

Srinivasa N. Raja, M.D., was acting Editor-in-Chief for this article.

Anesthesiology 2003; 98:1243-9

© 2003 American Society of Anesthesiologists, Inc. Lippincott Williams & Wilkins, Inc.

## Operating Room Utilization Alone Is Not an Accurate Metric for the Allocation of Operating Room Block Time to Individual Surgeons with Low Caseloads

Franklin Dexter, M.D., Ph.D.,\* Alex Macario, M.D., M.B.A.,† Rodney D. Traub, Ph.D.,‡ David A. Lubarsky, M.D., M.B.A.§

**Introduction:** Many surgical suites allocate operating room (OR) block time to individual surgeons. If block time is allocated to services/groups and yet the same surgeon invariably operates on the same weekday, for all practical purposes block time is being allocated to individual surgeons. Organizational conflict occurs when a surgeon with a relatively low OR utilization has his or her allocated block time reduced. The authors studied potential limitations affecting whether a facility can accurately estimate the average block time utilizations of individual surgeons performing low volumes of cases.

**Methods:** Discrete-event computer simulation.

**Results:** Neither 3 months nor 1 yr of historical data were enough to be able to identify surgeons who had persistently low average OR utilizations. For example, with 3 months of data, the widths of the 95% CIs for average OR utilization exceeded 10% for surgeons who had average raw utilizations of 83% or less. If during a 3-month period a surgeon's measured adjusted utilization is 65%, there is a 95% chance that the surgeon's average adjusted utilization is as low as 38% or as high as 83%. If two surgeons have measured adjusted utilizations of 65% and 80%, respectively, there is a 16% chance that they have the same average adjusted utilization. Average OR utilization can be estimated more precisely for surgeons performing more cases each week.

**Conclusions:** Average OR utilization probably cannot be estimated precisely for low-volume surgeons based on 3 months or 1 yr of historical OR utilization data. The authors recommend that at surgical suites trying to allocate OR time to individual low-volume surgeons, OR allocations be based on criteria other than only OR utilization (e.g., based on OR efficiency).

MANY surgical suites allocate operating room (OR) block time to individual surgeons.

At some surgical suites, this is done explicitly so that the surgeons can coordinate their clinic schedules with

their OR schedules. This is particularly common at private practice surgical suites.

At other surgical suites, block time is allocated instead to surgical services/groups, each of which may have more than one surgeon. But, if the same surgeon invariably operates on the same days of the week, for all practical purposes, block time is being allocated to individual surgeons.

OR utilization is a commonly used criterion for deciding whether to allocate more or less block time to a surgeon. OR utilization can be computed in two ways, raw and adjusted.<sup>1</sup> Raw utilization is the total hours of elective cases performed within OR block time divided by the hours of allocated block time.<sup>1</sup> Adjusted utilization uses the total hours of elective cases performed within OR block time, including "credit" for the turnover times necessary to set up and clean up ORs.<sup>1</sup> We consider both raw and adjusted utilization in this article.

OR block time allocation decisions that are based on historical raw or adjusted OR utilization may be perceived to be inequitable. Some surgeons may be allocated more OR block time than they use. Other surgeons may be allocated less OR time than they seem to need.

Several explanations are possible for this perceived disparity between the use and assignment of OR block time. One explanation is that these decisions are arbitrary and politically based. A second explanation is that these decisions cannot be made accurately.

The latter may be correct. Previously, we studied how to allocate the least amount of OR block time to assure that a surgeon can care for all of his or her patients needing elective surgery within a reasonable length of time (e.g., 2 weeks).<sup>2</sup> We found that, for a surgeon with an average adjusted utilization of 81%, even 10 yr of simulated data were insufficient to estimate average utilization precisely enough for practical use.

The reason for this seemingly bizarre data requirement is that utilizations of successive OR blocks are correlated to one another. In statistical terms, OR utilization data for individual surgeons are not independent random samples. They are repeated-measures data, also known as longitudinal data, time series data, or quality control data.<sup>3</sup>

\* Associate Professor and Director of the Division of Management Consulting, Department of Anesthesia, University of Iowa, Iowa City, Iowa. † Associate Professor of Anesthesia and Health Research and Policy, Department of Anesthesia, Stanford University, Stanford, California. ‡ Associate Professor, College of Business Administration, North Dakota State University, Fargo, North Dakota. § Professor & Chair, Department of Anesthesiology, University of Miami, Miami, Florida.

From the Division of Management Consulting, Department of Anesthesia, University of Iowa, Iowa City, Iowa. Submitted for publication June 12, 2002. Accepted for publication December 19, 2002. This work was funded solely by institutional sources.

Address reprint requests to Dr. Dexter: Division of Management Consulting, Department of Anesthesia, University of Iowa, Iowa City, Iowa 52242. Address electronic mail to: Franklin-Dexter@Ulowa.edu. Individual article reprints may be purchased through the Journal Web site, www.anesthesiology.org.

