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Implications of Perioperative Team Setups for Operating Room Management Decisions

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

BACKGROUND: Team performance has been studied extensively in the perioperative setting, but the managerial impact of interprofessional team performance remains unclear. We hypothesized that the interplay between anesthesiologists and surgeons would affect operating room turnaround times, and teams that worked together over time would become more efficient.
METHODS: We analyzed 13,632 surgical cases at our hospital that involved 64 surgeons and 48 anesthesiologists. We detrended and adjusted the data for potential confounders including age, American Society of Anesthesiologists physical status, and surgical list (scheduled cases of specific surgical specialties). The surgical lists were categorized as ear, nose, and throat surgery; trauma surgery; general surgery; and gynecology. We assessed the relationship between turnaround times and assignment of different anesthesiologists to specific surgeons using a Monte Carlo simulation.
RESULTS: We found significant differences in team performances among the different surgical lists but no team learning. We constructed managerial decision tables for the assignment of anesthesiologists to specific surgeons at our hospital. We defined a decision algorithm based on these tables. Our analysis indicated that had this algorithm been used in staffing the operating room for the surgical cases represented in our data, median turnaround times would have a reduction potential of 6.8% (95% confidence interval 6.3% to 7.1%).
CONCLUSIONS: A surgeon is usually predefined for scheduled surgeries (surgical list). Allocation of the right anesthesiologist to a list and to a surgeon can affect the team performance; thus, this assignment has managerial implications regarding the operating room efficiency affecting turnaround times and thus potentially overutilized time of a list at our hospital. (Anesth Analg 2017;124:262–9)

Overutilized operating room (OR) time of a surgical list (scheduled cases of specific surgical specialties) and turnover times are well-established measures for OR efficiency.[1]

Time is considered overutilized when 1 or more ORs of a surgical list run past an allotted time for this list, for example, because of the prolonged surgeries or turnaround times (overutilized OR time = [OR workload] − [allocated OR time], or 0 if this value is negative).[2] The procedural terms glossary of the Association of Anesthesia Clinical Directors provides 2 interpretations for turnover times: either the "time when the physician/surgeons have completed all procedure-related activities on the patient" to the "time the next procedure is begun" or the time elapsing from the moment when a "patient leaves the OR" until the next "patient [is] in OR" ("wheels out to wheels in"). The term "turnover time" is usually used for the latter. Studying the nonoperative time and to avoid ambiguity, we used the term "turnaround time" as done before.[3]

A milestone study found that the implementation of a checklist designed to improve perioperative team communication improved patient safety on a global scale.[4] In studies of OR teams performing unilateral total knee or hip replacement surgery, it has been shown that inconsistent makeup of the surgical team is associated with prolonged operative time, prolonged hospital stay, and 30-day hospital readmission.[5] Specific staff combinations can increase the efficiency in hand surgery,[6] minimally invasive surgery,[7] and robotic-assisted surgeries.[8] Tan et al[9] called for multidisciplinary OR team simulation for improving operative performance.

However, especially in big institutions with many surgeons and anesthesiologists, computerized scheduling based on historical evidence of efficient team performance might be a simpler and more effective way to improve the performance than multidisciplinary simulations as called for by Tan et al[9] Wachtel et al[10] showed that only the use of computerized decision-support systems prevented effects resulting from innate psychologic biases among OR managers. Up to today, only 1 single study included both anesthesiologists and surgeons in an attempt to minimize nonoperative tasks in the OR but without specifically studying team interplay.[11]

In summary, although considerable research has been done, the available studies remained largely focused within

From the *Department of Surgery, St. Marienhospital Vechta, Academic Teaching Hospital of the Medical School Hannover, Vechta, Germany; †PrognosiX AG, Zurich, Switzerland, and the Institute of Applied Simulation, Zurich University of Applied Sciences ZHAW, Waedenswil, Switzerland; ‡Saint Mary's Hospital Vechta, Teaching Hospital of Hannover University, Vechta, Germany; and §Department of Anesthesiology, Bern University Hospital Inselspital, University of Bern, Bern, Switzerland.

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

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the specialty and did not examine the implications deriving from different combinations of anesthesiologists and surgeons for OR management decisions.

We hypothesized that different combinations of anesthesiologists and surgeons would be associated with all our turnaround times at our hospital, and teams that worked together over time would become more efficient.

To understand the impact and managerial implications of the interplay between anesthesiologists and surgeons on OR efficiency, we analyzed 13,632 surgical cases, which involved 64 surgeons and 48 anesthesiologists. We analyzed and quantified the association between turnaround times and the assignment of different anesthesiologists to specific surgeons using a Monte Carlo simulation.

