Influence of the Operating Room Schedule on Tardiness from Scheduled Start Times

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BACKGROUND: Tardiness from scheduled start times in a surgical suite is a common source of frustration for both operating room personnel and patients.

METHODS: Data from two surgical suites were used to investigate the relative importance of various factors that contribute to tardiness, including average case duration, time of day, prolonged turnovers, whether a surgeon follows himself or another surgeon, the potential for starting cases early, concurrency (e.g., number of residents supervised simultaneously), expected under-utilized or over-utilized time, and case duration bias.

RESULTS: Average tardiness per case did not depend on the individual durations of preceding cases or on the relative numbers of long and short cases. In contrast, the total duration of preceding cases was important in determining tardiness. Tardiness per case grew larger as the day progressed because the total duration of preceding cases increased, but began to decline for cases scheduled to commence 6 h after the start of the workday. Tardiness was not affected by prolonged turnovers, differences in average case duration among services, or whether a surgeon followed himself or another surgeon in the same operating room. Tardiness was affected by expected under-utilized or over-utilized time at the end of the workday and by case duration bias.

CONCLUSIONS: Factors associated with the largest numbers of cases had the biggest influence on tardiness. Greater understanding of these factors aided in the development of several mathematical interventions to reduce tardiness in the two surgical suites. These interventions and their applicability for reducing tardiness are described in a companion article. At two surgical suites, tardiness from scheduled start times did not depend on average case duration or prolonged turnovers. Tardiness did depend on the total duration of preceding cases, expected under-utilized or over-utilized time at the end of the day, and case duration bias.

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Cases that begin later than their scheduled start times are a source of frustration for both operating room (OR) personnel and patients. Tardy starts can result in cases finishing late and can cause over-utilized OR time. Over-utilized time occurs when the OR runs past the usual end of the workday for which staffing has been planned.[1,2] Depending on staff scheduling, OR personnel may then have to stay late and may have to be paid overtime wages. When cases are tardy, a surgeon scheduled to follow another surgeon in the same OR may become irritated if his cases cannot start on time. Patient satisfaction may be reduced if cases are delayed beyond their scheduled start times, especially if patients have been waiting for several hours without food or drink. Cases scheduled for later in the day may even be cancelled.[3,4]

One cause of tardiness is inaccuracy in predicting case durations,[3,5–10] even after accounting for procedure and type of anesthetic.[11,12] In this article, we quantify the relative impact of several other quantitative variables on tardiness in two surgical suites. Our goal was to design mathematical interventions that would reduce tardiness, as presented in the companion article that follows.[13] Modifications in human behavior or changes in OR processes are not considered here.

Tardiness for each case was defined as the difference between the time the patient actually entered the OR and the scheduled start time of the case.[14] If a case started early or on-time, tardiness was zero for that case.

"Tardiness" is the appropriate metric for quantifying the extent to which a surgical suite runs behind

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schedule.[14] The number or percentage of cases that begin late is misleading.[14] Suppose that three cases were performed in OR #1 on a specific day. One case started on time, whereas the other two each started 10 min late (i.e., 67% of cases started late). Now suppose three cases were performed in OR #2. Two cases started on time, whereas the third began 1 h late (i.e., 33% of cases started late). The former scenario results in much less disruption to the OR schedule even though the percentage of cases starting late is greater.

Factors that could potentially influence tardiness include average case duration, time of day, prolonged turnovers, whether a surgeon follows himself or another surgeon, the potential for starting cases early, concurrency (e.g., number of residents supervised simultaneously), expected under-utilized or over-utilized time, and case duration bias. The tardiness experienced by surgeons differs from the tardiness experienced by patients.

Once those factors with the greatest effects on tardiness were identified, the information was used to develop adjustments to the OR schedule that could reduce tardiness. As described in our companion article,[13] these adjustments do not require changing staff behavior. Instead, they use relatively simple mathematical "corrections" to revise the OR schedule to compensate for predictable causes of tardiness.

METHODS

Data were from all surgical cases performed at an academic medical center in either its tertiary surgical suite of 24 ORs (MAIN suite), or in its ambulatory surgery center (ASC) suite of six ORs. Analysis was limited to cases performed on scheduled workdays from January 2005 to December 2006. Weekends and holidays were excluded. The number of cases performed was 26,003 in the MAIN suite, of which 2871 were added the day of surgery, and 11,541 in the ASC, of which 122 were added the day of surgery. The two suites were analyzed separately.

Tentative room assignments, scheduled start times, and predicted case durations were available for all cases listed on the "final" surgery schedule issued about noon the working day before surgery. The "final" schedule did not include cases added later that afternoon or on the day of surgery. Archived data on actual room assignments, scheduled start times, predicted case durations, the times that each patient entered and exited the OR, primary surgeon, and anesthesiologist of record were subsequently available for all cases. These data permitted determination of tardiness, earliness, turnover times, concurrencies, scheduled length of the workday, actual length of the workday, case durations, and case duration bias.

Tardiness and Waiting Times

Tardiness, as defined in the Introduction, was expressed as the average of: i) tardiness per case, ii) total tardiness per OR per day for all cases in an OR, or iii) total tardiness per day for all cases in all ORs in a suite.

Average tardiness per case represents the average waiting time of each patient. If a case is tardy, the patient must wait, either in a waiting room, examination room, or holding area, because the patient is not wheeled into the OR until past the time he expected his case to begin. The numerator of total tardiness per OR per day is the sum of waiting times for all patients. The average of total tardiness per OR per day is easy to comprehend in terms of its impact on OR activities. It was calculated for each 4-wk period by dividing the total tardiness for the entire suite by the number of ORs in use.

An OR was considered in use on any particular day if one or more cases scheduled at least a day in advance were performed in that OR. Thus, an OR reserved for orthopedic and trauma cases that performed only urgent add-on cases, all scheduled the day of surgery, was excluded from calculations of average tardiness per OR per day.

Total tardiness per day was presented for all cases in a suite, rather than by OR, when tardiness was analyzed based on surgical service. On a given day, more than one service sometimes performed cases in the same OR. Thus, simply counting the number of ORs in use by each service would yield spurious results. Each OR would have to be prorated according to the fraction of the workday it was occupied by each service. Quantifying the average of total tardiness per suite eliminated the problem of trying to split ORs between surgical services.

Tardiness and the OR Schedule

For calculations of tardiness, scheduled start times were derived from the "final" surgery schedule. This schedule was used by the OR manager to make room assignments and determine anesthesia staffing for the following day. Patients were contacted by telephone and told when to arrive at the hospital based on the scheduled start times listed on this version of the schedule. Numerous updates were issued, continuing throughout the day of surgery. Revisions to the schedule arising from cancellations, add-ons, changes in planned procedures, etc., resulted in hourly updates of case start times. However, these updates did not alter patient or "to follow" surgeon expectations of when their cases should begin. Patients and surgeons were not notified of some updates and, regardless, had already made their plans. Expectations were therefore based on the "final" schedule issued the previous day.

