Section Editor: **Franklin Dexter**

# Implications of Patient Age and ASA Physical Status for Operating Room Management Decisions

Markus M. Luedi, MD, MBA,* Peter Kauf, PhD,†‡ Lisa Mulks, MSc,§ Katharina Wieferich, BASc,§ Ralf Schiffer, BHA,‖ and Dietrich Doll, MD, PhD¶

**BACKGROUND:** In elderly, high-risk patients, operating room (OR) turnaround times are especially difficult to estimate, and the managerial implications of patient age and ASA physical status for OR management decisions remain unclear. We hypothesized that evaluating patient age and ASA physical status in the right model would improve accuracy of turnaround time estimates and, thus, would have decisive implications for OR management.

**METHODS:** By using various multivariate techniques, we modeled turnaround times of 13,632 OR procedures with respect to multiple variables including surgical list, age, ASA physical status, duration of the procedure, and duration of the preceding procedure. We first assessed correlations and general descriptive features of the data. Then, we constructed decision tables for OR management consisting of 50th and 95th percentiles of age/ASA-dependent estimates of turnaround times. In addition, we applied linear and generalized linear multivariate models to predict turnaround times. The forecasting power of the models was assessed in view of single cases but also in view of critical managerial key figures (50th and 95th percentile turnaround times). The models were calibrated on 80% of the data, and their predictive value was tested on the remaining 20%. We considered our data in a Monte Carlo simulation to deduce actual reductions of overutilized OR time when applying the results as presented in this work.

**RESULTS:** Using the best models, we achieved an increase in predictive accuracy of 7.7% (all lists), ranging from 2.5% (general surgery) to 21.0% (trauma surgery) relative to age/ASA-independent medians of turnaround times. All models decreased the forecasting error, signifying a relevant increase in planning accuracy. We constructed a management decision table to estimate age/ASA-dependent turnaround time for OR scheduling at our hospital.

**CONCLUSIONS:** The decision tables allow OR managers at our hospital to schedule procedures more accurately. Evaluation of patient age and ASA physical status as variables can help to better predict turnaround times, which can facilitate scheduling, for example, to schedule overlapping induction rooms, to reduce overutilized OR time by optimizing allocation of patients to several ORs, and to improve logistics of prioritizing transportation of advanced age/high ASA physical status patients to the OR. (Anesth Analg 2016;122:1169–77)

The ultimate goal of efficient operating room (OR) management must be the reduction of overutilized OR time.[1] Strum et al.[2] have defined any surgical cases that end (or begin) outside budgeted OR time as overutilization of a service; thus, overutilized OR time is the difference between total hours of cases (including turnover times) performed and the allocated OR time. A number of factors, including accurate OR data collection, analysis of causes of delays, improving strategies for minimizing common delays, improving personal accountability, streamlining procedures, and fostering interdisciplinary teamwork, have been shown to improve OR efficiency.[3] Optimizing staffing and case scheduling are central managerial strategies for net cost reductions in the perioperative setting.[4] It has been shown that anesthesiologists usually can make reasonable predictions regarding "anesthesia release time" (patient-on-table until release for surgical preparation),[5] but it is difficult to accurately predict induction times in individual patients, which is a central component of turnover time and turnaround time.

There have been different definitions of turnover time. The glossary developed by the Association of Anesthesia Clinical Directors[6] discusses different possibilities: either the "time from prior patient out of room to succeeding patient in room time for sequentially scheduled cases" or "any time when they [Surgeons] are unable to operate…thus…the time between the end of surgery on one case and the beginning of surgery on the next case" (Fig.1). Thus, depending on the definition, anesthesia team activities with the patient in the room are not necessarily part of turnover time. Commonly, the term turnover time is used for the interval a patient is out of room until the following patient enters. To avoid confusion, we have used the term turnaround time, as used before, e.g., by Sandberg et al.[7]

From the *Department of Anesthesiology, Bern University Hospital Inselspital, University of Bern, Bern, Switzerland; †PrognosiX AG, Richterswil, Switzerland; ‡Institute of Applied Simulation, Zurich University of Applied Sciences ZHAW, Waedenswil, Switzerland; §Department of Surgery, Saint Mary's Hospital Vechta, Teaching Hospital of Hannover University, Vechta, Germany; ‖Department of Finances and Controlling, Mary's Hospital Vechta, Teaching Hospital of Hannover University, Vechta, Germany; and ¶Department of Procto-Surgery, St. Marienhospital Vechta, Academic Teaching Hospital of the Medizinische Hochschule Hannover, Vechta, Germany.

Accepted for publication December 23, 2015.

Funding: None.

The authors declare no conflicts of interest.

A small fraction of the data (2622 turnover times) for this study was presented as letter in 2014 in the *European Journal of Anaesthesiology* by Doll et al.

Reprints will not be available from the authors.

Address correspondence to Markus M. Luedi, MD, MBA, Department of Anaesthesiology, Bern University Hospital Inselspital, University of Bern, Freiburgstrasse, 3010 Bern, Switzerland. Address e-mail to markus.luedi2@insel.ch.


DOI: 10.1213/ANE.0000000000001187

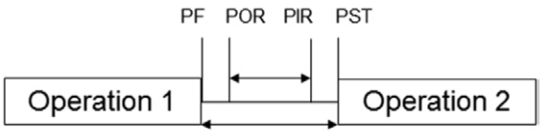


**Figure 1.** Possible definitions of turnover times (↔) as discussed by the Association of Anesthesia Clinical Directors. Procedure/surgery finish (PF): "Time when… …the physician/surgeons have completed all procedure-related activities on the patient." Patient out of room (POR): "Time at which patient leaves OR." Patient in room (PIR): "Time when patient enters the OR." Procedure/surgery start time (PST): "Time the procedure is begun." Studying the time PF to PST and to distinguish from the interval POR to PIR, we use the term turnaround time for the studied interval.

**Table 1. Known Evidence About Age and ASA Physical Status Dependence of Turnover Times**

| Publication | Study size | Age/ASA PS-related evidence for OR management |
|---|---|---|
| Clark et al.[10] | 707 patients | Outpatients undergoing thyroid or parathyroid surgery have significant shorter turnover times than inpatients. Age was comparable in both groups but inpatients had significantly greater ASA PS (mean, 2.30 vs 2.13, $P < 0.001$) |
| Small et al.[11] | 422 procedures | Dedicated operating rooms for orthopedic patients improve operating room efficiency. Age and ASA PS were not significantly different in study and control groups |
| Murray et al.[12] | 293 patients | Elective cases of inguinal hernia repair had shorter turnover times on Saturdays. But both, age, and ASA PS were significantly lower in patients operated on Saturdays |

PubMed search on October 18, 2015, with MeSH terms and with key words defined by Wachtel and Dexter[13]: ("turnover time" OR "turnaround time" OR "overutilized time") AND (age groups OR age factors) AND (operating rooms OR "operating room costs" OR "operating room efficiency"). A second search was defined as ("turnover time" OR "turnaround time" OR "overutilized time") AND (age groups OR age factors) AND (preincision OR pre-incision OR "anesthesia-controlled" OR "anesthesia-release" OR "anesthesia release") did not yield additional information.
OR = operating room; PS = physical status.