METHODS

Data and Statistical Analysis

The ethics committee of the medical association of Niedersachsen, Berliner Allee 20, 30175 Hannover, Germany (Professor Dr. med. Andreas Creutzig, Chair), approved the study based on §15 of the Niedersachsen Medical Association's professional code of conduct. On January 12, 2015, the requirement for approval of the study was waived because neither the psychologic nor the physical integrity of patients was affected at any time.

This retrospective study was performed at the St. Marienhospital in Vechta, Germany, a 321-bed teaching hospital of the Medical School of the University of Hannover, Germany. The hospital provides specialized surgical service, in general; trauma; hand; pediatric; ear, nose, and throat (ENT); plastic surgery; and gynecology and obstetrics.

Staff and patient data pertaining to a total of 36,834 cases over a 71-month period (May 30, 2007, to April 29, 2013) were taken from the ORBIS™ database and anonymized for analysis as described previously.[12] In brief, inpatient American Society of Anesthesiologists (ASA) physical status I to IV cases with a known procedure, anesthesiologist, and surgeon were included, yielding 36,281 cases. The time period was chosen because it provided the maximum of appropriate data for a period without any change in OR protocols.

The studied hospital is an academic teaching hospital of the medical school in Hannover. However, the departments do not train residents and trainees were only present occasionally for observing. All doctors in the study were attending physicians. During the period studied, 5 ORs were in service, each with 7.5 hours (08:00 to 15:30 o'clock) OR time allocation for elective cases on weekdays. The number of sequential cases reached from 1 to 15 with a median of 4 cases. Anesthesiologists were not subspecialized or dedicated to specific lists; everyone covered all surgical lists in a rotating manner. By rules of the protocol, 1 anesthesiologist covered 1 room and only covered a second in case of unforeseen events and emergencies. Thus, turnaround times in a specific room were all managed by 1 single anesthesiologist. Each anesthesiologist was assigned a nurse for support (unlike in the United States, German anesthesia nurses are not certified registered nurse anesthetists and do not supervise anesthesia independently).

To ensure comparable conditions (all cases studied follow a preceding case), first cases of the day and cases after a switch of the surgical list in the room were excluded, leaving 14,712 cases. Cases in which the turnaround time exceeded 90 minutes (implying "hard stop events," in which anesthesiologists had to stop the OR list, eg, for out-of-OR emergencies) were also excluded, yielding 13,632 cases for final analysis. To quantify the effects of potential confounders, multivariable analysis was conducted. This analysis included age (numeric/ordinal, categorized in bins of 20 years), ASA physical status (numeric/ordinal), surgical list (categorical), duration of the surgical procedure (numeric), duration of the preceding surgical procedure (numeric), and time (year). Multivariable correlation structures of these variables within the study data were described previously.[12] Additional parameters for minimizing confounding relationships would be, for example, specific procedure conducted, gender, body mass index, comorbidities, and other patient risk factors potentially related to outcome. However, these data were not directly at hand in our database and including all potentially confounding relationships would become a very complex task.

OR protocols were not changed during the period analyzed. No new OR processes were implemented leading to sweeping procedural adjustments. The OR managerial team was in place continuously and constantly during the time analyzed.

The data were anonymized. Numeric names were assigned to the surgeons (S_01, ..., S_64) and anesthesiologists (A_01, ..., A_48) in the decreasing order of the numbers of cases each surgeon/anesthesiologist registered within the data set.

Patient age was categorized into 5 groups (0–20 years, 21–40 years, 41–60 years, 61–80 years, and >80 years). Arguably, there are surgeries that are predominantly performed in older patients, implying reason to compute age groups per procedure (eg, based on age quintiles per procedure). Such an approach was not used in this study because comparability of age groups among different surgical cases and lists would be lost.

To correct for effects on turnaround times based on surgical list, age, and ASA physical status, all turnaround times were adjusted. For each surgical list, age, and ASA physical status group, median turnaround times were computed and subtracted to make all the turnaround times comparable (compare Luedi et al[12]). If, for example, we observed a turnaround time of 46 minutes in ENT with a patient of ASA III and age group 21 to 40 years, we subtracted the median turnaround time of this combination, 34.8 minutes (Supplemental Digital Content 1, Supplemental Table 1, http://links.lww.com/AA/B535) and got an adjusted turnaround time of 11.2 minutes. To counter a slight trend of increasing turnaround times with increasing number of surgical cases in the study period (when split into lists, patient age, and ASA physical status; increase of 0.011 seconds turnaround time per case, $P < .0001$), a linear model was fitted to detrend the data. The detrending was applied to set all data to the levels of the most recent observations in the study period (ie, the trend was respected for data in the past, eg, detrended turnaround time case 100 = turnaround time case 100 + 0.011 × [total number of cases − 100]). After

Table 1. Number of Cases per Age Category and Surgical List

Age Group (y)	Ear, Nose, and Throat	General Surgery	Gynecology	Trauma Surgery
0–20	1437	232	85	199
20–40	1131	519	753	298
40–60	1069	1298	1432	549
60–80	685	1598	870	676
>80	109	341	128	223

this detrending step, all turnaround times became comparable. The detrending of the aggregate data in the study period relativizes single providers' (surgeons' and/or anesthesiologists') increasing or decreasing trends in view of all the providers in the study group and thus allows for comparison among providers even if the case numbers are centered around different times within the study period.