Cases that were not listed on the "final" schedule, but were still scheduled at least 1 calendar day in advance, were included in determinations of tardiness. Cases added the day of surgery were not included. Such add-on cases were performed whenever time was available, and thus often did not have planned start times. In addition, the consequences of tardiness, such as surgeon inconvenience, were less for add-on cases.

Earliness

Earliness for each case was calculated as the positive difference between its scheduled start time and its actual start time. If the scheduled start time for a case was later than its actual start time, earliness for that case was the difference between the two times. If a case started late or on time, earliness was zero for that case. First cases of the day were not included in calculations of earliness, since the earliness of first cases averaged 7 s in the MAIN suite and 8 s in the ASC.

First-Case-of-the-Day Starts

A case was considered a first-case-of-the-day start[15] if it was performed as the first case of the day, and was either scheduled to begin within 30 min of the start of the scheduled workday (start of workday 8:00 AM Mondays and Tuesdays; 7:15 AM Wednesdays, Thursdays, and Fridays), or was moved forward in the schedule so that it actually began within 30 min of the start of the scheduled workday. When calculating the average earliness of first cases, however, cases were included only if they were originally scheduled to be first cases based on the "final" schedule.

Analyses were repeated after excluding first cases of the day. Tardiness was much less for first cases of the day relative to other cases (Table 1), and thus they shifted the distribution of tardiness values toward shorter times. Tardiness measured after excluding first cases of the day provides a better picture of the extent to which subsequent cases ran later than scheduled.

Prolonged Turnovers

A turnover time was considered prolonged if it was at least 15 min longer than the average for the surgical suite, as described previously.[16] The average for each suite was determined by taking the average of 25 four-wk periods. When estimating the average, values longer than 90 min in the MAIN suite and 75 min in the ASC were excluded.[16] These typically included gaps in the OR schedule because of nonsequential case scheduling, not just cleanup and setup times. However, such long values were still considered prolonged turnovers. Tardiness was then compared for cases that were preceded by turnovers that were prolonged or not prolonged. The increase in tardiness caused by prolonged turnovers was also apportioned across all cases to determine its impact on tardiness for the entire suite.

Average turnover times in the MAIN suite and the ASC were 35 ± 1 min and 21 ± 1 min, respectively. Any turnovers that were at least 50 min and 36 min in duration were considered prolonged.[16]

List of Cases

The series of cases that a surgeon is scheduled to perform sequentially in the same OR on a single day was considered the surgeon's "list of cases." Intervening turnovers were included in the time to complete the list of cases.

"To Follow" Surgeons

If one surgeon is scheduled to follow another surgeon in the same OR, and cannot begin his list of cases until the first surgeon finishes, the second surgeon is considered a "to follow" surgeon.

Concurrency

Concurrency is the number of ORs for which an anesthesiologist is providing simultaneous medical direction of multiple resident physicians, Certified Registered Nurse Anesthetists (CRNAs), or nurse anesthesia students. We considered the concurrency for a case to be 1 if the anesthesiologist was not listed as the supervising staff for any other case that overlapped in time. Tardiness values were compared for cases with concurrencies of 1 and cases with concurrencies greater than 1.

Under-Utilized and Over-Utilized Time

Under-utilized time is the hours for which staffing had been planned but the OR sat idle.[1,2] Over-utilized time is the hours that cases extended beyond the length of the workday for which staffing had originally been planned.[1,2,17]

The ideal length of the workday for which staffing and case scheduling should be planned was first determined for both the MAIN suite and the ASC. Because of the expense of overtime wages and the intangible price of having staff work beyond the end of their scheduled shifts, the cost of over-utilized time was considered to be twice the cost of under-utilized time.[1,2] Consequently, ORs should finish early 2/3 of the time and finish late only 1/3 of the time. The optimal length of the workday is equal to the 67th percentile of the actual length of all workdays. Confidence intervals (CI) for the 67th percentile were determined using the Clopper-Pearson method.[18] The optimal length of the workday was 10 h in the MAIN suite (95% CI 9 h 55 min–10 h 3 min) and 8 h in the ASC (95% CI 7 h 54 min–8 h 5 min). The actual length of each workday was the difference between the scheduled start of the workday and the time that the last patient of the day exited the OR.

The efficiency of use of OR time is determined by the extent to which case scheduling is matched to the length of the staffed workday. In practice, 34% of ORs in the MAIN suite and 38% of ORs in the ASC finished late, close to the desired value of 1/3. Under-utilized time was approximately twice over-utilized time in each suite (Table 1). However, at least 1 OR had over-utilized time on 100% of days in the MAIN suite and 86% of days in the ASC.

The tardiness of last cases of the day that were expected to produce under-utilized time or over-utilized time was compared with the tardiness of last

Table 1. Summary of Factors Affecting Tardiness

	MAIN surgical suite		ASC	
	Per case	Per OR per day	Per case	Per OR per day
Average case duration	3:24 ± 0:01		1:30 ± 0:01	
Length of scheduled workday		10 h		8 h
Average number of cases per day		2.15 ± 0.02		4.04 ± 0.04
Average tardiness for all cases scheduled at least 1 day in advance[a]	0:29 ± 0:01	1:03 ± 0:01	0:24 ± 0:01*	1:38 ± 0:02*
Average tardiness not including first cases of the day[b]	0:44 ± 0:01*	1:09 ± 0:01[c]*	0:30 ± 0:01*	1:37 ± 0:02*
Average tardiness of first cases of the day	0:08 ± 0:01		0:04 ± 0:01	
Average earliness for all cases scheduled at least 1 day in advance[d]	0:12 ± 0:01	0:27 ± 0:01	0:16 ± 0:01	1:04 ± 0:02
Average earliness not including first cases of the day	0:21 ± 0:01	0:27 ± 0:01	0:20 ± 0:01	1:09 ± 0:02
Average earliness of first cases of the day	0:00:07		0:00:08	
Prolonged turnovers				
Average tardiness of cases following turnovers that were not prolonged	0:43 ± 0:01		0:29 ± 0:01	
Average tardiness of cases following prolonged turnovers[e]	1:00 ± 0:02*		0:42 ± 0:01*	
"To Follow" surgeon tardiness				
Surgeon followed himself	0:45 ± 0:01		0:30 ± 0:01	
Surgeon followed another surgeon[f]	0:45 ± 0:01 ns		0:34 ± 0:01†	
"To Follow" surgeon earliness				
Surgeon followed himself	0:14 ± 0:01		0:17 ± 0:01	
Surgeon followed another surgeon[f]	0:17 ± 0:01*		0:19 ± 0:01 ns	
Concurrency				
Average tardiness for cases in which anesthesiologist provided medical direction for no more than 1 CRNA or trainee	0:33 ± 0:01		0:40 ± 0:01	
First cases of the day	0:07 ± 0:01		0:07 ± 0:01	
Not first cases of the day	0:48 ± 0:01		0:46 ± 0:02	
Average tardiness for cases in which anesthesiologist provided medical direction for >1 CRNA or trainee[g]	0:29 ± 0:01*		0:22 ± 0:01*	
First cases of the day[g]	0:08 ± 0:01 ns		0:04 ± 0:01 ns	
Not first cases of the day[g]	0:42 ± 0:01‡		0:28 ± 0:01*	
Inefficiency of use of OR time				
Average under-utilized time		1:39 ± 0:02		1:01 ± 0:02
Average over-utilized time		0:45 ± 0:01		0:30 ± 0:01
Average tardiness of last cases of the day scheduled to finish at least 2 h earlier than end of usual scheduled workday[h]	0:47 ± 0:01‡		0.43 ± 0.02*	
Average tardiness of last cases of the day scheduled to finish at least 2 h later than end of usual scheduled workday[h]	0:22 ± 0:03*		0.22 ± 0.03†	
Case duration bias per 8 h OR time[i]		0:39 ± 0:01		0:32 ± 0:01