In elderly, high-risk patients who receive invasive monitoring, preparation times are especially difficult to estimate and almost always take longer than expected.[8] Only a few years ago, "demographic change" was perceived as a theoretical construct, but in today's OR settings, age-related demographic changes, specifically the greater share of elderly patients, have become reality. In an analysis of 1558 cases, Escobar et al.[9] showed by multivariate regression analysis that patient age and ASA physical status (PS), among other factors, are predictive for OR turnover time. Other studies with smaller cohorts found ambiguous results (Table 1) or did not analyze the effect of age/ASA PS of the studied subjects. The managerial implications of patient age and ASA PS for OR management decisions, however, remain unclear.

We hypothesized that evaluating patient age and ASA PS in a large cohort and with the right model would improve accuracy of turnaround time estimates and, thus, would have decisive implications for OR management.

The availability of accurate estimates of turnaround times would permit reducing overutilized OR time. For practical application of this analysis, we computed a table for OR managers, which allows the OR manager to make improved scheduling decisions in many contexts.

## METHODS

This retrospective study was conducted at the Saint Mary's Hospital in Vechta, Germany, a 321-bed teaching hospital of Hannover University, with specialized surgical service in general, trauma, hand, pediatric, ear-nose-throat (ENT), plastic, as well as gynecology and obstetrics. Patient data, times, and surgical list were taken from the ORBIS™ database.

The ethics committee of the medical association of Niedersachsen, Hannover, Germany (Prof. Dr. med. Andreas Creutzig, Chair) evaluated the study based on § 15 of the Niedersachsen Medical Association's professional code of conduct. On January 12, 2015, the study was waived for approval because neither the psychologic nor the physical integrity of patients was affected at any time.

Data for analysis were extracted from a database containing 36,834 cases in a 71-month period (May 30, 2007, through April 29, 2013). Samples with missing age and/or ASA PS were excluded, leaving 36,281 cases. Three ASA PS V cases were excluded. Limiting the analysis to scheduled inpatient cases in general surgery, trauma surgery, gynecology, and ENT on weekdays resulted in a dataset of 21,702 cases. First cases of the day and cases after a switch of the list in the room were excluded, leaving 14,712 cases. Cases in which the turnaround time exceeded 90 minutes were also excluded. This yielded 13,632 cases for final analysis.

Multivariate analyses included age (numeric/ordinal, binned into categories of 20 years), ASA PS (numeric/ordinal), surgical list (categorical), duration of the procedure (numeric), duration of the preceding procedure (numeric), and time (year). Thus, the durations of operative times and turnaround times are correlated with the studied periods. Other potentially relevant factors were not considered (e.g., time of day). The OR protocols were not changed during the time analyzed. No new OR processes were seen leading to sweeping procedural adjustments. The OR managerial team was in place continuously during the time analyzed. The numbers of OR procedures increased moderately during the 71-month period (0.044%, $P = 0.0034$). To correct for trends, the durations of operative times and the turnaround times were detrended by list, where a significant trend was found. The detrending was applied to set all the data to the levels of the most recent observations in the study period (meaning that we added the trend to data further in the past).

First, we assessed correlations and general descriptive features of the data. Then, we constructed decision tables consisting of 50th and 95th percentiles of age/ASA PS-dependent estimates that allow OR managers at our hospital to improve accuracy in scheduling turnaround times. In addition, we applied linear and generalized linear multivariate models to predict turnaround times. The forecasting power of the models was assessed in view of single cases but also in view of critical managerial key figures (50th and 95th percentile turnaround times). The models were calibrated on 80% of the data, and their predictive value was tested on the remaining 20%.

Data were collected and managed with MS Excel 2010 (Microsoft, Redmond, WA). Statistical analysis was performed with the use of R and RStudio (version 3.0.1, R Foundation, Vienna Austria). All statistical tests were used in a 2-sided setup; $P < 0.05$ was considered significant. To compute correlations, the Spearman coefficient was used because of lack of normal distribution and linearity. To identify best-fitting parametric models, Box-Cox transformations were applied to the potential (numeric) predictors (age and ASA PS were considered numeric in this setup in view of their bivariate relation to turnaround times). The Box-Cox transform helps stabilize variability in regression models by defining transformed variables as $T(X) = \frac{X^{\lambda} - 1}{\lambda}$ for $\lambda \neq 0$ and $T(X) = \ln(X)$ for $\lambda = 0$. The transformed predictors were then used to define generalized linear models of turnaround times for all lists combined as well as separated by list. All possible combinations of predictors (per list and in total) were tested, and the best models in terms of Akaike information criterion were selected. The models were fitted with the use of least squares optimization. Because the predictors correlated, we computed the variance inflation factors for each model, which indicates how sensitive the models are on correlating predictors. Because linear and generalized linear models exhibit drawbacks associated with specific assumptions on the connection of variables and with the involvement of quantities known only with uncertainty before surgical procedure (duration of preceding surgical procedure, duration of surgical procedure), we included 50th and 95th percentile estimates of turnaround times by age, ASA PS, and list in our considerations. These estimates were then summarized in decision tables for OR management.

Confidence intervals (CI; 95%) were computed with 10,000 bootstrap samples (drawn with replacement; NA was entered if there were <8 samples in a respective age/ASA PS category). To assess the amount of surgical case variability explained by the model, adjusted $R^2$ (linear, generalized linear models) and residual square sums (50th percentile models) were used. For the 50th and 95th percentile estimates of turnaround times, we considered the absolute differences between the age/ASA PS-dependent and age/ASA PS-independent forecasts divided by the age/ASA PS-independent forecast. This yielded a surgical case-independent assessment of key figure forecasting capability using an age/ASA PS model.

The defined models were assessed by training the models on 80% of the available data (randomly chosen without replacement) and applying them to the 20% remaining (test) data. One surgical case within these data contained information on the variables age, ASA PS, list, duration of the procedure, and turnaround time (no additional side constraints such as identity of the surgeon were considered). This training-testing procedure was repeated 10,000 times. To measure the predictive power of the model, we computed a robust variation of mean absolute percentage error (MAPE) for each fit as $\text{median}\left[\frac{|\text{pred}_i - \text{real}_i|}{\text{real}_i}\right]$, where $i$ denotes the samples within the 20% test data. The classical implementation of MAPE uses the mean instead of the median. A drawback of MAPE, therefore, is its sensitivity to small measured values, resulting in potentially very high MAPE. This problem was addressed by using the median.