For example, suppose that a surgeon has 8 h of OR time at an outpatient surgery center every Tuesday. Then, having 3 months (*i.e.*, 13 weeks) of block time utilization data that surgeon would not be analogous to measuring the effect of an oral drug on the blood pressure of 13 patients. A better analogy would be taking hourly blood pressure measurements on the same patient for 13 h.

The preceding analyses<sup>2</sup> apply to surgeons for whom OR utilizations tend to be moderate to high (*i.e.*, adjusted utilizations greater than 75%). Organizational conflict is likely to occur when a surgeon's OR utilization is relatively low and his or her allocated block time may be reduced.<sup>4</sup> The goal of this study was to use computer simulation to determine whether 3 months or 1 yr of data on OR block time utilization are sufficient to precisely identify surgeons with persistently low OR utilizations.

## Methods

As we have done in other studies,<sup>2,5,6</sup> we designed a mathematical computer model to “act like” a surgical suite with respect to surgical case scheduling. Simulated cases were scheduled into OR block time. After simulating the creation and scheduling of thousands of hypothetical cases, OR utilization was calculated. Mathematical details of the computer simulations are given in the Appendix.

### *Strategy in Using Computer Simulation*

From previous work, we knew many of the factors that tend to increase the number of weeks of data required to estimate OR utilization accurately.<sup>2</sup> We deliberately designed our computer simulations to model hypothetical conditions under which the average OR utilization can be estimated more precisely than it can be under “real world” conditions. By doing so, we assured that our study underestimated the actual widths of confidence intervals (CI) for the average OR utilization.

Specifically, our simulated surgeons never took vacations, got sick, expanded their practices, lost patients, or changed the days of the week when they operate. Thus, the average OR caseloads of the surgeons in the simulation model remained the same for decades. That had the effect of artificially reducing the widths of CIs for the average OR utilization.

To further make sure that our study underestimated the actual widths of CIs for the average OR utilization, we programmed every patient and surgeon to arrive for surgery as scheduled. The intensive care unit, wards, and postanesthesia care unit were never full. Necessary equipment was available for every case.<sup>7,8</sup> No case was ever canceled.

### *Assumptions of the Computer Simulations*

The baseline computer simulations of case scheduling had the following assumptions. We comment on them in the Limitations section of the Discussion.

**Assumption No. 1.** The number of workdays between requests of successive patients to be scheduled for surgery was exponentially distributed.<sup>9</sup> The exponential distribution is characterized by the mean number of patients each week who request surgical care. The use of the exponential distribution for patient arrivals implies that the timing of a patient request for surgery is not affected by how many days the patient expects to wait to have surgery. It also implies that the decision of one patient to be scheduled for surgery does not affect the decision of another patient to be scheduled for surgery.

**Assumption No. 2.** Each case was assigned a time duration generated randomly from a log-normal distribution with mean  $\pm$  SD = 3.79  $\pm$  2.36 h.<sup>2,3,5</sup> This log-normal distribution describes the durations of cases performed at the main surgical suite of the University of Iowa.<sup>5</sup> These cases are a mixture of routine and specialized procedures, performed on an inpatient, same-day admit, or outpatient basis. The lower and upper quartiles of case duration were 2.2 h and 4.7 h. By using historical case durations to schedule cases, we assured that the cumulative hours of underutilized OR time (*i.e.*, the time that a case is completed early) was approximately equivalent to the cumulative hours of overutilized OR time (*i.e.*, time that a case is completed late).<sup>10,11</sup>

**Assumption No. 3.** Scheduled turnover times (“patient out” to “patient in”) were 30 min.

**Assumption No. 4.** All surgeons were allocated one 8-h block of OR time each week.

**Assumption No. 5.** When a patient requests to be scheduled for surgery, the case is scheduled to be performed on the earliest possible date with sufficient open block time for the case.

**Assumption No. 6.** Patients balk (*i.e.*, leave the queue for surgery) if they have to wait more than 4 weeks for surgery. This means that they either receive care at a different surgical suite, with a different surgeon, or do not have surgery.

### *Analyzing Simulation Output to Calculate Confidence Intervals for Average OR Utilization*

Each computer simulation used a different mean number of patients requesting each week that they be scheduled for surgery (assumption No. 1). Each computer simulation produced 10,000 3-month or 1-yr periods.

We computed the OR utilization for each of these 10,000 periods. The average of the 10,000 measurements of OR utilization was taken as the average OR utilization (*i.e.*, the expected value of OR utilization). This average OR utilization was plotted on the vertical axes of the figures. The 2.5th, 5th, 95th, and 97.5th

percentiles of the 10,000 measurements were plotted along the horizontal axes of the figures. The 2.5th and 97.5th percentiles provided 95% CIs for the average OR utilization. The 5th and 95th percentiles provided 90% CIs for the average OR utilization.