Time values are expressed as h:min and are the average ± SE of 25 four-wk periods. SE less than 1 min are displayed as 1 min (0:01). The MAIN surgical suite consists of 24 ORs and the ASC has 6 ORs. On average, 22.2 ORs in the MAIN suite and 5.8 ORs in the ASC were in use each day for cases scheduled at least a day in advance.

ns = not significant; ASC = ambulatory surgery center; OR = operating room.

[a] ASC compared with MAIN suite.

[b] Compared with tardiness for all cases scheduled at least a day in advance.

[c] Total tardiness per OR per day in the MAIN suite was actually increased when first cases of the day were omitted. This apparently anomalous result can easily be explained by ORs in which only a single case was performed as the first case of the day. Total tardiness per OR per day is simply the tardiness of the first case of the day. When first cases are excluded, the entire OR, with its small value of tardiness, is also excluded.

[d] Mixed effects modeling showed that earliness varied significantly among services ($P < 0.0001$, $F[11,267] = 4.1$), but was unrelated to average case duration ($P = 0.23$, $F[1,267] = 1.5$), even after exclusion of first cases of the day ($P = 0.46$, $F[1,256] = 0.5$).

[e] Compared with tardiness of cases following turnovers that were not prolonged.

[f] Compared with tardiness or earliness when a surgeon followed himself.

[g] Compared with medical direction of no more than one CRNA or trainee.

[h] Compared with tardiness not including first cases of the day when the day was expected to finish on time.

[i] Mixed effects modeling analyzed each surgical service separately for the MAIN suite. Increased case duration bias was associated with increased average tardiness per case ($P < 0.0001$, $F[1,267] = 35.7$), even after exclusion of first cases of the day ($P < 0.0001$, $F[1,260] = 39.1$).

* $P < 0.001$, † $P < 0.05$, ‡ $P < 0.01$; ns not significant.

cases when the workday was expected to end within 2 h of its optimal length. Last cases of the day that were apparently going to finish at least 2 h earlier than the end of the optimal workday created expected under-utilized time. Last cases of the day that were apparently going to finish at least 2 h later than the end of the optimal workday created expected over-utilized time. To estimate the time that each OR was apparently going to finish each day, the predicted duration of the case scheduled to be the last case of the day was added to the actual time the patient entered the OR. Last cases of the day that were also first cases of the day were excluded from this analysis.

Surgical Services

Some data were analyzed based on surgical service. At the hospital studied, block time was planned for 12 surgical services that used the MAIN suite and six services that used the ASC. The services were departments or divisions within the hospital. In practice, each service then apportioned OR time to individual surgeons or small groups of surgeons who practiced in the same specialty or subspecialty.[1,19]

Case Duration Bias

Case duration bias was measured as the difference between i) the actual time required by a service to perform a series of sequential cases in a single OR on the dame day, and ii) the scheduled duration of the series of cases. Case duration bias was calculated separately for each surgical service. Total bias was summed across all series of cases and turnovers performed by a given service within each 4-wk period, then normalized to 8 h of actual OR time used.[1,20] Both positive bias (systematic under-estimation of case durations) and negative bias (over-estimation of case durations) were included in the total. Turnover times were included because they can contribute to tardiness. Although turnovers are not usually included when calculating bias,[19] we use the phrase "case duration bias" anyway because almost all bias will be caused by the cases rather than the turnovers.

Analysis of bias was limited to the MAIN suite. In the ASC, average case duration bias was strongly correlated with average case duration. The surgical service with the shortest case times had the highest average bias, and the service with the second longest case times had the lowest average bias. Thus, the effect of case duration bias on tardiness could not be determined independently.

Statistical Analyses

Data calculations and paired Student's *t*-test were performed in Excel or Excel Visual Basic for Applications. Additional statistical analyses used Systat 12 (SYSTAT Software, San Jose, CA) and StatXact 7 (Cytel Software Corporation, Cambridge, MA).

Tardiness values for a series of cases are not normally distributed. i) Tardiness is always nonnegative. ii) Tardiness is zero for cases that start early.[21] iii) Tardiness values for successive cases are generally correlated, not independent.[13,21] Suppose that one case has a late start. The next case in the same OR on the same day is more likely than by chance to start later than scheduled. iv) Different ORs can be affected by common factors. If a housekeeper calls in sick and turnover times are prolonged in one OR, cases in additional ORs are more likely to start late, too.[16]

To eliminate the effects of correlation in tardiness among cases, mean tardiness per case, mean total tardiness per OR per day, and mean total tardiness per suite per day were determined independently for 25 successive nonoverlapping 4-wk periods.[22–25] Values are thus reported as the average ± standard error (SE) of the means of 25 four-wk periods. At least 10 cases must have been performed in a given 4-wk period for that period to have been included in these averages. Thus, averages were sometimes based on fewer than 25 time periods. For last cases of the day that were scheduled to finish at least 2 h later than the end of the usual workday in the ASC, all 25 four-wk periods were used even though the number of cases per period never exceeded 9. The significance of differences between averages was determined using paired Student's *t*-test applied to the 25 means from the 25 time periods.