To deduce actual reductions of overutilized OR time when applying the results presented in this work, the following 2 scenarios were considered in a Monte Carlo simulation (with 10,000 runs):

1. Scenario A: scenario without estimates of times of procedure: We assumed that the OR manager 1 is scheduling the turnaround time 1 according to the medians of his past data (in our case, 80% of the available data, randomly chosen), either in general or separated by lists. OR manager 2 is using our data (computed based on the same 80% of randomly chosen data as OR manager 1). OR manager 2 schedules an age/ASA PS-specific turnaround time 2 as maximum of turnaround time 1 and our age/ASA PS-specific data. Then we let OR managers 1 and 2 apply their strategies to 20% of the remaining data and computed for each $\Delta 1$ = max (effectively measured turnaround time − scheduled turnaround 1, 0) and $\Delta 2$ = max (effectively measured turnaround time − scheduled turnaround time 2, 0), which are the overutilized OR times for each procedure. We computed the reduction of overutilized OR time for OR manager 2 by the fraction (sum($\Delta 1$) − sum($\Delta 2$))/sum($\Delta 1$).
2. Scenario B: scenario including estimates of times of procedure: The turnaround times are estimated the same way as in scenario A. Additionally, the times of procedure are estimated as follows: for each procedure in the 20% of "unknown" data, the time of procedure is scheduled as the median time of procedures that the respective surgeon was using in the 80% "known" data in the same list. If there are no reference procedures for that surgeon, the overall median of procedures in the list was used as prediction of procedure time. This yields estimated total times of procedure and subsequent turnaround times (PT) 1 and PT 2. We defined $\Delta 1$ = max(effectively measured time of procedure + effectively measured turnaround time − PT1, 0) and $\Delta 2$ = max (effectively measured time of procedure + effectively measured turnaround time − PT 2, 0). Again, this expresses that if the procedure + turnaround time ended before schedule, all is fine ($\Delta$=0).

In both scenarios, we assumed that overutilized OR time is penalized. Both scenarios could be used in settings with and without induction rooms. In both scenarios, specific daily patterns were not considered, and the procedures in the unknown 20% of data were assumed to take place one after the other. Because we randomly split the data (80%–20%) 10,000 times in both scenarios A and B, we considered the precedence of age, ASA PS, procedures, etc. in the study population.

Scenarios A and B were only applied with the orientation Tables 7–11, because they represent an easier-to-implement instrument for the OR manager than complex parametric models that would require additional software solutions.

**Table 2. Number of Cases per Age Category and Surgical List**

| Age (y)[a] | General surgery | Trauma surgery | ENT | Gynecology |
|---|---|---|---|---|
| 0–20 | 232 | 199 | 1437 | 85 |
| 20–40 | 519 | 298 | 1131 | 753 |
| 40–60 | 1298 | 549 | 1069 | 1432 |
| 60–80 | 1598 | 676 | 685 | 870 |
| >80 | 341 | 223 | 109 | 128 |
| Total | 3988 | 1945 | 4431 | 3268 |

[a]Minimal age was 0.0 y; 1st quartile, 32.0 y; median, 50.0 y; mean, 48.4 y; 3rd quartile, 67.0 y; maximum, 102.0 y.
ENT = ear-nose-throat.

**Table 3. Number of Cases per ASA Physical Status and Surgical List**

| ASA | General surgery | Trauma surgery | ENT | Gynecology |
|---|---|---|---|---|
| I | 365 | 327 | 1511 | 327 |
| II | 2265 | 1065 | 2340 | 2453 |
| III | 1177 | 512 | 544 | 471 |
| IV | 181 | 41 | 36 | 17 |
| Total | 3988 | 1945 | 4431 | 3268 |

ENT = ear-nose-throat.

**Table 4. Linear Trend in Surgical Procedure Times over the Studied Period**

| List | Intercept (min) | Slope (min/d) | Max. correction | Adj. $R^2$ |
|---|---|---|---|---|
| Overall | 57.90 ($P < 0.0001$) | 2.14E-05 ($P = 0.973$) | Not applied | <0.0001 |
| General surgery | 67.11 ($P < 0.0001$) | −0.0078 ($P < 0.0001$) | −16.39 min | 0.0142 |
| Trauma surgery | 52.09 ($P < 0.0001$) | 0.0038 ($P = 0.0049$) | +8.05 min | 0.0036 |
| ENT | 45.02 ($P < 0.0001$) | 0.0028 ($P = 0.0132$) | +5.76 min | 0.0012 |
| Gynecology | 60.84 ($P < 0.0001$) | 0.0090 ($P < 0.0001$) | +18.79 min | 0.0102 |

ENT = ear-nose-throat.

## RESULTS

### Description of the Study Group

After using the described selection for the cases of the 36,834 patients represented in the database over the 71-month period, 13,632 cases were available for final analysis. As expected, the cases distributed unequally into age and ASA PS categories (compare Tables 2 and 3). The slope values for detrending the data by list, as well as the resulting maximum correction, the intercept, and adjusted $R^2$ are shown in Table 4 (duration of procedure) and Table 5 (turnaround times). Detrending was only applied if the slope was significant ($P < 0.05$). The characteristics of turnaround times in the sample are shown in Table 6.

### Orientation Tables for OR Management

Table 7 shows 50th and 95th percentiles (medians) of detrended turnaround times in all lists combined. With this table, median turnaround times can be predicted more accurately than without age/ASA PS information (accuracy gain: all lists, 8.80%; general surgery, 4.46%; trauma surgery, 6.97%; and gynecology, 4.22%). Broken down into single-case predictions, this model explains 6.41% of case variability around an overall median and explains 1.85% of case variability around an overall median in general surgery, 5.57% in trauma surgery, 7.51% in ENT, and 1.73% in gynecology. The 50th and 95th percentiles of turnaround times separated by age and ASA PS categories are shown in Table 8 for general surgery, Table 9 for trauma surgery, Table 10 for ENT, and Table 11 for gynecology. With these tables, 50th and 95th percentiles of turnaround times can be predicted more accurately than without age/ASA PS information (accuracy gain: all lists, 5.97%; general surgery, 5.85%; trauma surgery, 5.21%; and gynecology, 3.86%).