#### *Understanding the Reasons for Our Results (Sensitivity to Assumptions)*

Auto-correlation is the measure of the degree of correlation between successive measurements. We measured the correlation between the OR utilizations of successive blocks for 50,000 consecutive blocks. Note that, based on assumption No. 4, consecutive blocks are equivalent to consecutive weeks.

We repeated the simulations using the mean numbers of patients requesting to be scheduled for surgery that achieved correlation coefficients of 0.3 and 0.1, respectively.

Dependence of autocorrelation on average utilization can be accounted for by the two sources of random variation in the simulations: random variation in the numbers of patients each week requesting to be scheduled for surgery and random variation in case durations. To evaluate which source of random variation was more important, we assessed the sensitivity of our results to the mean and the SD of case duration. We repeated the analyses while assigning every case a fixed duration of 3.75 h. Since the simulated surgeon had one 8-h block each week (assumption No.4 above), the surgeon could perform 0, 1, or 2 cases weekly. Utilizations of each block could be 0% ( $[0] \div 8$  h), 47% ( $[3.75] \div 8$  h), or 100% ( $[3.75 + 0.5 + 3.75] \div 8$  h). Finally, we assigned every case a fixed duration of 25 min and used a turnover time of 5 min.

## Results

The absolute width of the CI for the average OR utilization is important because it affects the utility of the OR utilization metric for purposes of allocating OR block time. We found that each reduction in the measured OR utilization caused an increase in the width of the 95% CI.

With 3 months of data, the differences between the upper and lower limits of the 95% CIs exceeded 10% for average adjusted utilizations of 90% or less (fig. 1).

With 1 yr of data, the differences exceeded 10% for average adjusted utilizations of 87% or less (fig. 2).

The results were similar for raw utilization. With 3 months of data, the differences exceeded 10% for average raw utilizations of 83% or less (fig. 3).

Suppose that, during a 3-month period, two surgeons have adjusted utilizations measured at 65 and 80%, respectively. An OR manager or surgical committee needs to decide whether to reduce the block time of the surgeon with the 65% adjusted utilization to give the

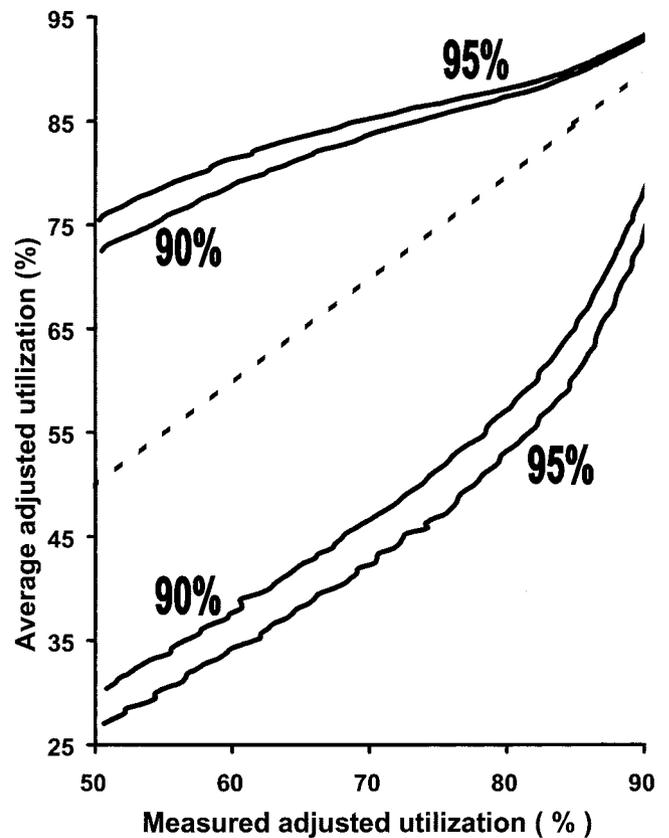


Fig. 1. Adjusted operating room (OR) utilizations obtained with 3 months of historical data. The average adjusted OR utilization is the independent variable in the computer simulations. The dashed line is the line of equality between average adjusted OR utilizations and measured adjusted OR utilizations. The pair of lines labeled with “90%” give 90% CIs for average adjusted OR utilizations obtained by using 3 months of data. The next pair of lines labeled “95%” give the corresponding 95% CIs. For example, if a hypothetical surgeon’s measured adjusted utilization is 80% during a 3-month period, then the 95% CI for the average adjusted utilization ranges from 53% to 88%. In more “real world” conditions (e.g., surgeon takes vacation or cases are cancelled), the CIs would be wider.

time to the surgeon with the adjusted utilization of 80%. Analysis of the computer simulations used to create figure 1 revealed that there is at least a 16% chance that the surgeon with the lower measured utilization does not actually have a lower average utilization (*i.e.*, that the difference was due just to random error).

#### *Understanding the Reasons for Our Results (Sensitivity to Assumptions)*

Correlation coefficients between utilizations of successive blocks varied depending on the average utilization. The autocorrelation was low (e.g., less than 0.1) when the average utilizations were relatively high (e.g., adjusted or raw utilizations exceeding 87 and 81%, respectively) (fig. 4).

