# Optimizing the Arrival, Waiting, and NPO Times of Children on the Day of Pediatric Endoscopy Procedures

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**BACKGROUND:** Research in predictive variability of operating room (OR) times has been performed using data from multidisciplinary, tertiary hospitals with mostly adult patients. In this article, we discuss case-duration prediction for children receiving general anesthesia for endoscopy. We critique which of the several types of OR management decisions dependent on accuracy of prediction are relevant to series (lists) of brief pediatric anesthetics.

**METHODS:** OR information system data were obtained for all children (aged 18 years and younger) undergoing a gastroenterology procedure with an anesthesiologist over 21 months. Summaries of data were used for a qualitative, systematic review of prior studies to learn which apply to brief pediatric cases. Patient arrival times were changed to be based on the statistical method relating actual and scheduled start times (Wachtel and Dexter, Anesth Analg 2007;105:127–40).

**RESULTS:** Even perfect case-duration prediction would not affect whether a brief case was performed on a certain date and/or in a certain OR. There was no evidence of usefulness in calculating the probability that one case would last longer than another or in resequencing cases to influence postanesthesia care unit staffing or patient waiting from scheduled start times. The only decision for which the accuracy of case-duration prediction mattered was for the shortest time that preceding cases in the OR may take. Knowledge of the preceding procedures in the OR was not useful for that purpose because there were hundreds of combinations of preceding procedures and some cases cancelled. Instead, patient ready times were chosen based on 5% lower prediction bounds for ratios of actual to scheduled OR times. The approach was useful based on a 30% reduction in patient waiting times from scheduled start times with corresponding expected reductions in average and peak numbers of patients in the holding area.

**CONCLUSION:** For brief pediatric OR anesthetics, predictive variability of case durations matters principally to the extent that it affects appropriate patient ready times. Such times should not be chosen by having patients start fasting, arrive, and be ready fixed numbers of hours before their scheduled start times. (Anesth Analg 2010;110:879–87)

Substantial progress has been made in quantifying the predictive variability of operating room (OR) times for surgery.[1–5] However, this work has been performed using data from multidisciplinary, tertiary hospitals with mostly adult patients.[2–5] Which results are useful for brief pediatric anesthesia cases is unknown.

One characteristic feature of outpatient pediatric anesthesia is series (lists) of children each undergoing a brief anesthetic. For these cases, the total daily time encompassed by turnovers, anesthesia inductions, and anesthesia emergence is high.[1,6] Our first objective was to collect and use observational data about series of pediatric anesthetics to perform a qualitative systematic review of the scientific literature to learn what principles in case-duration prediction apply to series of cases with high percentages of anesthesia times.

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The assumption should not be made that prior results principally from adult OR cases will apply well to brief pediatric cases. We made that mistake previously for anesthesia times for radiology, wherein different statistical methods should be applied.[7] In this article, we discuss how best to predict OR times for children receiving general anesthesia for endoscopy. We critique which of the several types of OR management decisions dependent on case-duration prediction are relevant to series (lists) of brief pediatric anesthetics. We show the need to investigate suitable ways to choose how soon before scheduled start times that patients should be nil per os (NPO) (fasting) for liquids and arrive at the facility.[8]

## METHODS

This project was performed as a quality-improvement initiative to reduce the fasting times and waiting times of children on arrival at a pediatric surgery facility. Publication of the results was approved by the State University of New York Upstate IRB.

OR information system data were obtained for all children (aged 18 years and younger) undergoing a gastroenterology procedure with an anesthesiologist from July 1, 2007 through April 30, 2009. Two pediatric gastroenterologists performed almost all (96.3%) of the cases of lower and upper endoscopy at the facility. These procedures comprised almost all (97.9%) OR cases these physicians performed. We studied all consecutively scheduled elective cases performed by 1 of these 2 physicians on each day that either physician had 2 or more such cases. We excluded the rare single case because our objective was to study series of short pediatric OR cases.