For ease of reading, SE <1 min are reported as 1 min (0:01) rather than expanding the number of digits to include seconds. SE <1% are reported as 1%.

Linear mixed effects modeling was used for subgroup analyses. The dependent variable was the logarithm of mean tardiness (or earliness) per case for each surgical service for each 4-wk period. The independent variables were service, case duration, and bias. Service was treated as a fixed effect. The different 4-wk periods were considered replications. Analysis was limited to combinations of service and 4-wk period that had at least 10 cases. Logarithmic transformation of tardiness (or earliness) was used because average tardiness was right skewed and always positively valued. With logarithmic transformation, the $n = 282$ residuals were close to normally distributed (Lilliefors' $P = 0.014$).

Many of the mixed effects modeling results for subgroup analyses are reported only for the MAIN suite and not the ASC. Average case duration did not differ greatly among surgical services in the ASC, ranging from 75 min to 100 min. In addition, three of the six services were responsible for 86% of the cases. Because of the resulting collinearity among service, average case duration, and average bias, the results of subgroup analyses were not meaningful for the ASC.

Tardiness from the Perspective of Surgeons

Average tardiness per case and average tardiness per OR per day represent the amount of time patients must wait for their surgery beyond their scheduled start times. Preventing excessive tardiness is important for maintaining patient satisfaction.[8,21,26–28]

We also studied tardiness from the perspective of surgeons, because surgeon waiting is not the same as patient waiting. A surgeon's series of cases he or she was scheduled to perform sequentially in the same OR on a single day was considered to be the surgeon's "list." To determine surgeon waiting, the average tardiness of first cases in lists was calculated for both first-case-of-the-day surgeons and "to follow" surgeons. The time to complete a list of cases was calculated including intervening turnovers.

Surgeon waiting is the tardiness of only the first case in each list of cases. If a subsequent case in the surgeon's list of cases starts later than scheduled, the surgeon himself is likely knowledgeable about the reasons. If the first case in the list of cases of a "to follow" surgeon cannot start on time, he will likely blame the preceding surgeon and/or the surgical suite for running late or being delayed.

Statistical significance of the relationship between a surgeon's total hours of OR time and first-case-of-the-day-starts was tested using the Cochrane-Armitage trend test.[29]

RESULTS

Comparison of Results to Simulations of Individual ORs

Discrete event simulations of individual ORs[20] found that average tardiness per case was the same whether the schedule was a series of many short cases or a small number of relatively long cases. Similarly, tardiness per case was the same whether preceding cases were homogeneous in duration or were a mixture of both short and long cases. Only the total duration of the preceding cases in an OR was a factor in determining tardiness, not the number of cases or their individual durations. Average tardiness per case therefore increased as the scheduled workday became longer. When cases were grouped according to the time of day that the cases were scheduled to begin, cases scheduled to start later in the day had greater average tardiness because of the greater duration of preceding cases.

Results from the simulations of individual ORs were compared with results on interacting ORs from the academic medical center under study, where cases were often moved from one OR to another. Both tardiness and average case duration varied considerably among surgical services in the MAIN suite. Average tardiness per case was not associated with average case duration, even after exclusion of first cases of the day (Fig. 1). Tardiness was compared between the MAIN suite, where the optimal length of the workday was 10 h, and the ASC, where the optimal length of the workday was 8 h. Average tardiness per case was 29 min in the MAIN suite and 24 min in the ASC (Table 1), with SE <1 min. The ratio of 29 min to 24 min is 1.21, which is close to the ratio of the lengths of the workdays, 10 h/8 h = 1.25. Tardiness was proportional to the length of the workday.

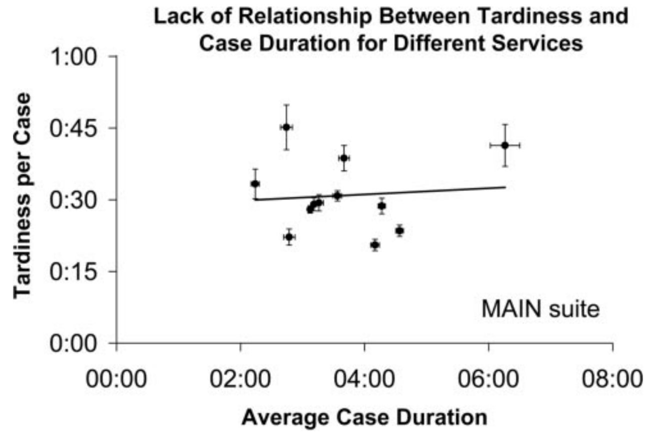

Figure 1. Average tardiness per case is plotted as a function of average case duration for 11 surgical services in the MAIN suite. Tardiness varied among surgical services ($P < 0.0001$, $F[11,268] = 10.4$), but tardiness did not depend on case duration ($P = 0.62$, $F[1,268] = 0.2$). When first cases of the day were excluded, tardiness remained independent of average case duration ($P = 0.87$, $F[1,260] = 0.1$). Error bars show ± SE. Lines are least squares fits.

The lower value for average tardiness per case in the ASC means that average patient waiting per case was less in the ASC. This finding is consistent with surgeon perceptions that the ASC is less tardy. However, total tardiness per OR per day was higher in the ASC (98 ± 2 min) than the MAIN suite (63 ± 1 min) (Table 1). Although average tardiness per case was 16% lower in the ASC, the average number of cases per day was 87% higher (Table 1, $P < 0.001$). The smaller tardiness per case was therefore overwhelmed by the larger number of cases per day. Tardiness per OR per day was higher in the ASC, meaning that total patient waiting was greater.

Uncertainty in the duration of a series of cases becomes greater as the total duration of the preceding cases increases. As the day progresses, cases may therefore start late by a greater amount. Similarly, cases may start early by a greater amount as the day progresses.

Average tardiness should increase as scheduled start times move further away from the start of the workday. Figure 2A shows that tardiness per case initially increased as the day progressed, then unexpectedly declined for cases scheduled to start 6 h or more after the start of the workday.

Because ORs were not independent, tardiness may have declined later in the day because cases were moved to different ORs. Tardiness was therefore recalculated while assuming that cases which were moved to different ORs had not been moved but were instead performed as originally scheduled. Figure 2B shows tardiness per case throughout the day after correcting for the effect of moving cases. The decrease in tardiness is much less at times >6 h.