**Table 5. Linear Trend in Turnaround Times**

| List | Intercept (min) | Slope (min/d) | Max. correction | Adj. $R^2$ |
|---|---|---|---|---|
| Overall | 38.60 ($P < 0.0001$) | 0.0006 ($P = 0.0074$) | Not applied | 0.0005 |
| General surgery | 39.28 ($P < 0.0001$) | −0.0005 ($P = 0.177$) | $P > 0.05$ | 0.0002 |
| Trauma surgery | 40.91 ($P < 0.0001$) | 0.0059 ($P < 0.0001$) | +12.28 min | 0.0434 |
| ENT | 34.00 ($P < 0.0001$) | −0.0001 ($P = 0.687$) | $P > 0.05$ | 0.0002 |
| Gynecology | 39.68 ($P < 0.0001$) | 0.0026 ($P < 0.0001$) | +5.53 min | 0.0130 |

ENT = ear-nose-throat.

### Bivariate Correlations

Although correlations do not permit prediction of outcomes, they are relevant to our models. All computed correlations are significant, indicating that chances of finding $\rho > 0$ in other study groups is substantial. Table 12 shows Spearman rho of the assessed variables over the lists; Table 13 shows their correlation with turnaround time.

### Generalized Bivariate Relations Between Predictors and Turnaround Times Using Box-Cox Transformation

The values of $\lambda$ for the Box-Cox transform (outcomes are the turnaround times for each model) were 0.677 for ASA PS, 0.990 for age, 0.182 for the duration of the preceding surgical procedure, and 0.182 for the scheduled operation. When we used the detrended data (turnaround times, duration of preceding surgical procedure, and duration of scheduled surgical procedure), we obtained 0.677 for ASA PS and 0.990 for age, duration of preceding surgical procedure, and duration of scheduled surgical procedure. In the detrended calculations, only the relationship of turnaround time to ASA PS was far from linear ($\lambda < 1$); the other variables showed almost linear behavior.

### Linear and Generalized Linear Models

Linear and generalized linear models comprising all possible combinations of predictors (age, ASA PS, detrended duration preceding surgical procedure, and detrended duration this surgical procedure) were tested for ability to explain turnaround times for all 4 lists combined and separately per list (16 × 5 = 80 models). The models with lowest Akaike information criterion were then selected as representing an optimal set of predictors of turnaround time. Because the

**Table 6. Characteristics of Turnaround Times and Surgical Procedure Times (Without Trend Correction)**

| | Minimum | First quartile | Median | Mean | Third quartile | Maximum |
|---|---|---|---|---|---|---|
| Turnaround time (min) | 0.60 | 28.80 | 37.20 | 39.21 | 46.2 | 90.00 |
| Surgical procedure time | 1.20 | 27.00 | 46.80 | 57.92 | 76.80 | 502.2 |

**Table 7. Median and 95% CIs for 50th and 95th Percentiles for Turnaround Time and Number of Cases for All 4 Analyzed Surgical Lists Combined**

| | | ASA I | | ASA II | | ASA III | | ASA IV | |
|---|---|---|---|---|---|---|---|---|---|
| Age (y) | Percentile | Median (95% CI) | *n* | Median (95% CI) | *n* | Median (95% CI) | *n* | Median (95% CI) | *n* |
| 0–20 | 50th | 30 (28.8–31.2) | 1226 | 31.2 (30–31.8) | 676 | 36 (31.8–40.2) | 43 | 42.8 (30–73.8) | 8 |
| 20–40 | 50th | 34.8 (34.2–36) | 845 | 36 (35.9–37.2) | 1765 | 40.2 (36–42) | 87 | 35.5 (NA) | 4 |
| 40–60 | 50th | 37 (34.9–39) | 381 | 40.1 (39–40.2) | 3448 | 40.8 (39.1–42) | 491 | 41.4 (36–48) | 28 |
| 60–80 | 50th | 38.8 (34.5–43.2) | 70 | 40.2 (39.2–40.8) | 2073 | 40.7 (40.2–42) | 1546 | 43.8 (40.8–46.2) | 140 |
| >80 | 50th | 35.1 (10.2–68.2) | 8 | 39.7 (37–43.8) | 161 | 45 (43.2–46.8) | 537 | 48 (44.7–54) | 95 |
| 0–20 | 95th | 59.1 (56.3–61.9) | 1226 | 67.2 (61.8–70.8) | 676 | 70.7 (53.7–84) | 43 | 81.2 (47.8–85.2) | 8 |
| 20–40 | 95th | 70.7 (64.7–73.6) | 845 | 70.2 (67.2–72.4) | 1765 | 75.2 (58.7–84.2) | 87 | 59.3 (NA) | 4 |
| 40–60 | 95th | 66.3 (61.1–72) | 381 | 70 (67.8–71.7) | 3448 | 75.6 (70.2–80.3) | 491 | 86.3 (60–90) | 28 |
| 60–80 | 95th | 74.1 (52.2–85.2) | 70 | 76.2 (73.7–78) | 2073 | 75.9 (73.7–79.4) | 1546 | 78.1 (74.8–82.2) | 140 |
| >80 | 95th | 86.6 (35.4–96.5) | 8 | 74.5 (65.6–77.9) | 161 | 81.4 (79.7–86.9) | 537 | 79.3 (74.9–89.6) | 95 |

CI = confidence interval; NA = not available.

**Table 8. Median and 95% CIs for 50th and 95th Percentiles for Turnaround Time and Number of Cases for General Surgery**

| | | ASA I | | ASA II | | ASA III | | ASA IV | |
|---|---|---|---|---|---|---|---|---|---|
| Age (y) | Percentile | Median (95% CI) | *N* | Median (95% CI) | *N* | Median (95% CI) | *N* | Median (95% CI) | *N* |
| 0–20 | 50th | 34.2 (31.8–37.2) | 81 | 36 (31.8–40.2) | 85 | 40.2 (NA) | 7 | 25.8 (NA) | 1 |
| 20–40 | 50th | 34.8 (33.0–37.2) | 140 | 34.8 (34.2–36) | 355 | 34.2 (30–39) | 24 | NA (NA) | 0 |
| 40–60 | 50th | 33.0 (31.8–34.8) | 108 | 34.8 (34.2–34.8) | 981 | 39 (36.6–40.8) | 191 | 40.8 (34.8–54) | 18 |
| 60–80 | 50th | 37.8 (31.8–43.8) | 27 | 34.8 (34.8–36) | 765 | 37.2 (36–37.8) | 707 | 42 (37.8–46.2) | 99 |
| >80 | 50th | 10.2 (NA) | 1 | 34.8 (30.0–37.8) | 52 | 37.8 (36–40.2) | 231 | 43.2 (39–46.8) | 57 |
| 0–20 | 95th | 66.0 (58.2–79.8) | 81 | 78.1 (66.6–84) | 85 | 47.6 (NA) | 7 | 25.8 (NA) | 1 |
| 20–40 | 95th | 58.2 (53.5–67.8) | 140 | 69.3 (61.8–76.8) | 355 | 44.8 (40.8–48) | 24 | NA (NA) | 0 |
| 40–60 | 95th | 67 (49.6–78) | 108 | 64.2 (58.8–67.8) | 981 | 75.6 (67.8–82.9) | 191 | 88.5 (58.6–90) | 18 |
| 60–80 | 95th | 62.4 (51.0–79.8) | 27 | 72 (65.8–76.2) | 765 | 71.6 (68.9–79.2) | 707 | 76.9 (66.8–80) | 99 |
| >80 | 95th | 10.2 (NA) | 1 | 50 (46.2–68.1) | 52 | 70.2 (63.6–78) | 231 | 76.6 (66.1–85.2) | 57 |

CI = confidence interval; NA = not available.