For statistical analysis and visualizations, the statistical software package R (version 3.1.0, Vienna, Austria) in the R-studio framework (version 0.98.982, Vienna, Austria) was used. Statistical significance was assumed if $P < .05$. All tests were considered in a two-tailed setup. For all pairwise correlation analysis performed in this study, we used Spearman rank correlation because of nonnormality of the data. For error inflation correction in multiple testing, P value adjustment following Holm was used to protect type I error within each of the multiple hypotheses assessed. For all pairwise comparisons of central tendencies in this study, Wilcoxon signed-rank test was used (lack of normality in data); for comparisons of more than 2 groups, Kruskal–Wallis rank sum test was applied (again the lack of normality in data). To visualize results of Holm-corrected pairwise testing, letters were assigned to groups such that groups exhibiting significant differences did not share letters, for example, 2 groups are assigned the letters "a" and "b"; they exhibit significant differences (they do not share a letter). If they are assigned letters "a" and "ab," they do not exhibit significant differences (they share the letter "a"); if they are assigned letters "a" and "a," they do not exhibit significant differences.

To assess individual and team learning, the adjusted turnaround times for each individual (surgeon alone, anesthesiologist alone) and each team (surgeon together with anesthesiologist) were correlated with their respective number of cases performed using Spearman rank correlation. Only individuals and teams that performed 2 or more surgical cases were considered in this analysis, in which learning curves were considered until the maximal number of surgical cases performed by the respective individual and teams. Linear regression analysis could not be performed in this case, because normality was far off (assessed with Shapiro testing, Kolmogorov–Smirnov testing, and visual inspection with QQ-plot). A more directly interpretable slope with palatable units for individuals resulting from such an analysis was not reported because significance testing of such a slope would not yield reliable results because of the lack of normality of standardized residuals from the linear regression. Although we assessed individual and team learning using Spearman rank correlation, the underlying basis for this correlation analysis of adjusted turnaround times is built on a multivariable model including trend, age, list, and ASA physical status. A detailed multivariable analysis on the data presented in this work was published previously.[12]

Because this is not a traditional study, not all of the involved analysis could be accompanied by reports of power that we had to find differences of interest with the given sample sizes. Within the setups of multiple testing with Holm correction for correlation analysis, the minimal detectable (ie, $P = .05$) Spearman correlations ranged from 0.92 (10 samples) to 0.11 (1000 samples; see Supplemental Digital Content 2, Supplemental Table 8, http://links.lww.com/AA/B536).

Decision Algorithm for OR Management

To derive managerial implications, for each surgical list, that is, scheduled cases of specific surgical specialties, we determined whether there were differences in turnaround performance between the anesthesiologists for an assigned surgeon. For this, we split the data into lists, and for each list, we only chose surgeons with ≥20 cases on the list. The choice to set the minimal number of cases per surgeon to 20 was made after considering the data, gauging the advantage of including a high number of surgeons into the study with the disadvantage of highly increasing the number of unrepresentative samples because of low case numbers. For each such surgeon, we assessed the detrended, age–ASA physical status adjusted turnaround times split by anesthesiologist. This assessment resulted in tables of letters indicating the significant differences by anesthesiologist for each surgeon (compare Table 2 and Supplemental Tables 5, 6, and 7, Supplemental Digital Content 3, 4, and 5, http://links.lww.com/AA/B537, http://links.lww.com/AA/B538, and http://links.lww.com/AA/B539). For these tables, significance testing was done only for selected anesthesiologists who performed at least 13 cases with the assigned surgeon. If an anesthesiologist performed fewer than 13 cases with the given surgeon, he was included in the table, but no significance testing of his or her performance with respect to other anesthesiologists was done. This restriction was defined after considering the data because of too high numbers of multiple tests, potentially biasing results despite error inflation corrections, again gauging the number of involved teams with the number of unrepresentative samples because of low case numbers.

With these restrictions (surgeons with ≥20 cases, anesthesiologists ≥13 cases with respective surgeon), a total of 38 surgeons was considered and on average 7 anesthesiologists per surgeon were included in the significance testing (for 11 surgeons, no anesthesiologist was included in the significance testing; the maximal number of anesthesiologists included in the significance testing for 1 surgeon was 22).