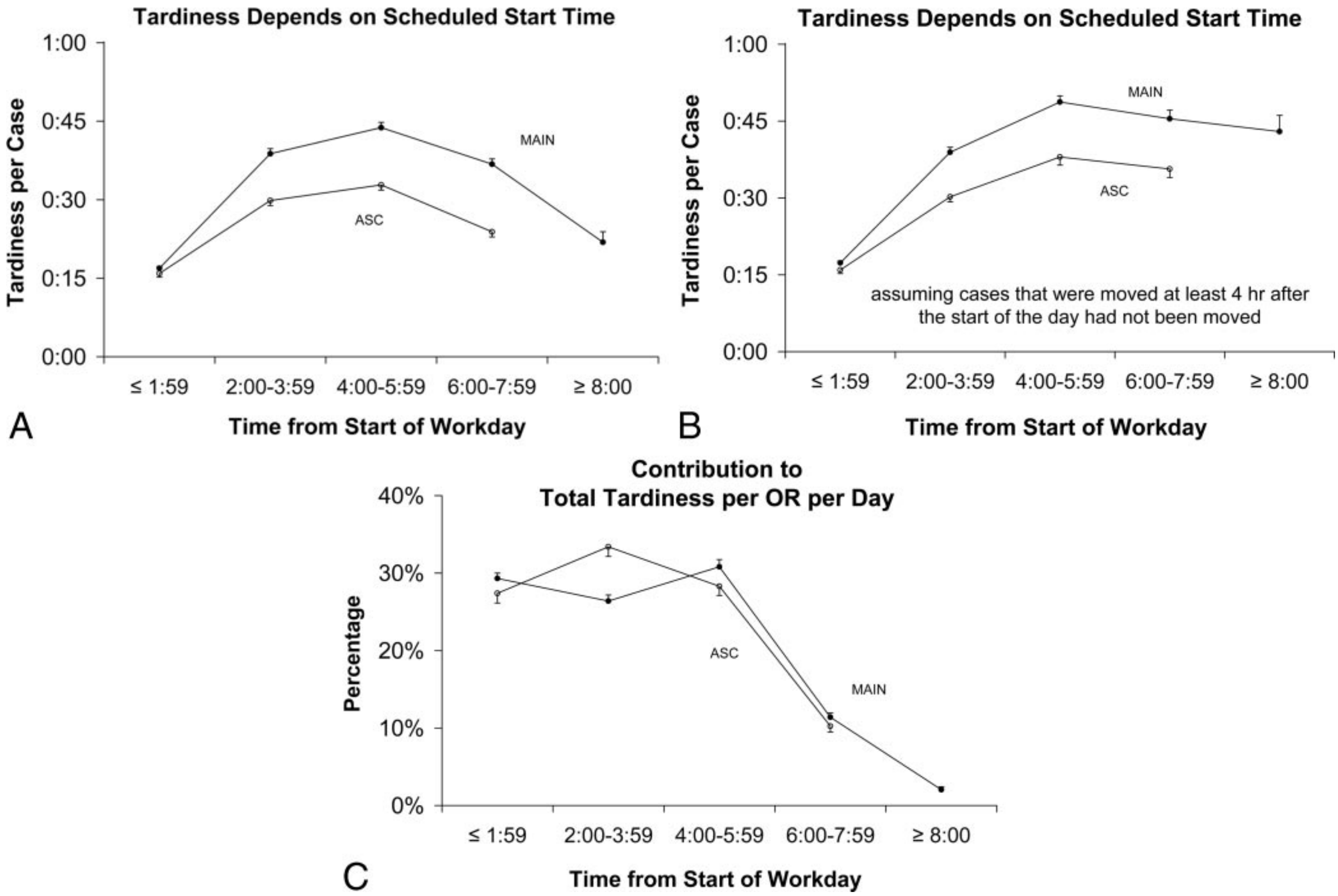

Figure 2. Tardiness depended on scheduled start times. Scheduled start times were binned into 5 time periods depending on the interval since the scheduled start of the workday. Tardiness was then determined separately for cases scheduled to begin during each period. (A) Tardiness initially increased as the day progressed, then dropped off toward the end of the day. Tardiness may have been less than expected[21] at the end of the day because cases were moved to different ORs to reduce tardiness. In the MAIN suite and the ASC, an average of 1.6 ± 0.1 and 1.0 ± 0.1 cases were moved each afternoon. (B) The graph shows what tardiness would have been if cases that were moved at least 4 h after the start of the workday had been performed as originally scheduled, with no change in location or sequence. (C) The majority of patient waiting occurred early in the day because most cases were scheduled to begin then. The graph shows the percentage contribution of each time period to the total tardiness per OR per day. Error bars show ± SE.

Although average tardiness per case is greater later in the afternoon than earlier in the day, most of the patient waiting occurs earlier in the day because the majority of cases are scheduled to begin then (Fig. 2C). The number of cases scheduled to start <2 h after the start of the workday is 5.6-fold (MAIN suite) and 4.2-fold (ASC) greater than the number of cases scheduled to start between 6 h and 7 h 59 min after the start of the workday. Interventions will have a greater potential to reduce tardiness and decrease patient waiting if they focus on cases starting earlier in the day.

Factors that did Not Influence Tardiness

Prolonged Turnovers

Average tardiness was increased only negligibly by prolonged turnovers.[16] In the MAIN suite and the ASC, the average tardiness of cases that followed prolonged turnovers was 17 ± 1 min (40% ± 5%) and 13 ± 1 min (45% ± 7%) greater than the tardiness of cases following turnovers that were not prolonged (Table 1). When the tardiness due to prolonged turnovers was distributed across all cases, average tardiness per case was increased by 2 min in the MAIN suite (7%) and 1 min (4%) in the ASC. Thus, the number of prolonged turnovers, averaging 2.3 ± 0.1 per day in the MAIN suite (14% ± 1% of all turnovers) and 1.4 ± 0.1 per day in the ASC (9% ± 1% of all turnovers), was insufficient to contribute substantively to overall tardiness.[30]

Surgeon Following Himself

If a case finishes early, then the next case in the same OR may be able to start early if surgeon and patient are ready.[31] If the same surgeon is performing both cases, then the surgeon should be available. A surgeon may therefore accumulate earliness as he performs his list of cases. This earliness may compensate for cases that take longer than their scheduled durations, thus preventing tardiness.