In figure 5, all simulated cases had the same case durations, but the CIs were wider than in figure 1. Consequently, the predominant cause of autocorrelation

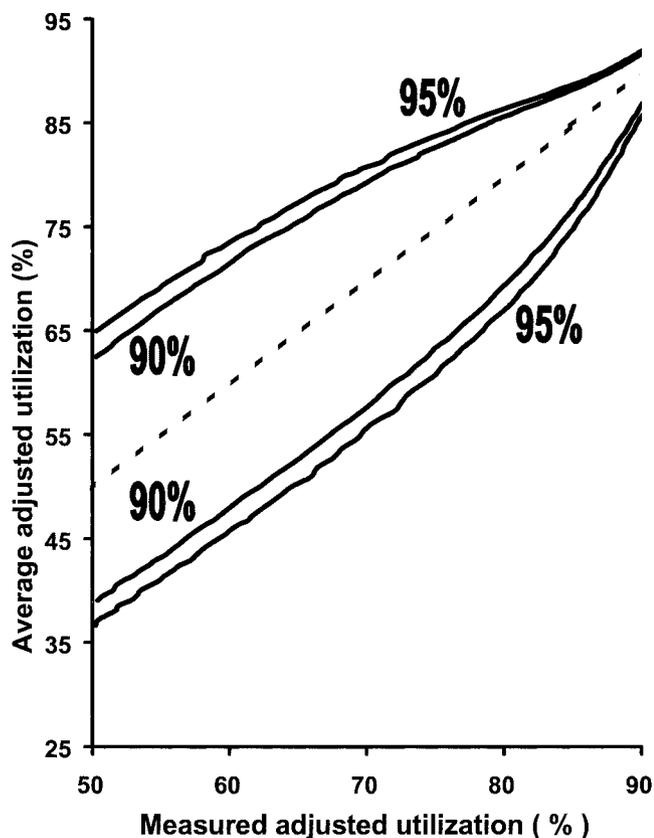


Fig. 2. Confidence intervals (90% and 95%) for average adjusted average operating room utilizations obtained by using 1 yr of data. The same axes are shown as seen in figure 1. Please refer to the figure 1 for details.

and wide CIs was random variation in the numbers of patients each week requesting to be scheduled for surgery. At the higher OR utilizations, random variation in case duration affected whether a case could be scheduled into any one block. This reduced the autocorrelation (fig. 4) and thus reduced the widths of the CIs (figs. 1 and 5).

Simulations with cases of 25-min durations (fig. 5) show that our results are sensitive to the number of patients who can have surgery in OR block time each day. Average OR utilization can be estimated more precisely when more patients have surgery in OR block time each week.

## Discussion

### Implications

Confidence intervals for the average OR utilizations are wider than OR managers may predict intuitively. This is partly because successive measurements of OR utilization are correlated with one another. Although increasing the amount of historical data from 3 months to 1 yr decreases the statistical uncertainty about a surgeon's average utilization, CIs remain wide. Most importantly,

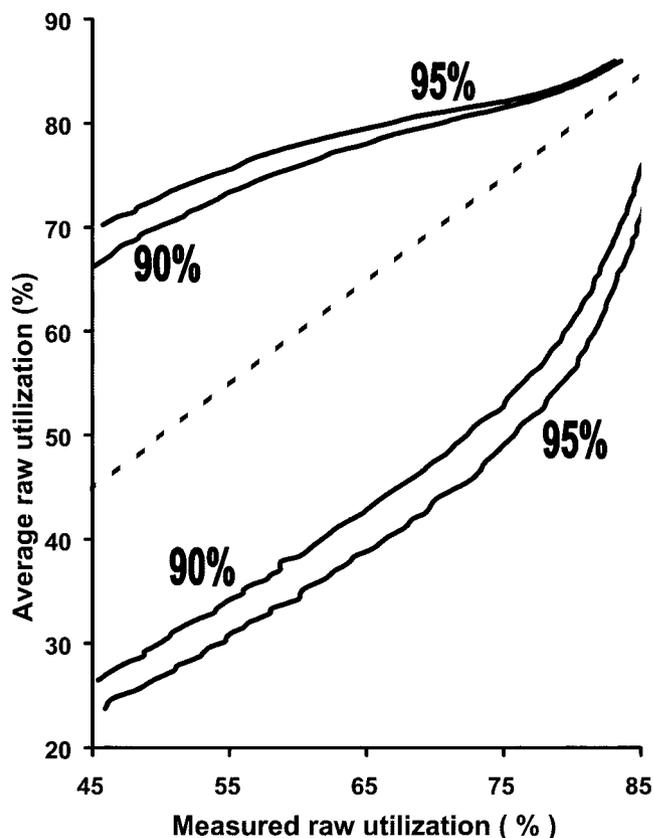


Fig. 3. Raw operating room (OR) utilizations obtained with 3 months of historical data. The average raw OR utilization is the independent variable in the computer simulations. The dashed line is the line of equality between average raw OR utilizations and measured raw OR utilizations. The pair of lines labeled with "90%" give 90% CIs for average raw OR utilizations obtained by using 3 months of data. The next pair of lines labeled "95%" give the corresponding 95% CIs. For example, if the measured raw utilization of a hypothetical surgeon is 70% during a 3-month period, then the 95% CI for the average raw utilization ranges from 44 to 81%.

each reduction in the measured utilization causes an increase in the width of the CIs.