**Table 9. Median and 95% CIs for 50th and 95th Percentiles for Turnaround Time and Number of Cases for Trauma Surgery**

| | | ASA I | | ASA II | | ASA III | | ASA IV | |
|---|---|---|---|---|---|---|---|---|---|
| Age (y) | Percentile | Median (95% CI) | *N* | Median (95% CI) | *N* | Median (95% CI) | *N* | Median (95% CI) | *N* |
| 0–20 | 50th | 45.8 (43.8–47.6) | 154 | 50.1 (47.9–58.6) | 41 | 35.7 (NA) | 2 | 52.7 (NA) | 1 |
| 20–40 | 50th | 51.5 (47.1–54.9) | 112 | 49.1 (46.8–53.5) | 179 | 61 (NA) | 7 | NA (NA) | 0 |
| 40–60 | 50th | 44.5 (41.4–48.6) | 47 | 48.2 (46.9–49.6) | 447 | 56.2 (49.6–61.8) | 53 | 61.9 (NA) | 2 |
| 60–80 | 50th | 43.3 (31.8–45.4) | 11 | 50.1 (48.1–52.1) | 359 | 55.3 (53–57.2) | 292 | 69.2 (42.8–75.9) | 14 |
| >80 | 50th | 82.35 (NA) | 2 | 51.8 (48.3–63.4) | 39 | 59.3 (58–62.3) | 158 | 66.9 (57.5–74.5) | 24 |
| 0–20 | 95th | 79.6 (67.5–84.6) | 154 | 87.8 (69.2–94.3) | 41 | 37.1 (NA) | 2 | 52.7 (NA) | 1 |
| 20–40 | 95th | 87.8 (77.0–91.4) | 112 | 83 (73.9–89.1) | 179 | 82.6 (NA) | 7 | NA (NA) | 0 |
| 40–60 | 95th | 68.6 (58.1–83.2) | 47 | 77.7 (75–81.4) | 447 | 81.5 (69.6–88.4) | 53 | 66.4 (NA) | 2 |
| 60–80 | 95th | 67.3 (44.2–85.2) | 11 | 82.8 (78.1–86.2) | 359 | 88.3 (82–91.8) | 292 | 83.3 (74.8–88.9) | 14 |
| >80 | 95th | 95.1 (NA) | 2 | 80.5 (75.3–87.5) | 39 | 89.8 (84.6–93.6) | 158 | 90 (75.2–92.6) | 24 |

CI = confidence interval; NA = not available.

predictors correlate (Tables 12 and 13), we also computed the square root of the variance inflation factor to assess additional imprecision that must be considered in the estimates of the model coefficients (maximum value of 1.32, indicating low impact of correlated predictors; Tables 14 and 15).

A reasonable model fit for trauma surgery (23.49% of case variability explained) was observed. The model suggests a dependence of detrended turnaround time on ASA PS, detrended duration of the preceding surgical procedure, and detrended duration of the surgical procedure. From such models, turnaround time can be predicted from knowledge of the predictor variables and coefficients. In the case of trauma surgery, the model reads (all times in minutes):

$$\text{Turnaround time} = 31.78 + 3.23 \times \text{ASA} + 0.06 \times \text{duration of preceding OP} + 0.19 \times \text{duration of the scheduled OP.}$$

**Table 10. Median and 95% CIs for 50th and 95th Percentiles for Turnaround Time and Number of Cases for ENT**

| | | ASA 1 | | ASA II | | ASA III | | ASA IV | |
|---|---|---|---|---|---|---|---|---|---|
| Age | Percentile | Median (95% CI) | *N* | Median (95% CI) | *N* | Median (95% CI) | *N* | Median (95% CI) | *N* |
| 0–20 | 50th | 28.2 (27–28.2) | 942 | 28.8 (28.2–30.0) | 477 | 31.2 (25.5–52.5) | 15 | NA (NA) | 0 |
| 20–40 | 50th | 30 (28.8–31.2) | 424 | 31.2 (30–31.8) | 685 | 34.8 (28.2–41.1) | 21 | 42 (NA) | 1 |
| 40–60 | 50th | 31.2 (30–34.2) | 123 | 34.8 (34.2–34.8) | 791 | 34.8 (33.6–37.5) | 148 | 42 (NA) | 7 |
| 60–80 | 50th | 36 (25.8–40.2) | 17 | 36 (34.2–37.2) | 351 | 37.5 (36–39) | 296 | 43.8 (41.7–51) | 21 |
| >80 | 50th | 25.8 (NA) | 3 | 32.1 (27–40.2) | 36 | 40.2 (38.1–45) | 63 | 48 (NA) | 7 |
| 0–20 | 95th | 46.8 (44.4–49.2) | 942 | 52.6 (48–58.3) | 477 | 71.7 (49–73.8) | 15 | NA (NA) | 0 |
| 20–40 | 95th | 58.0 (52.7–64.2) | 424 | 59.6 (52.2–67.7) | 685 | 51 (42–58.8) | 21 | 42 (NA) | 1 |
| 40–60 | 95th | 61.2 (53.6–73.8) | 123 | 61.2 (58.2–64.2) | 791 | 66 (56.1–78) | 148 | 51.8 (NA) | 7 |
| 60–80 | 95th | 70.3 (40–82.8) | 17 | 66.3 (58.2–71.3) | 351 | 67.4 (61.2–75.5) | 296 | 73.2 (54.1–90) | 21 |
| >80 | 95th | 33.4 (NA) | 3 | 61.4 (47.9–76.2) | 36 | 79.1 (67.2–87.2) | 63 | 63.8 (NA) | 7 |

CI = confidence interval; ENT = ear-nose-throat; NA = not available.