Table 2. Turnaround Times for Ear, Nose, and Throat Surgeons (With >20 Surgical Cases in the Data) With Different Anesthesiologists[a]

Staff	*KrWa*	*A01*	*A02*	*A03*	*A04*	*A05*	*A06*	*A07*	*A08*	*A09*	*A10*
S03	0.029	a	a	a	a	a	a	a	a	a	a
S04	0.016	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab
S05	0.629	a	a	a	a	a	a	a	a	a	a
S07	0.034	a	a	a	a	a	a	a	a	a	a
S09	0.098	a	a	a	a	a	a	a	a	a	a
S13	0.043	b	ab	ab	ab	ab	ab	ab			ab
S22	0.429		a	a		a	a	a			a
Staff	*KrWa*	*A11*	*A12*	*A13*	*A14*	*A15*	*A16*	*A17*	*A18*	*A19*	*A20*
S03	0.029	a	a	a	a	a		a			a
S04	0.016	a	ab	ab		ab		b			
S05	0.629	a	a	a	a	a					
S07	0.034	a	a	a	a						
S09	0.098	a	a	a							
S13	0.043	ab		ab	ab	ab		a			
S22	0.429				a						
Staff	*KrWa*	*A21*	*A22*	*A23*	*A24*	*A25*	*A26*	*A27*	*A28*	*A29*	*A30*
S03	0.029										a
S04	0.016		a								
S05	0.629										
S07	0.034										
S09	0.098										
S13	0.043										
S22	0.429										
Staff	*KrWa*	*A31*	*A32*	*A33*	*A34*	*A35*	*A36*	*A37*	*A38*	*A39*	*A40*
S03	0.029										
S04	0.016										
S05	0.629										
S07	0.034										
S09	0.098										
S13	0.043										
S22	0.429										

a/ab: if two groups are assigned the letters "a" and "b," they exhibit significant differences. If they are assigned, that is, letters "a" and "ab," they do not exhibit significant differences, if they are assigned, that is, letters "a" and "a," they do not exhibit significant differences.

Abbreviation: KrWa, Kruskal–Wallis rank-sum test.

[a]Only anesthesiologists with at least 13 cases together with the respective surgeon are taken into account. For some surgeons, it matters with which anesthesiologists they are working; and for some, not. If anesthesiologists share a letter, they do not perform differently with the assigned surgeon.

Also, if there were no anesthesiologists available with ≥13 cases for the respective surgeon, the simulation described subsequently could be applied (see step 4 subsequently).

If the minimal number of cases for an anesthesiologist with a respective surgeon was altered from 13 to, for example, 10, an average number of 8 anesthesiologists was considered for significance testing per surgeon, with, for example, minimally 20 cases, this average lowered to 5.

These tables were then used to simulate a more effective assignment of anesthesiologist to surgeons according to the following 6 steps:

1. We selected from the complete data set all surgical cases that were done by surgeons with at least 20 cases in the data set (yielding 13,447 from the original 13,632 surgical cases). From these, we created a set of adjusted turnaround times (detrended, age–ASA physical status – list medians subtracted). The assignment of surgeons to the cases was considered fixed.
2. From the 13,447 surgical cases, we computed the managerial tables, as described previously.
3. We randomly selected 13,447 from our data set of 13,447 surgical cases (with replacement to preserve distributional properties of the study group).
4. Random assignment of anesthesiologist: equivalent to the OR setting in the studied hospital where anesthesiologists are not subspecialized or dedicated to specific lists and supervise the entire anesthesia; for each procedure in step 3, the defined surgeon was randomly assigned an anesthesiologist with whom he or she had already worked at least once (counted from the data in step 2). The median adjusted turnaround time of that randomly selected anesthesiologist was adjusted for age, ASA physical status, and surgical list of the procedure. The computed turnaround times for each of the 13,447 surgical cases were then added to yield a total sum of turnaround times.

5. Improved assignment of anesthesiologist: for each procedure in step 3, the defined surgeon for this procedure was identified in the tables created in step 2. If there were no significant differences between his or her anesthesiologist assignments, an anesthesiologist was randomly assigned as in step 4. If there were significant differences, the median adjusted turnaround time with best performance among the group of anesthesiologists for the surgeon was computed, detrended, adjusted for age, ASA physical status, and surgical list, and added to yield a total sum of improved turnaround times.
6. We performed 200 iterations of steps 3 to 5 and computed median efficiency gains of step 5 toward step 4 and their corresponding 95% confidence intervals (CIs; through quantiles of the 200 Monte Carlo samples). Results were stable with 200 runs; compare Supplemental Figure 9 (Supplemental Digital Content 6, http://links.lww.com/AA/B540).