Thus, OR utilization is the least accurate for precisely those surgeons for whom it is likely to matter. For example, suppose that, during one quarter, the measured adjusted utilization is 65% for a surgeon. Then, the average adjusted utilization could be as low as 38% or as high as 83% for that surgeon. With 1 yr of data, the average adjusted utilization for that surgeon ranges between 50 and 78%.

Our results show that 3 months or 1 yr of OR caseload data alone are insufficient to estimate raw and adjusted utilizations precisely enough for use in making statistically sound data-driven decisions on OR block time allocation for individual surgeons. The problem is not in trying to estimate average OR utilization precisely *per se*, but in trying to do so for individual surgeons rather than groups of surgeons.

Our results are important because the allocation of OR time to individual surgeons using only historical OR

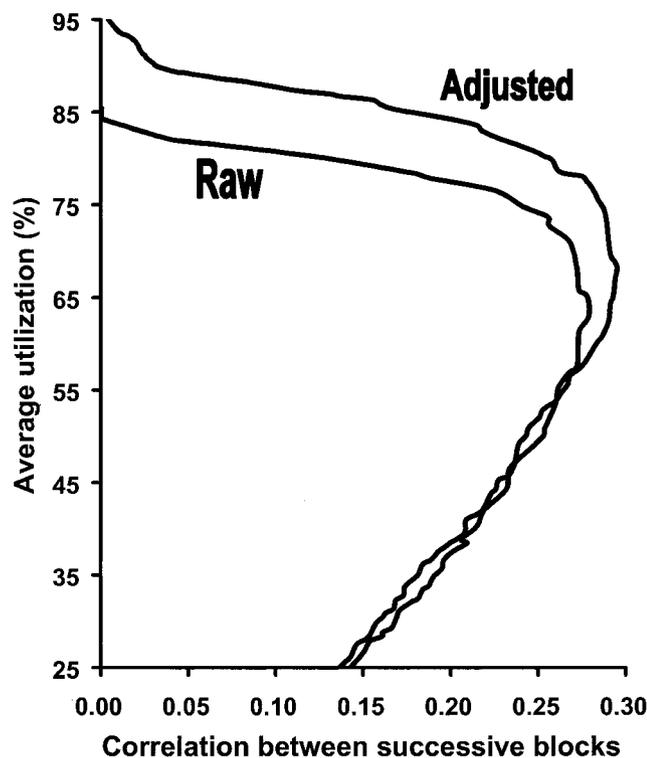


Fig. 4. Measured correlations between the adjusted and raw utilizations of successive blocks. The average adjusted and raw OR utilizations are the independent variables in the computer simulations. They are plotted on the vertical axis, as in Figs. 1–3. “Adjusted” and “Raw” in the figure identify curves for adjusted utilization and raw utilization, respectively. Auto-correlations are plotted on the horizontal axis. The figure shows that the correlations between utilizations of successive OR blocks are correlated.

utilization, as the data-driven component of that decision, is a widespread practice. At many facilities, the OR manager may claim that the block time is being allocated to surgical services/groups, not to individual surgeons. However, if the services then simply allot their OR time by surgeon, then the OR time has in effect been allocated to the surgeons.

#### Statistically Sound Solutions to the Problem

Most surgical suites in the United States perform all cases scheduled by its surgeons, provided a case can be done safely. The cases may need to be scheduled as “add-on” or called “urgent,” but the cases are done. At such a surgical suite, OR time is allocated not because the surgical suite has only a fixed number of hours of OR time available, but as a way to care efficiently for all of the patients undergoing surgery.<sup>12</sup>

If too much OR time is allocated, then utilization is low, which reduces OR efficiency (*i.e.*, the weighted sum of underutilized and overutilized OR time).<sup>12,13</sup> If too little OR time is allocated, then the staff work late, which also reduces OR efficiency.<sup>12,13</sup> The allocation of OR time providing the optimal balance maximizes OR efficiency. Methods are available to accurately calculate