**Table 11. Median and 95% CIs for 50th and 95th Percentiles for Turnaround Time and Number of Cases for Gynecology**

| | | ASA I | | ASA II | | ASA III | | ASA IV | |
|---|---|---|---|---|---|---|---|---|---|
| Age | Percentile | Median (95% CI) | *N* | Median (95% CI) | *N* | Median (95% CI) | *N* | Median (95% CI) | *N* |
| 0–20 | 50th | 41.6 (36.7–44.6) | 38 | 39.6 (37.8–47.5) | 46 | 33.1 (NA) | 1 | NA (NA) | 0 |
| 20–40 | 50th | 38.2 (36.3–39.5) | 169 | 40.5 (39.2–41.8) | 546 | 44.2 (41–53.6) | 35 | 29 (NA) | 3 |
| 40–60 | 50th | 43.5 (41.3–45.2) | 103 | 45.0 (44.2–46.2) | 1229 | 47.4 (43.7–50.3) | 99 | 29.7 (NA) | 1 |
| 60–80 | 50th | 44.6 (35.2–48.4) | 15 | 44.2 (43.2–45.2) | 598 | 44.1 (42.7–45.1) | 251 | 48.4 (NA) | 6 |
| >80 | 50th | 45.2 (NA) | 2 | 40.5 (36.7–48.6) | 34 | 43.7 (42.1–47.9) | 85 | 55.2 (NA) | 7 |
| 0–20 | 95th | 50.4 (48.4–61.4) | 38 | 75.3 (64.0–92.3) | 46 | 33.1 (NA) | 1 | NA (NA) | 0 |
| 20–40 | 95th | 71.8 (59.6–80.7) | 169 | 69.1 (64.9–75.4) | 546 | 78.6 (57.6–91.7) | 35 | 59 (NA) | 3 |
| 40–60 | 95th | 65.9 (57.4–73.6) | 103 | 72.3 (69.1–74.8) | 1229 | 70.9 (67.4–80.9) | 99 | 29.7 (NA) | 1 |
| 60–80 | 95th | 63.74 (47.9–90.7) | 15 | 77.9 (71.3–81.0) | 598 | 69.0 (64.5–74.4) | 251 | 75.4 (NA) | 6 |
| >80 | 95th | 53.4 (NA) | 2 | 61.2 (51.3–73.2) | 34 | 73.5 (61.3–79.9) | 85 | 62.9 (NA) | 7 |

CI = confidence interval; NA = not available.

**Table 12. Spearman Correlations of All Variables, Aggregated over All Lists**

| | Turnaround time | Age | ASA | Duration preceding surgical procedure | Duration scheduled surgical procedure |
|---|---|---|---|---|---|
| Turnaround time | 1 | 0.239 | 0.200 | 0.162 | 0.410 |
| Age | 0.239 | 1 | 0.630 | 0.094 | 0.194 |
| ASA | 0.200 | 0.630 | 1 | 0.064 | 0.156 |
| Duration preceding surgical procedure | 0.162 | 0.094 | 0.064 | 1 | 0.142 |
| Duration surgical procedure | 0.410 | 0.194 | 0.156 | 0.142 | 1 |

$P < 0.0001$ for all correlations. Turnaround times and surgical procedure durations were detrended.

SEs of the coefficients were between 3% (intercept) and 15% (ASA PS coefficient). With Box-Cox transformed predictors, slightly different sets of predictors for the models were obtained, but due to almost linear relations of most of the variables, the explained case variabilities did not change relevantly.

## Comparison of All Models

In view of their generalizability and, thus, predictive power, the aforementioned models were compared by training on 80% of the data and predicting on the remaining 20%. A robust version of MAPE was then computed: absolute differences of the predicted and the measured turnaround times (single cases) were divided by the measured turnaround times. We computed the median of these values and repeated the entire procedure 10,000 times. For comparison, we also computed the predictive power of simple medians taken over the turnaround times for each list category. Table 16 shows that the models perform differently among the lists. All 3 models decreased the forecasting error when the turnaround times were not separated by list. In gynecology, the age/ASA PS median model performed worse than the parametric models in the first 2 columns, but better than an overall median without age/ASA PS. The parametric models performed better in all lists, except for general surgery. In surgery, the age/ASA PS model performed best, even though the difference from the overall median model was only approximately 2.5%; In the best cases (trauma surgery and ENT), our parametric models performed approximately 20% better than a median estimate of turnaround times. These results indicate that the models provide a relevant increase in planning accuracy for the single cases.

## Reduction of Overutilized OR Time of a Service with Orientation Tables

Even though the parametric models were able to predict turnaround times more accurately (compare Table 16), they are arguably more complex in application for the OR

**Table 13. Correlations of Detrended Turnaround Times and Age, ASA, Duration of Preceding Surgical Procedure, Duration of Surgical Procedure, Separated by Lists**

| Correlation turnaround time with | General surgery | Trauma surgery | ENT | Gynecology |
|---|---|---|---|---|
| Age | 0.077 | 0.164 | 0.281 | 0.098 |
| ASA | 0.123 | 0.192 | 0.230 | 0.080 |
| Duration preceding surgical procedure | 0.098 | 0.193 | 0.070 | 0.090 |
| Duration surgical procedure | 0.274 | 0.510 | 0.417 | 0.284 |

*P* < 0.0001 for all correlations. Like turnaround time, surgical procedure durations are detrended.
ENT = ear-nose-throat.

**Table 14. Explained Case Variability Percent (95% CI) by AIC Optimal Models (Detrended Variables)**

| Sets | Explained case variability | Predictors (linear model) |
|---|---|---|
| All lists combined | 15.46% (14.83%–16.13%) | age+asa+ duration_preceding_surgical_procedure+ duration_this_surgical_procedure |
| Trauma surgery | 23.49% (21.84%–25.00%) | asa+ duration_preceding_surgical_procedure+ duration_this_surgical_procedure |
| General surgery | 7.17% (6.05%–8.03%) | age+asa+ duration_preceding_surgical_procedure+ duration_this_surgical_procedure |
| ENT | 16.62% (15.27%–17.93%) | age+asa+ duration_this_surgical_procedure |
| Gynecology | 7.39% (6.40%–8.48%) | age+asa+ duration_preceding_surgical_procedure+ duration_this_surgical_procedure |

AIC = Akaike information criterion; CI = confidence interval; ENT = ear-nose-throat.

**Table 15. Explained Case Variability Percent (95% CI) by AIC Optimal Models with Box-Cox Transformed Predictors (All Variables Detrended)**

| Set | Explained case variability | Predictors (generalized linear model) |
|---|---|---|
| All lists combined | 14.95% (14.38%–15.56%) | asa+duration_preceding_surgical_procedure+duration_this_surgical_procedure |
| Trauma surgery | 23.00% (24.57%–26.23%) | asa+duration_preceding_surgical_procedure+duration_this_surgical_procedure |
| General surgery | 6.00% (5.08%–6.75%) | asa+duration_preceding_surgical_procedure+duration_this_surgical_procedure |
| ENT | 14.76% (13.80%–15.65%) | asa+duration_this_surgical_procedure |
| Gynecology | 7.12% (6.18%–8.32%) | asa+duration_preceding_surgical_procedure+duration_this_surgical_procedure |

AIC = Akaike information criterion; CI = confidence interval; ENT = ear-nose-throat.

manager. The simplest yet most-effective approach is given through our age/ASA PS orientation tables. In terms of reduction of overutilized OR time of a service, they produce a significant impact. Table 17 shows the reduction of overutilized OR time of a service in scenario A (only estimates of turnaround times) and scenario B (estimates of turnaround times and durations of procedures). In general, we see that the impact of the orientation tables is relativized if times of procedure are estimated under uncertainty (scenario B).

