologists underestimated their patients' rate of PONV by an absolute difference of 21±16%. This is consistent with some physicians' beliefs that their patients did not have bad outcomes.

Given these data, it was expected that the anesthesiologists would access the electronic feedback to learn more about their outcomes, educate themselves on current literature, and possibly change their practices. Unfortunately, electronic feedback to attending anesthesiologists did not result in change in practices. This could be due to several factors.

First, it seems as physicians did not adequately use the site to look up their statistics. Of the five people who received feedback e-mails, four looked at the web site at least once. However, overall usage was quite low. Surprisingly, physicians always logged in using the link in the e-mail and never logged in directly by accessing the web site URL. This could be due to the fact that the physicians were not compelled enough to review material on the web site consistently but the e-mail served as a reminder to view the statistics.

Once on the web site, subjects spent a total of 4.7±2.7 min looking at material on the site. They spent almost 40% of this time viewing the section on literature guidelines. This could be due to their trying to familiarize themselves with the guidelines. Physicians spent an average of 0.6±0.7 min viewing their practices and 0.7±0.9 min viewing their patients' outcomes.

Another reason for a lack of change in practices could be a lack of time on the physician's part. Because all charting is paper based at BWH, it would take extra time for the physician to access the web site and review material. For example, in order to use the online PONV risk calculator, they would have to find a computer, log into the computer, log into the web site, and then enter patient history factors to calculate the risk score. This process could take upwards of two minutes.

Physicians treating more patients logged in more often. These physicians were specialized ambulatory surgery anesthesiologists and the above fact may indicate these physician's greater interest in their patients' well-being.

One additional reason for lack of use may have been that the site did not provide them with the information they wanted. However, extensive feedback and testing was done during creation of the web site to ensure the users would have easy access to the information they preferred to see.

Lack of compliance by attending anesthesiologists could also be due to absence of a requirement for them to use the system. Other studies have employed some verification and compliance measure, such as reporting of the physician to the department chairperson for non-compliance or publishing individual physicians' compliances in public.

Follow-up interviews with the subjects substantiated some of the above reasons for lack of change in practices by the subjects. Many of the subjects thought viewing the web site took too much time and they were too busy to use it on a regular basis. Some indicated that they did not know where to look on the web site to access information they wanted to see.

One other reason several anesthesiologists provided was that they felt that residents often made decisions when they were not around and, therefore, felt they were not always in control of practice. They felt that they should provide residents with the freedom to decide on a different anesthetic plan or that the residents would give patients medications without prior discussion with the attending. Some of the physicians who did not regularly practice ambulatory anesthesia felt that PONV was

not an important patient outcome that warranted a change in their practice. One subject disagreed with the guidelines. He indicated that he did not believe that several of these measures would change the outcome.

The responses of these follow-up interviews provide good insight into the difficulties of implementing an electronic feedback system. Although most physicians want feedback on patient outcomes and educational literature, they are less open to a system that provides protocol based care or appears to dictate patient care. Combined with the extra work required to use the system since it is not at the "point-of-care," an electronic system is difficult to implement without a formal requirement or compliance measure.

# 7 Conclusions

This study's primary objective was to develop and evaluate a sustainable electronic peri-operative patient outcomes feedback system for its effectiveness in increasing anesthesiologist compliance with best care practices. We selected PONV in ambulatory surgery patients as the best care practice to implement and evaluate for the demonstration system.

In the process of developing such a system, we instituted an informatics infrastructure at the BWH Department of Anesthesiology as well as developed and evaluated a new, improved PONV risk prediction model. This new risk prediction model is the first to incorporate certain anesthetic practices as predictors. It was developed specifically for the ambulatory surgery patient population and clearly performs better than existing models.

The electronic system we developed monitored provider practice of multi-modal PONV control regimens as well as patient outcomes, and it provided anesthesiologists with information on their practices and their patients' outcomes. This system was evaluated through a prospective study examining physician practicing behavior.

Although no significant change in provider practice behavior was noted, examination of reasons for this lack of change provided useful insight on how to improve compliance with best practices. In addition to providing physicians with data and guidelines, compliance should be actively enforced and physicians need to be constantly reminded about their compliance. Any future system should be integrated into the physician's workflow and at the "point-of-care" to minimize additional burden on the provider.