Within this algorithm, no additional boundary conditions (like, for example, conditions on the availability of an anesthesiologist at a certain time or restrictions in resources of a single anesthesiologist) were implemented. Thus, this algorithm is designed to show the efficiency potential. For direct practical application in OR management, more boundary conditions would play a role.

Although decisions in step 5 of this algorithm were based on a univariate Wilcoxon test, the data basis is built on multivariable models involving trend, age, list, and ASA physical status, as described previously.[12] Beforehand, individual differences in adjusted turnaround times by surgeons and by anesthesiologists were assessed. This study focuses on teaming effects given individual working habits; therefore, these individual differences were only taken into indirect consideration (see step 5).

Validation of Computer Code

Because extensive programming was involved in this study, careful testing of the implemented code was applied. First, the correct import of the original data into the R framework was checked by picking several (randomly chosen) cases from the data and comparing the raw data with all the columns in the respective rows in the R data frame. Algorithms for detrending and adjustment of turnaround times were checked by randomly selecting 1 case within each age/ASA combination (distributed randomly within the 4 considered lists) and comparing the algorithmic results with manually computed numbers. Results from statistical testing were always visualized and with that checked for validity (not all visualizations were shown in the article). The Monte Carlo simulation was checked by manually reviewing the single algorithmic steps for 4 assignments (1 from each list, mix between random assignment and assignment according to letters, random mix of age–ASA combination). Cumulatively summed variables were carefully assigned to 0 before the simulations and monitored by screen printouts during the runs.

RESULTS

Minimum patient age was 0.0; maximum was 102.0 years. Median age was 50.0 years (interquartile range [IQR] 32.0–67.0 years; mean age 48.44 years). ASA physical status was as follows: 2530 patients had ASA physical status 1 (1511 ENT, 365 general surgery, 327 gynecology, and 327 trauma surgery), 8123 had ASA physical status 2 (2340 ENT, 2265 general surgery, 2453 gynecology, and 1065 trauma surgery), 2704 had ASA physical status 3 (544 ENT, 1177 general surgery, 471 gynecology, and 512 trauma surgery), and 275 had ASA physical status 4 (4 ENT, 36 general surgery, 181 gynecology, and 17 trauma surgery). Table 1 shows the number of cases per age category and surgical list. Differences in the age distributions among the lists were significant ($P < .0001$, Kruskal–Wallis test).

Within the selected cases, a total of 64 surgeons had worked with 48 anesthesiologists (Supplemental Digital Contents 7 and 8, Supplemental Tables 2 and 3, http://links.lww.com/AA/B541 and http://links.lww.com/AA/B542). Turnaround times in the sample exhibited a (defined) maximum of 90 minutes; the first quartile was 28.8 minutes, and the third quartile was 46.2 minutes. The median was 37.2 minutes, and the mean was 39.2 minutes. The times for surgical cases were a minimum of 1.2 minutes and a maximum of 502.2 minutes; the first quartile was 27.0 minutes, and the third quartile was 76.8 minutes. The median was 46.8 minutes, and the mean was 57.9 minutes. Approximately 14 cases (0.10% of all cases) were below 3 minutes. Because there was no evidence on the irrelevance of these cases (eg, removal of a screw in general anesthesia), they were left within the sample. Their small number suggests very little influence on the overall findings.

The data (Supplemental Digital Contents 7 and 8, Supplemental Tables 2 and 3, http://links.lww.com/AA/B541 and http://links.lww.com/AA/B542) show preferences for assignment of certain anesthesiologists to certain surgical lists ($P < .0001$, χ^2 test, assumptions on minimal case numbers per class not fully met), although the department policy is that all anesthesiologists cover all surgical lists without specialization.

To compare team performance, age, ASA physical status, and surgical list-adjusted turnaround times were used (ie, the medians of each age–ASA physical status list category were subtracted from the measured turnaround times, see Data and Statistical Analysis under Methods and Supplemental Digital Content 1, Supplemental Table 1, http://links.lww.com/AA/B535). The adjusted turnaround times exhibited a slight but significant linear trend in numbers of surgical cases performed in the facilities (Spearman ρ 0.084, $P < .0001$; Pearson's product moment correlation 0.055, $P < .0001$ [data not compatible with normality of residuals to linear regression]; increase of 0.012 seconds per case in the study period, standard error for the slope 0.001845 seconds; overall influence within study period: 163 seconds). This trend was adjusted for by a linear model as described in Data and Statistical Analysis.

Individual Effects on Turnaround Time

Adjusted turnaround times significantly depend on surgeon ($P < .0001$, Kruskal–Wallis test) as well as anesthesiologist ($P < .0001$, Kruskal–Wallis test). The data are not shown.