When a surgeon followed himself rather than another surgeon, tardiness was either the same (MAIN suite) or slightly decreased (ASC), but the difference was barely significant (Table 1). In retrospect, we

Table 2. Characteristics of Surgeons' Lists of Cases[a]

	MAIN surgical suite			ASC		
	Per list of cases	Per suite per day	Percent of suite total	Per list of cases	Per suite per day	Percent of suite total
Number of cases		47.7 ± 0.5			23.5 ± 0.3	
Number of cases in lists						
First case of the day lists	1.75 ± 0.01	36.6 ± 0.4		3.33 ± 0.04	18.8 ± 0.3	
Not first case of the day lists[b]	1.15 ± 0.01	11.1 ± 0.3	23% ± 1%*	1.76 ± 0.03	4.7 ± 0.2	20% ± 1%*
Tardiness of all cases in lists: patient waiting	0:46 ± 0:01	23:00 ± 0:38		1:10 ± 0:02	9:40 ± 0:16	
First case of the day lists	0:45 ± 0:01	15:29 ± 0:23		1:17 ± 0:02	7:16 ± 0:14	
Not first case of the day lists	0:49 ± 0:01	7:31 ± 0:20	32% ± 1%	0:54 ± 0:02	2:24 ± 0:09	25% ± 1%
Tardiness of first cases in lists: surgeon waiting[c]	0:19 ± 0:01*	9:30 ± 0:19*		0:13 ± 0:01*	1:45 ± 0:05*	
First cases of the day	0:08 ± 0:01	2:51 ± 0:05		0:04 ± 0:01	0:25 ± 0:01	
Not first cases of the day[d,e]	0:40 ± 0:01*	6:39 ± 0:16	70% ± 1%*	0:30 ± 0:01*	1:20 ± 0:05	75% ± 2%*
Hours of cases in lists		165:18 ± 2:07			35:20 ± 0:23	
First case of the day lists	6:16 ± 0:02	133:06 ± 1:31		4:53 ± 0:03	27:38 ± 0:24	
Not first case of the day lists[b]	3:18 ± 0:02	32:12 ± 1:00	19% ± 1%*	2:54 ± 0:03	7:41 ± 0:18	22% ± 1%*
Number of lists		29.9 ± 0.3			8.0 ± 0.1	
First case of the day lists		20.2 ± 0.1			5.4 ± 0.1	
Not first case of the day lists		9.7 ± 0.2	31% ± 1%		2.6 ± 0.1	33% ± 1%
Percent of rooms with "To Follow" surgeon			25% ± 1%			30% ± 1%
Percent of rooms with "To Follow" service (when a "To Follow" surgeon belongs to a different surgical service than the preceding surgeon)			8% ± 1%			4% ± 1%

A surgeon's list of cases is the series of cases he is scheduled to perform sequentially in the same OR. A "To Follow": surgeon is scheduled to begin his list of cases after another surgeon finishes in the same OR. Time values are expressed as hour:min and are the average ± SE of 25 four-wk periods. SE less than 1 min are displayed as 1 min (0:01). SE less than 1% are shown as 1%.

ASC = ambulatory surgery center.

[a] Arithmetic manipulation of some individual values for number of lists or lengths of lists to calculate totals for a suite do not produce the values listed for many reasons, such as: calculations were based on the average of 25 four-wk periods, not global means; some turnover times were not included when the cases for a day were separated into lists for each surgeon; some cases scheduled for the evening were neither first case starts nor "To Follow" starts; etc.

[b] Compared with 50%.

[c] Compared with tardiness of all cases in lists.

[d] Compared with tardiness of first cases in lists that were also first cases of the day.

[e] Compared with 50%.

* $P < 0.001$.

should not have expected that earliness would have the potential to reduce subsequent tardiness, for three reasons. i) Simulations of individual ORs[21] found that tardiness was essentially the same for probabilities of 95% and 5% that a case would start early if the preceding case finished early. ii) Tardiness cannot be reduced before the third case in an OR, assuming the second case starts early. In the MAIN suite and the ASC, surgeons with first-case-of-the-day starts averaged only 1.8 and 3.5 cases per day (Table 2), so that opportunities for earliness to prevent tardiness of subsequent cases were limited. iii) Case durations are log normally distributed and right skewed. The 5% lower prediction bound for the duration of a case is 57% of its mean duration.[8] At the other end of the distribution, a comparable number is the 90% upper prediction bound, where case duration is 149% of the mean.[8] Thus, the extent to which cases last longer than planned is greater than the extent to which they finish early.

To provide a greater understanding of the prevalence and impact of beginning a case early, earliness was measured directly. In each suite, earliness varied significantly among services. Like tardiness, earliness was unrelated to average case duration, even after exclusion of first cases of the day (Table 1 legend). Earliness increased progressively throughout the day, as shown in Figure 3, because uncertainty in the duration of preceding cases increased as their total duration increased. Although the ASC performed more cases each day in a shorter workday, earliness was effectively the same as that of the MAIN suite when controlling for the total duration of preceding

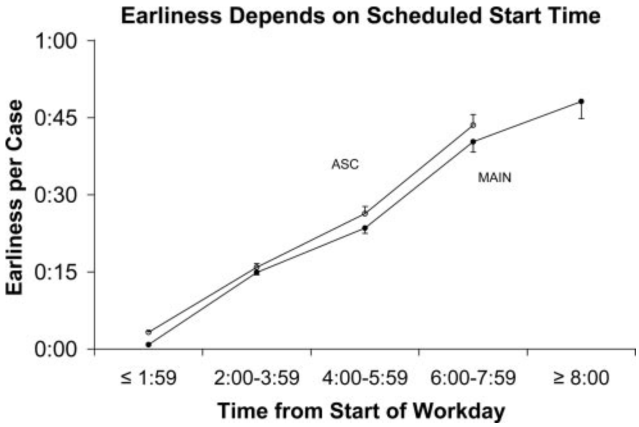

Figure 3. Earliness depended on scheduled start times and increased progressively throughout the day. Earliness is the positive difference between the scheduled start time of a case and its actual start time. If the case begins later than scheduled, earliness is zero for that case. Error bars show ± SE.

cases (Fig. 3).[27] Earliness was not greater when a surgeon followed himself rather than another surgeon in either the MAIN suite or the ASC (Table 1).

Anesthesiologist Concurrency

We were unable to determine the effect of concurrency on tardiness. Simultaneous direction of more than one room was associated with a statistically significant *decrease* in average tardiness of 18 min in the ASC (Table 1). The decrease of 4 min per case in the MAIN suite was barely statistically significant. Both results were likely artifacts arising from correlations between concurrency and case start times and between case start times and tardiness. When an anesthesiologist supervises two rooms for the day, one room invariably finishes first. Cases that begin in the remaining room then have a concurrency of 1. Thus, some cases probably had concurrencies of 1 only because they began later in the day. They also had greater tardiness because they began later in the day. Thus, concurrencies of 1 were associated with more tardiness. If concurrency were alternatively defined based on room assignments rather than actual cases performed, the effect of concurrency could not have been distinguished statistically from that of service. We include these observations in hopes of preventing a hospital from examining overall tardiness based on concurrency and drawing inappropriate conclusions.