The procedure(s), surgeon, and type of anesthetic are the principal factors predicting OR times for surgical cases.[9,10] Because all patients in our studied cases received general anesthesia, the type of anesthetic did not apply. Factors predicting OR times for endoscopy in adults were found to be the procedure(s) and gastroenterologist.[11] No incremental predictive value was found for age, gender, start time, or primary and secondary diagnoses.[11] Thus, based on the adult study,[11] we classified data by the combination of physician and procedure(s). The data obtained for each case were its OR, date, start and end time (i.e., in and out of OR), scheduled start and end time, gastroenterologist, and procedure(s).

In the Results section, we list the types of decisions made by OR managers involving case-duration prediction. Relevance of decisions to series of pediatric gastroenterology cases was assessed by using measures of central tendency (e.g., medians, means, and standard errors of means) and variability (e.g., SDs and absolute errors). The standard errors of the SDs listed in the tables were calculated by dividing the widths of 2-sided 95% asymptotic confidence intervals[12] for normally distributed variables by 2 times the corresponding inverse of the cumulative normal distribution. In the Results section, it will be evident that these standard errors are important only for showing qualitatively that they are negligibly small. Levene's test[13] was used to evaluate whether SDs differed significantly among combinations of procedure(s) and gastroenterologists.

As explained in the Introduction, the focus of the Results section will be the process of choosing the time by which each child should be ready to enter his or her OR (Table 1). The time of arrival of the patient at the facility and the time to start fasting are calculated from that time (see below).[8] The time at which the patient needed to be ready was calculated on a percentage basis by relating scheduled and actual times of OR entrance among cases that were not first cases of the day[8]:

$$\text{Earliness Ratio} = \frac{[\text{Actual Start Time} - (\text{Start of Workday} + \text{Turnover Time})]}{[\text{Scheduled Start Time} - (\text{Start of Workday} + \text{Turnover Time})]}. \quad (1)$$

From Appendix 1 of Ref. 8, Eq. (1) can be derived by envisioning each case as being preceded by 1 long virtual case. The first cases of the day are excluded because the earliest times that they can start are, by definition, the start of the workday. To pick the "Turnover Time" in Eq. (1), we excluded turnover times longer than 90 minutes, as previously validated,[14] resulting in a mean ± SE (SEM) of turnovers of 29.3 ± 0.6 minutes. Because 29.3 minutes was so close to 30 minutes, we used 30 minutes in Eq. (1), as we did previously.[8]* For the "Start of Workday," we used 8:00 AM because that scheduled start time was 6 times more common than the next most common start time of 8:30 AM. We only applied Eq. (1) to cases that were either scheduled to start or started at 9:00 AM or later, because the other patients were either first case of the day starts or functionally the same as first cases of the day with respect to arrival times and fasting times.*

In previous studies of 2 surgical suites, earliness ratios differed among combinations of suite, specialty, and day of the week.[8] In our current study, there is only 1 suite and specialty. Also, for the 2 gastroenterologists, 93% and 94% of the earliness ratios were for cases performed on the physician's most common OR weekday. Consequently, comparing earliness ratios among weekdays was equivalent to comparing them between physicians.* The Smirnov test was used to compare probability distributions of earliness ratio between physicians.[15] In the Results section, we show significant differences, and thus the remainder of

**Table 1. Patient Ready, Arrival, and NPO Times Calculated Empirically from Scheduled Start Times and Displayed on Paper at Scheduler's Desks**