Individual Learning Over Time

For each doctor with at least 2 surgical cases (58 surgeons, 37 anesthesiologists), we looked at the time ordered series of turnaround times and assessed Spearman rank correlation with increasing number of surgical cases. For 5 surgeons, we found significant correlations (after Holm *P* value adjustment; $P < .0002$) with Spearman correlation coefficients of $\rho = 0.131$, $\rho = -0.144$, $\rho = -0.152$, $\rho = 0.155$, $\rho = -0.218$ (compare Supplemental Figure 1, Supplemental Digital Content 9, http://links.lww.com/AA/B543). In the cases of the 3 surgeons with a significant (but only moderately relevant) negative correlation, learning with number of procedures could have taken place. For anesthesiologists, we found no statistically significant learning with number of cases (Supplemental Digital Content 10, Supplemental Figure 2, http://links.lww.com/AA/B544).

Team Learning

Of the 3072 possible teams composed of 64 surgeons and 48 anesthesiologists, 853 teams with at least 1 procedure and 659 teams with at least 2 surgical cases in the study period were formed (Supplemental Digital Content 11, Supplemental Table 4, http://links.lww.com/AA/B545). No significant correlations could be found between case numbers and turnaround times of the teams, indicating that learning over time is negligible in our study group (Supplemental Digital Contents 12 and 13, Supplemental Figures 3 and 4, http://links.lww.com/AA/B546 and http://links.lww.com/AA/B547). This implies that the same pairs of surgeon–anesthesiologists do not improve over time with the number of performances.

Performance of Individuals in Studied Surgical Lists

In each list, we analyzed turnaround times of surgeons over all their cases independently of the assigned anesthesiologists. For all the lists, we observed significant differences among the surgeons (all $P < .0001$). The same analysis for anesthesiologists, independent of the assigned surgeon, over all cases per list also yields significant differences (all $P < .0001$). Details of this analysis can be found in the Supplemental Figures 5, 6, 7, and 8 (Supplemental Digital Contents 14, 15, 16, and 17, http://links.lww.com/AA/B548, http://links.lww.com/AA/B549, http://links.lww.com/AA/B550, and http://links.lww.com/AA/B551).

Performance of Teams in Studied Surgical Lists

Table 2 shows exemplarily an analysis of team performance in ENT (Supplemental Tables 5, 6, and 7, Supplemental Digital Contents 3, 4, and 5, http://links.lww.com/AA/B537, http://links.lww.com/AA/B538, http://links.lww.com/AA/B539, accordingly for trauma surgery, general surgery, and gynecology, respectively): we analyzed team performance by list of a surgeon (row) with ≥20 cases in the respective list working together with different anesthesiologists (columns). Differences in performance of all the involved anesthesiologists with the surgeon in each row were assessed with a Kruskal–Wallis test. In each row, anesthesiologists working together with the respective surgeon for at least 13 cases were further subjected to pairwise Wilcoxon testing (with Holm *P* value correction). Letters were assigned such that anesthesiologists sharing a letter in 1 row did not exhibit significant differences when working together with the respective surgeon. Anesthesiologists without letters did <13 cases together with the respective surgeon and were not considered in the pairwise Wilcoxon testing.

Although there are differences in performance among the anesthesiologists working in ENT, general surgery, and gynecology, no differences were observed in trauma surgery.

Team Performance-Dependent Assignment Algorithm and Evaluation

On the basis of the results presented, we defined a decision algorithm aimed to reduce turnaround times (described in detail in Decision Algorithm for OR Management) as follows: Step 1: Check whether the surgeon performs differently with different anesthesiologists using Table 2 and Supplemental Tables 5, 6, and 7, Supplemental Digital Contents 3, 4, and 5, http://links.lww.com/AA/B537, http://links.lww.com/AA/B538, and http://links.lww.com/AA/B539. If performance differences exist, go to step 2. If not (if all letters are the same, no differences), assign any of the anesthesiologists and go to step 3. Step 2: Check which (group of) anesthesiologists show best performance with the given surgeon; assign an anesthesiologist out of this group. Proceed to step 3. Step 3: Done. Proceed with the next surgeon. Improvements in turnaround times overall and by discipline are shown in Table 3 as a result of 200 Monte Carlo runs of the described algorithm on the whole study period (results were stable with 200 runs, compare Supplemental Figure 9, Supplemental Digital Content 6, http://links.lww.com/AA/B540).