**Table 16. Robust MAPE (Percent) of the Models Compared with Robust MAPE of Simple Medians within List Categories**

| | Linear model | Generalized linear model | Medians of age—ASA categories | Model without age—ASA |
|---|---|---|---|---|
| General surgery | 19.7% | 19.9% | 19.3% | 19.8% |
| Trauma surgery | 16.8% | 16.6% | 20.1% | 21.0% |
| ENT | 19.5% | 20.2% | 21.3% | 23.1% |
| Gynecology | 17.2% | 17.3% | 17.7% | 18.0% |
| All lists | 21.5% | 21.8% | 22.4% | 23.3% |

10,000 bootstrap samples, 80% training and 20% test data; the estimates are accurate to the displayed digits.
ENT = ear-nose-throat; MAPE = mean absolute percentage error.

**Table 17. Reduction in Overutilized OR Time of a Service When Applying the Orientation Tables in Scenarios A and B**

| Reduction of overutilized time (%) | Scenario A (95% CI) | Scenario B (95% CI) |
|---|---|---|
| All lists | 13.27% (12.13–14.31) | 4.49% (4.05–4.89) |
| General surgery | 6.27% (4.71–7.89) | 2% (1.44–2.59) |
| Trauma surgery | 14.38% (11.44–17.71) | 5.79% (4.5–8.33) |
| ENT | 15.54% (13.53–17.83) | 4.41% (3.75–5.11) |
| Gynecology | 7.74% (6.27–9.54) | 2.2% (1.72–2.84) |

Scenario B takes the uncertainty of the surgical procedure duration into account for scheduling, whereas scenario A does not. 10,000 repetitions of sampling of 80% training and 20% test data.
CI = confidence interval; ENT = ear-nose-throat; OR = operating room.

Within scenario B, we measured median overutilized OR times for a service of 23.1 minutes (95% CI, 21.5–24.7 minutes) for all lists combined, 21.2 minutes (95% CI, 18.9–23.4 minutes) for general surgery, 21.2 minutes (95% CI, 17.8–24.8 minutes) for trauma surgery, 22.6 minutes (95% CI, 20.0–25.4 minutes) for ENT, and 24.7 minutes (95% CI, 21.4–28.3 minutes) for gynecology. Our orientation tables, thus, yield a median reduction of overutilized OR times in scenario B on average per case of 1.0 minutes (all lists combined), 0.4 minutes (general surgery), 1.2 minutes (trauma surgery), 1.0 minutes (ENT), and 0.5 minutes (gynecology).

## DISCUSSION

Our data show that age and ASA PS are relevant predictors for OR turnaround time. Key figures such as 50th and 95th percentiles of turnaround times were predicted with greater accuracy when age and ASA PS were included in considerations. The parametric models included factors (duration of preceding surgical procedure and duration of this surgical procedure) that need to be predicted for scheduling. In practice, the quality of these estimates varies widely. Our OR management decision table (nonparametric model) does not require advance estimation of any uncertain properties; age and ASA PS are known well in advance within the recommended 2 working days for planning anesthesia assignments with the scheduling office.[14] Comparison of the predictive power of the presented models with a simple median prediction shows an increase in accuracy of 7.7% (all lists), ranging from 2.5 (general surgery) to 21.0% (trauma surgery), which could facilitate reducing overutilized OR time of a service.

Numerous factors could limit the generalizability of our findings. OR turnaround times are interdependent phenomena and include additional complex factors such as cleaning procedures, preparation of surgical instruments, timely availability of staff, or time of day,[15,16] which might impact OR management. Other factors, like a planned change of the surgeon,[17] have no impact on OR management.[4] Although the ASA PS classification of physical health is a widely used grading system for the preoperative health of surgical patients, multiple variations have been observed among assessments of individual anesthetists when describing common clinical problems.[18–21] The retrospective, single-center design of this study further limits the generalizability of our findings. Future prospective and multicenter studies might generate a more comprehensive model and allow generalization the findings. However, comprehensive inclusion of all contributing factors would be an exceedingly complex task.

Dexter et al.[22] showed that knowledge of OR efficiency was low among OR staff, even though seemingly simple actions can have large effects; for example, changing the supervision ratio of anesthesia residents from 1:2 to 1:3 has an effect on first-case starts.[23] Our results can be used for OR staff education. A review of experimental social-psychology studies by Prahl et al. showed that quality of decisions was improved when all group participants shared knowledge, because groups are more susceptible to analogous biases than are educated individuals. The implication of this finding is that leaders will find the most success if, instead of bringing OR management operational decisions to groups, they act autocratically while obtaining necessary information in one-on-one conversations.[24] Thus, making sure group participants are aware of such research is key to having meaningful one-on-one conversations.

Patient age and ASA PS are variables that affect turnaround time, and evaluating these variables can help to better predict turnaround times. Given that reducing overutilized OR time is a key issue in OR management,[1] the fact that our age/ASA PS-dependent model improved accuracy of forecasts for turnaround time, we suggest that critical OR stakeholders should understand the impact of ASA PS and age on turnaround time. Decision tables incorporating these factors, such as presented in this study, should be available and should be used in OR scheduling. Considering an aging population, turnaround times will be increasingly prolonged, directly impacting OR management for lists with many short operations (whereas potentially negligible in lists with few long cases). Our models are robust and may allow for more efficient operational decision making on the day of surgery by reducing minutes of overutilized OR time while their impact on strategic and tactical decisions might be limited.

There are numerous examples in which such a hospital-specific table would be of use, especially for lists with many short operations in a geriatric cohort: In cases of overlapping induction rooms, advanced age/high-score ASA PS patients could be scheduled earlier; if 2 ORs are available, advanced age/high-score ASA PS patients could be scheduled into the OR with the longer estimated underutilized time; in situations in which there is a shortage of transporters (e.g., early morning when all ORs are to be started and some transporters are missing), advanced age/high-score ASA PS patients could be given priority for transport to the OR. As well, longer standard turnaround times could be planned in ORs with advanced age/high-score ASA PS patients; relative "overloading" of an OR with advanced age/high-score ASA PS patients could be avoided by distributing advanced age/high-score ASA PS patients across multiple ORs where feasible. The influence of age/ASA PS on overutilized OR time will not only be just the change in turnaround time but also of the incidence of ASA PS and age. This will also be correlated to duration of the workday, add-on cases, and single/>1 surgeon, because of heterogeneity among specialties in these characteristics.