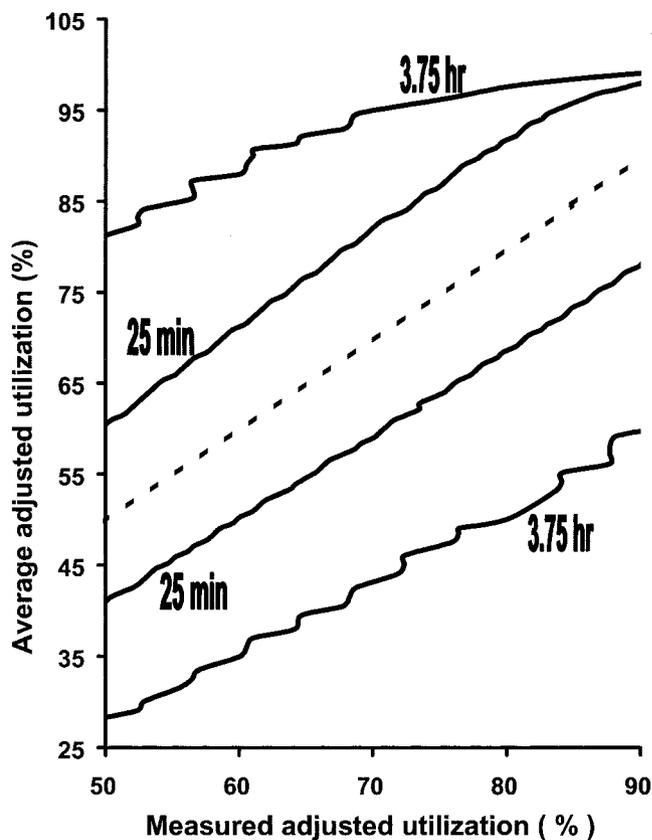


Fig. 5. Confidence intervals (90 and 95%) for average adjusted operating room utilizations obtained by using 3 months of data, while having all cases exactly the same duration: 3.75 h or 25 min. The average adjusted OR utilization is the independent variable in the computer simulations. The duration of 3.75 h matches the mean duration of cases in Figs. 1–4. The figure shows that average OR utilization can be estimated more precisely for surgeons who care for more patients each week in OR block time. Numbers of cases matters, not hours of cases.

the optimal OR allocation, whether the surgeon and patient choose the day of surgery<sup>12–17</sup> or whether all of the surgeons’ patients receive care within a predetermined reasonable number of days.<sup>2,6,14,18,19</sup> The latter methods<sup>2,6,14,18,19</sup> reduce uncertainty in OR utilization, caused by the autocorrelation described in the current paper, while still including some OR time allocated to individual surgeons. These methods to determine optimal OR allocations to maximize OR efficiency are statistically reliable, practical, and not related to measuring OR utilization.<sup>2,12–18</sup> By using these methods, the problem described in this article is avoided entirely. We recommend allocating OR time based on OR efficiency.

Some administrators are reluctant to use these methods<sup>2,6,12–19</sup> for outpatient and same-day-admit surgery patients at facilities with a fixed, externally determined, annual budget (*e.g.*, in Canada or a county hospital in the United States). Some of these facilities really may have fixed hours of OR time, because otherwise they would run a deficit. For facilities truly having fixed hours of OR time, methods have been developed to allocate OR block

time and schedule cases while considering restrictions on the facility budget,<sup>7,20,21</sup> even with limits on hospital bed availability.<sup>7,21-24</sup> Factors that can be included in the analysis, in addition to OR utilization, are strategic objectives of the facility, future externally determined annual budgets, and productivity. For example, block time can be allocated not by determining the time needed for all of the cases for one surgeon,<sup>2</sup> but by planning enough block time to perform most of the cases within the regular block time for that one surgeon.<sup>2</sup> As many as possible of the remaining cases are performed in other OR time scheduled on a first-come-first-serve basis, either allocated to all surgeons or to services.<sup>6,19</sup> That way, the surgical suite gets a high OR utilization and surgeons get some individually allocated OR time. These methods<sup>2,6,7,20-24</sup> differ from the current study in that the OR management goals are not to allocate the right amount of OR time to each surgeon. Instead, the goals (for good or for bad depending on the perspective) are to maximize surgical suite objectives at the expense of some surgeons who may lose OR time based on random error.

#### *Other Reasons for Not Using Utilization As the Only Criterion for Allocating OR Block Time*

We recommend that OR utilization alone not be used to allocate OR block time to individual surgeons because that application of it is unreliable statistically (figs. 1-3). There are four other important reasons why we recommend that OR utilization not be used for this purpose.

First, allocating OR block time based on utilization does not consider the resulting effect on hospital ward and intensive care unit bed availability.<sup>7,21-24</sup> For example, at hospitals with 100% midnight occupancy of ward and intensive care unit beds, it make sense to preferentially increase OR block time allocations to surgeons who perform mostly outpatient surgery.

Second, the hospital contribution margin (revenue minus variable costs) achieved from allocated OR time can vary several hundred percent among surgeons with the same OR utilization.<sup>7,20</sup> The hospital may benefit from allocating more OR block time to surgeons who achieve a high contribution margin per hour of OR time.