In gynecology, 82.9% (95% CI, 81.7%–84.2%) of random assignments are corrected by our algorithm. This yields an improvement potential of 13.3% (95% CI, 12.8%–13.7%) as compared with assignments without team consideration

Table 3. Simulated Improvements in Turnaround Times Overall and by Discipline

	All Surgical Lists (CI)	Ear, Nose, and Throat (CI)	Trauma Surgery (CI)	General Surgery (CI)	Gynecology (CI)
Improvement % when algorithm is applied	6.758% (6.25%–7.12%)	4.552% (3.88%–5.24%)	0.094% (−1.23% to 1.57%)	7.257% (6.46%–7.96%)	13.294% (12.81%–13.71%)
Algorithm corrections %[a]	41.154% (40.34%–41.99%)	29.268% (27.9%–30.69%)	0% (0%–0%)	40.847% (39.55%–42.3%)	82.915% (81.67%–84.2%)

Abbreviation: CI, confidence interval.

[a]Percentage of cases for which the algorithm indicated assignment of the anesthesiologist. Note that trauma surgery did not exhibit team-specific turnaround times; therefore, the algorithm defaults to random anesthesiologist assignment, and no time is saved.

(actual median turnaround time for gynecology 40.8 minutes [IQR, 34.2–49.8 minutes]). This finding is opposed to trauma surgery, in which no efficiency can be gained through the presented algorithm (actual median turnaround time for trauma surgery 45.0 minutes [IQR, 34.8–58.2 minutes]). This is because of high variability of turnaround times within all teams in trauma surgery, the algorithm does not identify teaming that is more efficient than others in this setup. In general surgery, the algorithm influences 40.8% (95% CI, 39.6%–42.3%) of the decisions, yielding a 7.2% (95% CI, 6.5%–8.0%) gain in efficiency (actual median turnaround time for general surgery 36.0 minutes [IQR, 25.2–40.2 minutes]). In ENT, the presented algorithm is applied in 29.3% (95% CI, 27.9%–30.7%) of all the assignments, resulting in 4.5% (95% CI, 3.9%–5.2%) higher efficiency (actual median turnaround time for ENT 31.8 minutes [IQR, 34.2–49.8 minutes]). Altogether, our algorithm shows a potential of 6.8% (95% CI, 6.3%–7.1%) turnaround time improvement, influencing 41.2% (95% CI, 40.3%–42%) of all the assignment decisions (actual median turnaround time for all lists 37.2 minutes [IQR, 28.8–46.2 minutes]).

DISCUSSION

We showed that neither individuals nor teams exhibited any learning based on numbers of surgical cases performed. We constructed a managerial decision instrument to assign anesthesiologists to surgeons at our hospital. Table 2 and Supplemental Tables 5, 6, and 7, Supplemental Digital Contents 3, 4, and 5, http://links.lww.com/AA/B537, http://links.lww.com/AA/B538, and http://links.lww.com/AA/B539 indicate surgeons for whom the anesthesiologist makes a difference in turnaround time. An "anesthesiologist-sensitive" surgeon, together with median turnaround times of the teams, indicates which anesthesiologist may be best suited for the situation at hand (eg, a need for fast performance, or, contrary, a situation in which turnaround time does not matter).

The decision algorithm bases its main selection criterion on Holm-corrected multiple Wilcoxon testing. In principle, other sets of rules of identifying fast/slow performance teams could be used (such as nonstatistical rules), especially when there are many potential teams involved, in which multiple testing would become questionable. Improvements in turnaround time resulting from application of the algorithm were computed using artificial turnaround times (for comparison with and without the algorithm). These artificial turnaround times were constructed as medians of a surgeon/anesthesiologist team (first adjusted for trend, age, ASA physical status, and surgical list and then further adjusted to yield realistic times for comparison). These corrections avoid a strong influence of potential outliers in the data. An assessment of the algorithm using directly measured turnaround times could be considered, but the output would suffer from strong pointwise influences of confounders that level out when working with medians.

Furthermore, the assignment algorithm does not consider boundary conditions such as resources of a specific anesthesiologist at a certain time and focuses on efficiency-based scheduling (other assignment strategies could be interesting subjects to further studies). It therefore shows an efficiency potential. For practical purposes of OR management, more complex algorithms could become necessary. On the other hand, OR management can hardly be based entirely on mathematics and algorithmic decisions and further studies should aim at understanding why certain teams work together more efficiently (learning in our study was excluded, but other reasons like personal liking, character matches, etc, could not be assessed). For humans at work in this field, the presented algorithm could provide interesting insights in optimizing OR scheduling, as described previously.