Factors that did Influence Tardiness

Exclusion of First-Case-of-the-Day Starts

About 76% ± 1% and 85% ± 1% of first cases started within 10 min of their scheduled start times. Tardiness for first cases of the day averaged 8 min in the MAIN suite and 4 min in the ASC (Table 1). These values are 1/5–1/7 of the tardiness of cases that were not first cases. Excluding first cases from calculations of tardiness therefore provides a more representative picture of the extent to which cases in the surgical suites started later than scheduled.

Expected Under-Utilized or Over-Utilized OR Time

The time to complete a series of cases is generally modeled as independent of their scheduled start times.[28,32] In a study of knee and hip replacement surgeries,[33] OR times for procedures were only negligibly affected by multiple potential interventions, including increasing the percentage of cases that were first-case-of-the-day starts, adding extra staff members to ORs, changing the amount of time anesthesiologists were physically present in the OR, and starting cases later in the day. Because case durations did not vary under a variety of circumstances, we predicted that tardiness would not change based on expected under-utilized and over-utilized OR time.

ORs with 2 h or more of expected under-utilized time had *greater* average tardiness for last cases of the day in the ASC (Table 1). Tardiness was also greater for the MAIN suite, but the difference was barely statistically significant. ORs with 2 h or more of expected over-utilized time had *lower* average tardiness for last cases of the day in the MAIN suite (Table 1). Tardiness was also likely lower for the ASC, but the difference was barely significant. Regardless, if over-utilized time had been caused by deliberate underestimation of the duration of preceding cases to ensure that the last case would fit into allocated time, tardiness would have been greater, not less (see Discussion).

Case Duration Bias

Simulations of individual ORs found that tardiness did not differ among surgical services with equally accurate case duration predictions, even though average case durations differed three-fold.[21] In practice, different surgical services exhibited differences in case duration bias. We predicted that differences in tardiness among surgical services would be related to differences in case duration bias.

Overall bias for the two suites is listed in Table 1. When the different surgical services were analyzed separately for the MAIN suite, increased case duration bias was associated with increased average tardiness per case, even after excluding first cases of the day (Table 1 legend). When case durations are systematically underestimated, tardiness results.

The Surgeon's Perspective

We now consider tardiness from the perspective of surgeons rather than patients. For surgeons, tardiness is essentially the tardiness of only the first case in each list of cases.

The average number of cases in each surgeon's list of cases ranged from 1.1 to 3.3 (Table 2). Total surgeon waiting was less than half total patient waiting in the MAIN suite, and one fifth in the ASC. Surgeon waiting was less in the ASC partly because tardiness per case

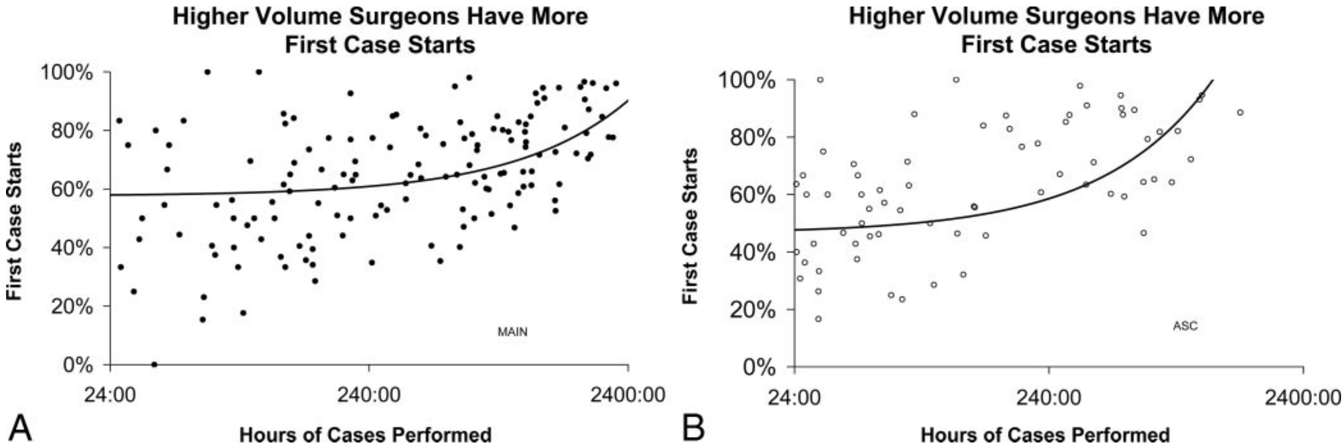

Figure 4. Surgeons with fewer lists that began with first cases of the day generally had lower workloads than surgeons with higher percentages of first-case-of-the-day starts. However, many high workload surgeons were frequently assigned "to follow" starts. (A) MAIN suite ($P < 0.0001$). (B) ASC ($P < 0.0001$). Each point represents a different surgeon. Surgeon workload is measured in terms of hours of cases over a 2-yr period. Note logarithmic abscissa to accommodate a wide range of surgeon workloads. Curve is a least squares linear fit on semilogarithmic axes.

was smaller, but also because each first-case-of-the-day list in the ASC consisted of about twice as many cases as in the MAIN suite.

Tardiness

First-case-of-the-day starts exhibited much less tardiness than other cases (Table 1), and thus the waiting times of surgeons with first-case-of-the-day starts were relatively small. In addition, most of the workload in both the MAIN suite and the ASC belonged to lists that started with first cases of the day (Table 2).

Lists of "to follow" surgeons represented 19%–23% of either the total number of cases or the hours of cases performed in each suite (Table 2). "To follow" surgeons were responsible for 32% and 25% of total patient waiting in the two suites (Table 2). However, "to follow" surgeons experienced the majority of surgeon waiting because average tardiness per case was 5–7 times greater when the first case in each list was not a first case of the day (40 min vs 8 min and 30 min vs 4 min, Table 2). Thus, 70%–75% of all surgeon waiting (Table 2) was sustained by "to follow" surgeons performing one fourth the caseload.

First-Case-of-the-Day Starts

We expect that most surgeons prefer first-case-of-the-day starts because the start times are more predictable. However, approximately 25% of ORs were scheduled for one or more "to follow" surgeons (Table 2). We therefore predicted that surgeons with lower workloads would be more likely than higher workload surgeons to be assigned "to follow" start times. Surgeons with lower workloads may not have enough hours of cases to fill an OR for the entire day, and thus several lower workload surgeons may have to share an OR. In addition, lower workload surgeons may not have the organizational advantages that entitle them to preferred start times.

Figure 4 shows the percentage of each surgeon's list of cases that began with first cases of the day as a function of surgeon workload. Surgeons with lower proportions of first-case-of-the-day starts generally had lower workloads. Yet, some of the higher workload surgeons were frequently "to follow" surgeons, too. For those surgeons, up to half their lists of cases did not begin with first cases of the day. "To follow" assignments were not relegated solely to surgeons who performed fewer hours of cases.