Third, hospital variable costs resulting from each hour of OR time varies several hundred percent among surgeons.<sup>20,21</sup> Suppose that more OR time is allocated to a surgeon with a relatively high OR utilization but also high variable costs per allocated hour of OR time. Then, allocating more OR time to that surgeon may result in higher hospital variable costs. At hospitals with a fixed annual budget, this may result in deficit spending.

Fourth, efforts to increase OR utilization can reduce the operating margin of a hospital.<sup>5</sup> For example, a hospital may sign more reduced fee-for-service contracts to increase the number of patients that can receive care at the hospital. But, each increase in the percentage OR utilization can be at the expense of a larger increase in

the average patient waiting time, prompting patients to seek care elsewhere. The net effect of signing more discounted contracts to increase patient volume can be a net reduction in the average revenue per case and overall hospital perioperative margin.<sup>5</sup>

#### *Limitations: Analyzing the Cause of Auto-correlation (Sensitivity to Assumptions)*

Figures 4 and 5 provide an understanding of the results shown in figures 1 to 3. Understanding the reason for our results is important, because this is how it is known that the results can be generalized to many surgical suites.

Figures 4 and 5 show that the case duration, the variation of duration in each case from its scheduled duration, the turnover time, the duration of OR block time, *etc.*, are unlikely to have important effects on our conclusions other than to the extent that they influence the average number of cases done per week.

As explained in the Results, figures 4 and 5 show that our results are sensitive to the pattern and frequency of arrival of requests from patients to be scheduled for surgery. In fact, it is the combination of the surgeon and patient together that matters, in that for convenience, we modeled the surgeon as never taking vacation or getting sick. Nonetheless, we assumed that there is never a change in an average OR caseload for a surgeon or in the days of the week when the surgeon operates at the surgical suite. We also assumed that every patient arrived as scheduled, the intensive care unit was never full requiring case postponement, and necessary equipment was available for every case. As explained in the Methods, to the extent that, by design, none of these assumptions reflect the extent of the variance in the real world, the results of figure 4 and 5 suggest that our CIs in figures 1-3 are likely narrower than in the real world.

Average OR utilization is least likely to be estimated precisely for a surgeon who does one or two long cases each week, but often changes his or her day of surgery because of other commitments, skips one week but operates twice the next week, and so forth. This pattern likely arises most often at academic medical centers. Therefore, our results may be most important for academic practices.

Average OR utilization is most likely to be estimated precisely for a surgeon with many very short cases and a high OR utilization. This would be analogous to a surgical clinic or office-based practice. Utilization may be a good basis for planning clinic-based resources. The experience of surgeons and hospital administrators in clinic management is not analogous to OR management, because many surgical suites average only two cases per OR per day.<sup>25</sup>

The sensitivity of our results to the pattern and frequency of arrival of patient requests to be scheduled for surgery represented a challenge to us in designing a final set of

simulations for presentation. The strategy we chose (see Methods) was to systematically underestimate the widths of CIs for the average OR utilization. This has a clear drawback. Although we increased the likelihood that our conclusions are sound for surgeons with low caseloads, we do not know the magnitude of our safety factor. We do not know how to determine how many cases per OR per day that a surgeon needs to do in order for utilization to be measured sufficiently precisely for reasonable management decision-making. We know that it is more than a couple of cases a week. However, whether a reasonable number is four, eight, *etc.*, is not evident from our study.

## Conclusions

We evaluated whether average OR utilization can be estimated precisely for a surgeon who performs a few cases a week in his or her 8 h of allocated OR time. We showed that for such a surgeon, neither average adjusted nor raw OR utilization can be estimated precisely using routine statistical methods with either 3 months or 1 yr of OR block time utilization data. We recommend that, at surgical suites trying to allocate OR time to a surgeon with a low volume of surgical cases, OR management decision-making not be based only on the simple average of historical utilizations. We recommend using the statistically sound alternative of allocating OR time based on OR efficiency.<sup>12-17</sup>

## Appendix

We wrote the computer code in Excel Visual Basic 6.0 (Microsoft, Redmond, WA) to perform each simulation in the following sequence.

### Step 1

The computer used a random number generator<sup>3</sup> to generate the length of time (*e.g.*, 0.5 days) until the next patient requests to be scheduled for surgery, as specified by assumption No. 1 (see Methods).

### Step 2

The computer used a random number generator to generate the duration of the new case from step 1, using assumption 2. Scheduled case durations were right-truncated at 8 h (assumption 4), so that the cases could be scheduled at the simulated surgical suite.

### Step 3

Using the time remaining in each future block, the duration of the case from step 2, and the turnover time from assumption 3, the computer determined the available surgical date for the new case (assumption 5). If there was insufficient time for the case within 4 weeks, then the patient was considered to balk (assumption 6).

### Step 4

After one quarter or 1 yr of simulated time has passed, the average utilization during the preceding quarter or year was calculated.

### Step 5

If fewer than 10,010 quarters or years were simulated, the simulation returned to step 1.