OR turnaround times derive from complex interactions and include additional factors such as preparation of surgical instruments, timely availability of staff, time of day, or cleaning procedures.[13,14] Choosing appropriate team members to promote high team performance is a key issue of leadership.[15] A surgeon is usually predefined for a surgical list. Allocation of the right anesthesiologist to the list and to the surgeon can affect team performance and potentially overutilized time of a service. Our analysis also suggests that, on days with predicted underutilized OR time, it might not be particularly useful to assign less efficient teams for training purposes, because no learning over time was found to occur under the current regimen without specific trainings. Reducing single minutes of overutilized time of a list is a managerial goal on the day of surgery.[1] The availability of tools for identifying optimal team configurations might reduce overutilized time of a surgical list and hence be of managerial implication on the day of surgery but more likely strategically. As the clinical outcome, OR managers may be unaffected by anesthesiologist–surgeon pairing on the day of surgery given there are other contributors to turnaround times such as general staffing patterns, nonanesthesiologist staffing, and other nonhuman resource factors. Self-explanatory, patient (and other) outcome should pre-empt short-term turnaround outcome improvement. However, in a longer term perspective, anesthesiologist–surgeon pairing may be considered for tactical considerations. In addition, overutilized time of a surgical list will always also be correlated to add-on cases, single/>1 surgeon, and the duration of the workday because of the heterogeneity among surgical specialties in these characteristics. Our findings are of specific interest for surgical lists with many short cases, whereas their implications for lists with few long cases might be limited. Also, the assignment steps 4 and 5 are not fixed to a list of cases for the OR of a specific day. Thus, they do not take into account variability in case durations, changes when waiting for a different anesthesiologist, and so on. An application of steps 4 and 5 to specific daily schedules was not considered in this study; thus, the assignment algorithm will allow for a general conclusion that teaming effects can matter for reducing turnaround times. However, a direct translation of the results to a specific clinical OR management setup would require more and site-specific boundary conditions in the assignment steps 4 and 5.

For practical purposes, it is interesting to know how many cases there were on average per day in each of the considered operation rooms (median: 4 surgical cases per OR). However, because we selected only surgical cases that were representative for the turnaround time analysis, this number is biased.

Certainly, the reduction of tardiness of first cases can reduce overutilized OR time and thus potentially has implications for OR management,[16] yet studying turnaround times implies, by definition, preceding cases. Thus, we excluded all first cases. In addition, processes leading to delays in first cases may be influenced by other means than turnaround times among surgical cases.

Masursky et al[17] showed that OR managers should neither rely on surgeons nor on anesthesiologists when evaluating turnover times. Open discussions about teamwork are key for the creation of a safety culture and significantly depend on how leadership supports such discussions.[9] Our analysis did not reveal learning over time. However, it has been shown previously that teams can decrease average OR turnover times when trained specifically in managerial methods such as six sigma[18,19] or by interdisciplinary workflow assessments.[20]

A surgeon is usually predefined for a surgical list. Allocation of the right anesthesiologist to a list and to a surgeon can affect the team performance of anesthesiologists and surgeons and has managerial implications by affecting OR efficiency through turnaround times and accordingly potentially overutilized time. Vice versa, on days with predicted underutilized OR time, speculatively, it might not make sense to align less efficient teams for training purposes without additional training measures because no learning over time seems to happen without specific training. Our methods such as the "improved assignment simulation" can certainly be further refined, for example, it might be informative to conduct a sensitivity analysis by assigning an anesthesiologist to all surgeons, independent of whether there are significant differences among them. Also, the specific assignment steps within our simulation algorithm could be adapted specific to management rules of different hospitals (eg, only allow assignments of anesthesiologists within the limitations of cases on 1 day). Although our methods are generalizable, the specific results will differ for other hospitals. OR management is about humans and numbers. Turnaround times derive from patients and places, but also from human interactions. When opting to enhance the last frontiers of turnaround time optimization, giving a surgeon the best fitting anesthesiologists might reduce turnaround times and thus have implications for OR management aiming to reduce overutilized OR time of a surgical list. ■

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DISCLOSURES

Name: Dietrich Doll, MD, PhD.
Contribution: This author helped design the study, conduct the study, analyze the data, and write the manuscript. Dietrich Doll attests to the integrity of the original data and the analysis reported in this manuscript.
Name: Peter Kauf, PhD.
Contribution: This author helped design the study, conduct the study, analyze the data, and write the manuscript. Peter Kauf attests to the integrity of the original data and the analysis reported in this manuscript.
Name: Katharina Wieferich, BASc.
Contribution: This author helped design the study, conduct the study, and analyze the data.
Name: Ralf Schiffer, BHA.
Contribution: This author helped conduct the study and analyze the data.
Name: Markus M. Luedi, MD, MBA.
Contribution: This author helped design the study, conduct the study, analyze the data, and write the manuscript. Markus Luedi attests to the integrity of the original data and the analysis reported in this manuscript.
This manuscript was handled by: Franklin Dexter, MD, PhD.

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