Future work will focus on validating the new BWH PONV risk prediction model at outside institutions and integrating the electronic feedback system into clinicians' workflow to improve compliance. Other outcomes, such as compliance with perioperative antibiotic guidelines and beta-blocker therapy, will be examined for incorporation in risk prediction models as well as for use in future iterations of the electronic feedback system.

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# 8 Bibliography


1. **Apfel CC [et al.]** A Factorial Trial of Six Interventions for the Prevention of Postoperative Nausea and Vomiting [Journal] // New England Journal of Medicine. - 2004. - 24 : Vol. 350. - pp. 2441-2451.
2. **Apfel CC [et al.]** A simplified risk score for predicting postoperative nausea and vomiting [Journal] // Anesthesiology. - 1999. - Vol. 91. - pp. 693-700.
3. **Apfel CC [et al.]** Comparison of predictive models for postoperative nausea and vomiting [Journal] // Br J Anaes. - 2002. - 2 : Vol. 88. - pp. 234-240.
4. **Apfel CC [et al.]** Volatile anaesthetics may be the main cause of early but not delayed postoperative vomiting: a randomized controlled trial of actorial design [Journal] // British Journal of Anaesthesia. - 2002. - 5 : Vol. 88. - pp. 659-668.
5. **Cabana MD [et al.]** Why Don't Physicians Follow Clinical Practice Guidelines?: A framework for improvement [Journal] // JAMA. - 1999. - 15 : Vol. 282. - pp. 1458-1465.
6. **Chia YY [et al.]** Does postoperative pain induce emesis? [Journal] // Clinical Journal of Pain. - 2002. - 5 : Vol. 18. - pp. 317-323.
7. **Cohen MM [et al.]** The postoperative interview: assessing risk factors for nausea and vomiting [Journal] // Anesth Analg. - 1994. - 78. - pp. 7-16.
8. **Cohen MM, Rose DK and Yee DA** Changing Anesthesiologists' Practice Patterns: Can it be done? [Journal] // Anesthesiology. - 1996. - 2 : Vol. 85. - pp. 260-269.
9. **DeLong ER, DeLong DM and Clarke-Pearson DL** Comparing the areas under two or more correlated receiver operating characteristic curves: A nonparametric approach [Journal] // Biometrics. - 1988. - Vol. 44. - pp. 837-845.
10. **Domino KB [et al.]** Comparative efficacy and safety of ondansetron, droperidol, and metoclopramide for preventing postoperative nausea and vomiting: a meta-analysis [Journal] // Anesth Analg. - 1999. - Vol. 88. - pp. 1370-1379.
11. **Gan T [et al.]** Consensus guidelines for managing postoperative nausea and vomiting [Journal] // Anesth Analg. - 2003. - Vol. 97. - pp. 62-71.
12. **Gan T [et al.]** How much are patients willing to pay to avoid postoperative nausea and vomiting? [Journal] // Anesth Analg. - 2001. - Vol. 92. - pp. 393-400.
13. **Gan TJ** Risk Factors for Postoperative Nausea and Vomiting [Journal] // Anesth Analg. - 2006. - Vol. 102. - pp. 1884-1898.
14. **Habib AS and Tong J** Evidence-based management of postoperative nausea and vomiting: a review [Journal] // Can J Anesth. - 2004. - 4 : Vol. 51. - pp. 326-341.
15. **Hanley J.A. and McNeil B.J.** A method of comparing the areas under receiver operating characteristic curves derived from the same cases [Journal] // Radiology. - 1983. - Vol. 148. - pp. 839-843.