Our methods are applicable for any department, whereas the specific results might differ, given the study design.

## DISCLOSURES

**Name:** Markus M. Luedi, MD, MBA.
**Contribution:** This author helped design the study, conduct the study, analyze the data, and write the manuscript.
**Attestation:** Markus M. Luedi has seen the original study data, reviewed the analysis of the data, approved the final manuscript, and is the author responsible for archiving the study files.
**Name:** Peter Kauf, PhD.
**Contribution:** This author helped design the study, conduct the study, analyze the data, and write the manuscript.
**Attestation:** Peter Kauf has seen the original study data, reviewed the analysis of the data, and approved the final manuscript.
**Name:** Lisa Mulks, MSc.
**Contribution:** This author helped design the study, conduct the study, and analyze the data.
**Attestation:** Lisa Mulks has seen the original study data, reviewed the analysis of the data, and approved the final manuscript.
**Name:** Katharina Wieferich, BASc.
**Contribution:** This author helped design the study, conduct the study, and analyze the data.
**Attestation:** Katharina Wieferich has seen the original study data, reviewed the analysis of the data, and approved the final manuscript.
**Name:** Ralf Schiffer, BHA.
**Contribution:** This author helped conduct the study and analyze the data.
**Attestation:** Ralf Schiffer has seen the original study data, reviewed the analysis of the data, and approved the final manuscript.
**Name:** Dietrich Doll, MD, PhD.
**Contribution:** This author helped design the study, conduct the study, analyze the data, and write the manuscript.
**Attestation:** Dietrich Doll has seen the original study data, reviewed the analysis of the data, and approved the final manuscript.
**This manuscript was handled by:** Franklin Dexter, MD, PhD.

## ACKNOWLEDGMENTS

The authors acknowledge Dr. Franklin Dexter's intensive course in operations research for surgical services and the concomitant guidance in the preparation of the research presented here. See www.FranklinDexter.net/education.htm.

## REFERENCES

1. Dexter F, Epstein RH, Traub RD, Xiao Y. Making management decisions on the day of surgery based on operating room efficiency and patient waiting times. Anesthesiology 2004;101:1444–53
2. Strum DP, Vargas LG, May JH. Surgical subspecialty block utilization and capacity planning: a minimal cost analysis model. Anesthesiology 1999;90:1176–85
3. Overdyk FJ, Harvey SC, Fishman RL, Shippey F. Successful strategies for improving operating room efficiency at academic institutions. Anesth Analg 1998;86:896–906
4. Dexter F. High-quality operating room management research. J Clin Anesth 2014;26:341–2
5. Escobar A, Davis EA, Ehrenwerth J, Watrous GA, Fisch GS, Kain ZN, Barash PG. Task analysis of the preincision surgical period: an independent observer-based study of 1558 cases. Anesth Analg 2006;103:922–7
6. Glossary of times used for scheduling and monitoring of diagnostic and therapeutic procedures. AORN J 1997;66:601–6
7. Sandberg WS, Daily B, Egan M, Stahl JE, Goldman JM, Wiklund RA, Rattner D. Deliberate perioperative systems design improves operating room throughput. Anesthesiology 2005;103:406–18
8. Ehrenwerth J, Escobar A, Davis EA, Watrous GA, Fisch GS, Kain ZN, Barash PG. Can the attending anesthesiologist accurately predict the duration of anesthesia induction? Anesth Analg 2006;103:938–40
9. Escobar A, Davis EA, Ehrenwerth J, Watrous GA, Fisch GS, Kain ZN, Barash PG. Task analysis of the preincision surgical period: an independent observer-based study of 1558 cases. Anesth Analg 2006;103:922–7
10. Clark N, Schneider DF, Vrabec S, Bauer PS, Chen H, Sippel RS. Increased efficiency of endocrine procedures performed in an ambulatory operating room. J Surg Res 2013;184:200–3
11. Small TJ, Gad BV, Klika AK, Mounir-Soliman LS, Gerritsen RL, Barsoum WK. Dedicated orthopedic operating room unit improves operating room efficiency. J Arthroplasty 2013;28:1066–71.e2
12. Murray BW, Huerta S, Anthony T. A strategy for reducing surgical backlogs: lessons from a veterans administration hospital. Am Surg 2011;77:597–601
13. Wachtel RE, Dexter F. Difficulties and challenges associated with literature searches in operating room management, complete with recommendations. Anesth Analg 2013;117:1460–79
14. Dexter F, Shi P, Epstein RH. Descriptive study of case scheduling and cancellations within 1 week of the day of surgery. Anesth Analg 2012;115:1188–95
15. Dexter F, Epstein RH, Marcon E, Ledolter J. Estimating the incidence of prolonged turnover times and delays by time of day. Anesthesiology 2005;102:1242–8
16. Doll D, Wieferich K, Erhart T, Hoenemann C. Waiting for Godot: an analysis of 2622 operating room turnover times. Eur J Anaesthesiol 2014;31:388–9
17. Austin TM, Lam HV, Shin NS, Daily BJ, Dunn PF, Sandberg WS. Elective change of surgeon during the OR day has an operationally negligible impact on turnover time. J Clin Anesth 2014;26:343–9
18. Daabiss M. American Society of Anaesthesiologists physical status classification. Indian J Anaesth 2011;55:111–5
19. Aronson WL, McAuliffe MS, Miller K. Variability in the American Society of Anesthesiologists Physical Status Classification Scale. AANA J 2003;71:265–74
20. Ranta S, Hynynen M, Tammisto T. A survey of the ASA physical status classification: significant variation in allocation among Finnish anaesthesiologists. Acta Anaesthesiol Scand 1997;41:629–32
21. Owens WD, Felts JA, Spitznagel EL Jr. ASA physical status classifications: a study of consistency of ratings. Anesthesiology 1978;49:239–43
22. Dexter EU, Dexter F, Masursky D, Garver MP, Nussmeier NA. Both bias and lack of knowledge influence organizational focus on first case of the day starts. Anesth Analg 2009;108:1257–61
23. Epstein RH, Dexter F. Influence of supervision ratios by anesthesiologists on first-case starts and critical portions of anesthetics. Anesthesiology 2012;116:683–91
24. Prahl A, Dexter F, Braun MT, Van Swol L. Review of experimental studies in social psychology of small groups when an optimal choice exists and application to operating room management decision-making. Anesth Analg 2013;117:1221–9