DISCUSSION

We studied the influence of numerous factors that may cause surgical cases to begin later than their scheduled start times. Insight into the causes of tardiness guides development of methods to reduce patient and surgeon waiting on the day of surgery. Some of these methods involving mathematical recalculation of the surgery schedule are described in a companion article.[13]

Some results from the two surgical suites with interacting ORs, in which cases are moved from one OR to another, matched the findings of a prior study involving discrete event simulations of individual ORs.[21] Tardiness did not depend on whether preceding cases were short or long but only on their total duration. Tardiness did not depend on whether the same surgeon performed multiple cases in succession or whether a different surgeon performed some of the cases. Because identical conclusions were reached using both simulations of individual ORs and real data derived from interacting ORs, the conclusions can likely be applied to other surgical suites.

The finding that tardiness depends only on the total time elapsed, not the duration of individual cases, means that growth in the number of ambulatory surgery centers will not reduce patient waiting on the day of surgery simply by virtue of the types of cases performed. A surgical suite that performs only relatively short cases does not have an advantage relative to a suite with a more heterogeneous mix of case durations. In addition, greater uniformity in the types of procedures performed does not reduce total tardiness for the day. Thus, total patient waiting, which is an important end point from a societal perspective, is not inherently reduced by the types of cases performed in an ambulatory surgery center. Ambulatory surgery centers reduce tardiness and the waiting times of individual patients because they expand the number of first-case-of-the-day starts by providing additional ORs. They also tend to decrease the number of to-follow starts by reducing the length of the workday. In addition, ambulatory surgery centers have few add-on cases relative to a tertiary surgical suite. They thus have greater flexibility to move cases from ORs that are running late to ORs that have finished early, thereby reducing tardiness (see companion article).[13]

Total patient waiting can be considered important economically if a cost is assigned to the value of patients' time. However, we do not know the importance placed by patients on waiting past scheduled start times on the day of surgery.[34–37] Most patients may be more concerned with the number of days they had to wait for surgery. Many may conclude that the entire day will be useless for accomplishing other tasks, even if they need not report to the hospital until midday. Studies have shown that patients do not want to have surgery in the afternoon[36,38] and be NPO for long periods. They do want to be informed about any delays that cause their cases to start later than planned.[36,39]

Tardiness of first cases in lists is extremely important to surgeons. "To follow" surgeons scheduled to begin in the afternoon could potentially be delayed for long periods of time by cases that precede them in the same ORs. In simulations of individual ORs, tardiness increased progressively throughout the day. Results were different for the interacting ORs of the two suites. Tardiness actually declined later in the day because of moving of cases to different ORs. The tardiness of cases that begin in the afternoon may seem to hold little significance because the number of such cases is small. However, the tardiness of afternoon cases is extremely important to the "to follow" surgeon whose cases are scheduled to begin then. It is also of significance to the surgeon who must choose between possible start times for an add-on case.

Suppose a general surgeon is offered a choice of start times for an add-on colectomy: either 5 PM tonight or 12 PM tomorrow. The 5 PM start is appealing because the surgeon does not want to wait. In addition, he holds clinic the next day, and does not want to inconvenience his other patients by rescheduling their appointments. However, the surgeon may have little confidence in the 5 PM start time, believing that numerous delays accumulating throughout the day could push his real start time to 7 PM. Because we found that tardiness did not continue to increase throughout the day, but actually declined, a surgeon at our MAIN suite can reasonably consider the 5 PM start time to be as reliable as one earlier in the day.

In addition to examining tardiness, we also studied earliness. Earliness increased progressively throughout the day in both the MAIN suite and the ASC. This result has important implications for calculating patient arrival times. Surgeons can sometimes start a case early, so patients should be ready before their scheduled start times. Because earliness depends on the total duration of all preceding cases performed in the same OR,[27] our results again show that the common practice of asking patients to report a fixed length of time before their scheduled start times has no logical foundation.[27,40,41] Instead, to balance patient availability with patient waiting,[10,41] patients should arrive early by a greater number of hours as the day progresses.[27]

Tardiness was related to the expected inefficiency of use of OR time (i.e., under-utilized and over-utilized OR time). Managerial decisions on the day of surgery to balance the workload among ORs were likely responsible. When the hours of cases scheduled were shorter than the usual length of the workday, the OR may have been assigned a lower priority for support services such as central sterilizing, housekeeping, or circulating nurses.[28,42–44] When the scheduled cases would extend past the length of the workday for which staffing had been planned, cases waiting to start may have been moved to ORs that finished early. Improved patient flow,[45] preferential use of induction rooms,[46,47] and/or assignment of additional personnel[48] may also have contributed to the reduced tardiness. Results are inconsistent with the idea that staff may work more slowly because of fatigue.[49] When over-utilized time existed, resources such as extra personnel appear to have been appropriately assigned to reduce over-utilized time,[1,43] even at the expense of greater tardiness in other rooms. Reducing over-utilized time should be a greater priority than reducing tardiness.[1,28,42,43]

Results on the inefficiency of use of OR time are not inconsistent with our study of knee and hip replacements at multiple facilities,[33] in which case durations did not depend on the length of the scheduled workday. The ORs in which the knee and hip replacements were performed had only under-utilized time.[33] The ORs rarely ran longer than the usual length of the staffed workday. Staff had no incentive to alter the start times or durations of cases. An implication is that studies of tardiness and case durations in suites with only under-utilized time cannot be generalized to suites with occasional over-utilized time. Benchmarking tardiness among suites is of limited usefulness unless over-utilized time is taken into account.[1]

Note that the relationship between tardiness and expected inefficiency of use of OR time is the opposite of that produced by the scheduling vagaries of surgeons. Suppose a surgeon regularly had only 6 h of cases instead of 10 h on the days allocated to him, but did not want his time released to other surgeons.[50] He might then deliberately over-estimate the duration of his cases, creating negative bias. Cases would finish sooner than predicted. Tardiness would be reduced. Conversely, suppose a surgeon had 12 h of cases but was only permitted to schedule a 10 h day. He might deliberately underestimate case durations,[51] creating positive bias. Cases would run longer than planned, creating both over-utilized time and increased tardiness. Both examples predict the opposite of what we found. Our findings are not the result of inaccuracies in case scheduling.

One of the most important factors contributing to tardiness was case duration bias. Some surgical services consistently underestimated their case durations. In the following article,[13] we use this result to develop an intervention to reduce tardiness by applying mathematical corrections to the surgery schedule. Such corrections reduce tardiness by compensating for case duration bias.

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