### Step 6

The last 10,000 of the 10,010 quarters or years were analyzed as described in the Methods section "Analyzing simulation output. . ." The first 10 quarters or years were ignored for analysis, to eliminate the effect of the start-up conditions on simulation results.

## References

1. Donham RT, Mazzei WJ, Jones RL: Procedural times glossary. *Am J ANESTHESIOLOGY* 1996; 23(5 Suppl):4-12
2. Dexter F, Macario A, Traub RD, Hopwood M, Lubarsky DA: An operating room scheduling strategy to maximize the use of operating room block time. Computer simulation of patient scheduling and survey of patients' preferences for surgical waiting time. *Anesth Analg* 1999; 89:7-20
3. Law AM, Kelton WD: *Simulation Modeling and Analysis*, 2nd edition. New York, McGraw-Hill, 1991, pp 284-285, 337, 486, 491, 492, 551-553
4. Blake JT, Dexter F, Donald J: Operating room managers' use of integer programming for assigning allocated block time to surgical groups: a case study. *Anesth Analg* 2002; 94:143-8
5. Dexter F, Macario A, Lubarsky DA: Impact on revenue of increasing patient volume at surgical suites with relatively high operating room utilization. *Anesth Analg* 2001; 92:1215-21
6. Dexter F, Macario A, O'Neill L: Scheduling surgical cases into overflow block time: Computer simulation of the effects of scheduling strategies on operating room labor costs. *Anesth Analg* 2000; 90:980-6
7. Dexter F, Blake JT, Penning DH, Lubarsky DA: Calculating a potential increase in hospital margin for elective surgery by changing operating room time allocations or increasing nursing staffing to permit completion of more cases: a case study. *Anesth Analg* 2002; 94:138-42
8. Gallivan S, Utley M, Treasure T, Valencia O: Booked inpatient admission and hospital capacity: Mathematical modelling study. *BMJ* 2002; 324:280-2
9. Hall RW: *Queueing Methods for Services and Manufacturing*. Englewood Cliffs, NJ, Prentice Hall, 1991, pp 272-274
10. Macario A, Dexter F: Estimating the duration of a case when the surgeon has not recently performed the procedure at the surgical suite. *Anesth Analg* 1999; 89:1241-45
11. Dexter F, Traub RD, Qian F: Comparison of statistical methods to predict the time to complete a series of surgical cases. *J Clin Monit Comput* 1999; 15:45-51
12. Strum DP, Vargas LG, May JH, Bashein G: Surgical suite utilization and capacity planning: a minimal cost analysis model. *J Med Syst* 1997; 21:309-22
13. Strum DP, Vargas LG, May JH: Surgical subspecialty block utilization and capacity planning: A minimal cost analysis model. *ANESTHESIOLOGY* 1999; 90:1176-85
14. Dexter F, Macario A: Changing allocations of operating room time from a system based on historical utilization to one where the aim is to schedule as many surgical cases as possible. *Anesth Analg* 2002; 94:1272-9
15. Dexter F, Epstein RH, Marsh HM: Statistical analysis of weekday operating room anesthesia group staffing at nine independently managed surgical suites. *Anesth Analg* 2001; 92:1493-8
16. Epstein RH, Dexter F: Statistical power analysis to estimate how many months of data are required to identify operating room staffing solutions to reduce labor costs and increase productivity. *Anesth Analg* 2002; 94:640-3
17. Dexter F, Traub RD: How to schedule elective surgical cases into specific operating rooms to maximize the efficiency of use of operating room time. *Anesth Analg* 2002; 94:933-42
18. Dexter F, Macario A, Qian F, Traub RD: Forecasting surgical groups' total hours of elective cases for allocation of block time: Application of time series analysis to operating room management. *ANESTHESIOLOGY* 1999; 91:1501-8
19. Dexter F, Macario A, Traub RD: Which algorithm for scheduling add-on elective cases maximizes operating room utilization? Use of bin packing algorithms and fuzzy constraints in operating room management. *ANESTHESIOLOGY* 1999; 91:1491-1500
20. Macario A, Dexter F, Traub RD: Hospital profitability per hour of operating room time can vary among surgeons. *Anesth Analg* 2001; 93:669-75
21. Dexter F, Blake JT, Penning DH, Sloan B, Chung P, Lubarsky DA: Use of linear programming to estimate impact of changes in a hospital's operating room time allocation on perioperative variable costs. *ANESTHESIOLOGY* 2002; 96:718-24
22. Gerchak Y, Gupta D, Henig M: Reservation planning for elective surgery under uncertain demand for emergency surgery. *Manag Sci* 1996; 42:321-4
23. Young JP: Stabilization of inpatient bed occupancy through control of admissions. *Hospitals* 1965; 39:41-8
24. Hancock WM, Martin JB, Storer RH: Simulation-based occupancy recommendations for acute medical/surgical units using admission scheduling systems. *Inquiry* 1978; 15:25-32
25. Solovy A: Benchmarking guide 99. *Hosp Health Network* 1999; 73:49-62