16. **Hanley JA and McNeil BJ** The meaning and use of the area under a receiver operating characteristic (ROC) curve [Journal] // Radiology. - 1982. - 1 : Vol. 143. - pp. 29-36.
17. **Henzi I, Walder B and Tramer MR** Metoclopramide in the prevention of postoperative nausea and vomiting: a quantitative systematic review of randomized, placebo-controlled studies [Journal] // British Journal of Anaesthesia. - 1999. - 5 : Vol. 83. - pp. 761-771.
18. **Koivuranta M [et al.]** A survey of postoperative nausea and vomiting [Journal] // Anaesthesia. - 1997. - Vol. 52. - pp. 443-449.
19. **Lemeshow S and Hosmer DW** A review of goodness of fit statistics for use in the development of logistic regression models [Journal] // American Journal of Epidemiology. - 1982. - 1 : Vol. 115. - pp. 92-106.
20. **Lobach DF and Hammond W** Computerized Decision Support Based on a Clinical Practice Guideline Improves Compliance with Care Standards [Journal] // Am J Med. - 1997. - 1 : Vol. 102. - pp. 89-98.
21. **McQuay H and Moore R** Postoperative analgesia and vomiting, with special reference to day-case surgery: a systematic review [Report]. - 1998.
22. **Møiniche S** A Qualitative and Quantitative Systematic Review of Preemptive Analgesia for Postoperative Pain Relief [Journal] // Anesthesiology. - 2002. - Vol. 96. - pp. 725-41.
23. **Overdyk FJ [et al.]** Individualized outcome feedback produces voluntary antiemetic prescribing practice changes [Journal] // J Clin Anes. - 1999. - 1 : Vol. 11. - pp. 17-23.
24. **Palazzo M and Evans R** Logistic regression analysis of fixed patient factors for postoperative sickness: a model for risk assessment [Journal] // Br J Anaesz. - 1993. - Vol. 70. - pp. 135-140.
25. **Palazzo M and Strunin L** Anesthesia and emesis. I. etiology [Journal] // Can Anaesth Soc J. - 1984. - Vol. 31. - pp. 178-187.
26. **Pavlin D** Pain as a Factor Complicating Recovery and Discharge After Ambulatory Surgery [Journal] // Anesth Analg. - 2002. - Vol. 95. - pp. 627-34.
27. **Philip B** [Interview]. - 2006.
28. **Philip B** The Economic Impact of Opioids on Postoperative Pain Management [Journal] // J Clinical Anes. - 2002. - Vol. 14. - pp. 345-364.
29. **Pierre S [et al.]** A risk score-dependent antiemetic approach effectively reduces postoperative nausea and vomiting - a continuous quality improvement initiative [Journal] // Canadian Journal of Anesthesiology. - 2004. - 4 : Vol. 51. - pp. 320-325.
30. **Rose DK, Cohen MM and Yee DA** Changing the Practice of Pain Management [Journal] // Anesth Analg. - 1997. - 4 : Vol. 84. - pp. 764-772.

31. **Sandrick K** Waiting on Clinicians to Catch Up [Journal] // Health Management Technology. - 1998. - 2 : Vol. 19. - pp. 32-34.
32. **Sarin P and Philip B** Postoperative Pain Control in Day Surgery Patients: Can we be doing better? [Conference] // ASA. - Atlanta : [s.n.], 2006.
33. **Shiffman RN [et al.]** Computer-based Guideline Implementation Systems: a systematic review of functionality and effectiveness [Journal] // J Am Med Inform Assoc. - 1999. - Vol. 6. - pp. 104-114.
34. **Shtatland ES, Kleinman K and Cain EM** Stepwise Methods in Using SAS PROC LOGISTIC [Conference] // SUGI. - [s.l.] : SAS. - 258-28.
35. **Sinclair D, Chung F and Mezei G** Can postoperative nausea and vomiting be predicted? [Journal] // Anesthiology. - 1999. - Vol. 1. - pp. 109-118.
36. **Stomberg MW [et al.]** Postoperative Pain Management on Surgical Wards: Do quality assurance strategies result in long-term effects on staff member attitudes and clinical outcomes? [Journal] // Pain Management Nursing. - 2003. - 1 : Vol. 4. - pp. 11-22.
37. **Thomas R and Jones N** Prospective randomized, double-blind comparative study of dexamethasone, ondansetron, and ondansetron plus dexamethasone as prophylactic antiemetic therapy in patients undergoing day-case gynaecological surgery [Journal] // British Journal of Anaesthesia. - 2001. - 4 : Vol. 87. - pp. 588-592.
38. **Tramer MR** A rational approach to the control of postoperative nausea and vomiting: evidence from systematic reviews. Part I. Efficacy and harm of antiemetic interventions, and methodological issues [Journal] // Acta Anaesthesiol Scand . - 2001. - Vol. 45. - pp. 4-13.
39. **Van den Bosch JE [et al.]** Asessing the applicability of scoring systems for predicting postoperative nausea and vomiting [Journal] // Anaesthesia. - 2005. - Vol. 60. - pp. 323-331.
40. **Wachter RM** Making Health Care Safer: A critical analysis of patient safety practices [Report]. - [s.l.] : Agency for Healthcare Research and Quality, 2001. - Publication 01-E058.
41. **Watcha M** The cost-effective management of postoperative nausea and vomiting [Journal] // Anesthesiology. - 2000. - 4 : Vol. 92. - p. 931.