| Scheduled start time | Physician 1 Ready time | Physician 1 Arrival time | Physician 1 NPO liquids | Physician 2 Ready time | Physician 2 Arrival time | Physician 2 NPO liquids |
|---|---|---|---|---|---|---|
| 9:00 | 8:50 | 8:20 | 5:50 | 8:55 | 8:25 | 5:55 |
| 9:15 | 9:00 | 8:30 | 6:00 | 9:05 | 8:35 | 6:05 |
| 9:30 | 9:10 | 8:40 | 6:10 | 9:20 | 8:50 | 6:20 |
| 9:45 | 9:20 | 8:50 | 6:20 | 9:35 | 9:05 | 6:35 |
| 10:00 | 9:30 | 9:00 | 6:30 | 9:45 | 9:15 | 6:45 |
| 10:15 | 9:40 | 9:10 | 6:40 | 10:00 | 9:30 | 7:00 |
| 10:30 | 9:50 | 9:20 | 6:50 | 10:10 | 9:40 | 7:10 |
| 10:45 | 10:00 | 9:30 | 7:00 | 10:25 | 9:55 | 7:25 |
| 11:00 | 10:10 | 9:40 | 7:10 | 10:40 | 10:10 | 7:40 |
| 11:15 | 10:20 | 9:50 | 7:20 | 10:50 | 10:20 | 7:50 |
| 11:30 | 10:30 | 10:00 | 7:30 | 11:05 | 10:35 | 8:05 |
| 11:45 | 10:40 | 10:10 | 7:40 | 11:15 | 10:45 | 8:15 |
| 12:00 | 10:50 | 10:20 | 7:50 | 11:30 | 11:00 | 8:30 |
| 12:15 | 11:00 | 10:30 | 8:00 | 11:45 | 11:15 | 8:45 |
| 12:30 | 11:10 | 10:40 | 8:10 | 11:55 | 11:25 | 8:55 |
| 12:45 | 11:20 | 10:50 | 8:20 | 12:10 | 11:40 | 9:10 |
| 13:00 | 11:30 | 11:00 | 8:30 | 12:20 | 11:50 | 9:20 |
| 13:15 | 11:40 | 11:10 | 8:40 | 12:35 | 12:05 | 9:35 |
| 13:30 | 11:50 | 11:20 | 8:50 | 12:50 | 12:20 | 9:50 |
| 13:45 | 12:00 | 11:30 | 9:00 | 13:00 | 12:30 | 10:00 |
| 14:00 | 12:10 | 11:40 | 9:10 | 13:15 | 12:45 | 10:15 |

The clerks' paper contains the gastroenterologists' names replacing "Physician 1" and "Physician 2." The printed page is used by the gastroenterologists' schedulers to instruct the patients' parents. For example: "Your child's procedure is scheduled to start at 12 noon. However, it may start as early as 11 AM. Plan to arrive at the hospital 30 min ahead, at 10:30 AM. Your child should not drink after 8:30 AM . . ." To understand how the second to seventh columns were calculated, see the second to last and last paragraphs of the Results section.

*In the last sections of the Methods and Results, we refer to this footnote when describing similar results for patient arrival times at the endoscopy suite of another, similarly sized pediatric hospital serving a similar population. For pediatric gastroenterology conducted with one anesthesia team, turnover times at the other hospital also averaged 30 minutes. Specification of the day of the week and the gastroenterologist were also interchangeable. Also matching between hospitals was the fact that patients reported 30 minutes before the earliest possible start time. Earliness ratios were 0.677 one year and 0.755 another, also quite similar. The common findings serve as a check on the usefulness of the results for the studied hospital at other facilities.

the Methods refers to the statistics of each physician's earliness ratios.

The 5% lower prediction bound was calculated for each physician's earliness ratios. These values were slightly smaller than the fifth percentiles of the earliness ratios, being smaller because percentiles refer only to the past, whereas prediction bounds incorporate statistical uncertainty to predict the future. If the 0% prediction bounds had been used, the calculations would have specified that all patients arrive at 6:30 AM or so, resulting in expensive crowding and patient (parent) dissatisfaction. If the 100% prediction bounds had been used, then each patient would have been ready at the latest possible time that his or her case might start. Consequently, there would be substantial expense from the gastroenterologists, anesthesiologists, and OR nurses waiting for most patients. The 5% value is close to the optimal balance from the perspective of minimizing societal costs,[16,17] it matches observed rates in practice,[8] and it is easy to explain because it corresponds conceptually to the frequently used "$P < 0.05$." Derivation is in Ref. 16.

Previously, we recommended[8] calculation of the 5% lower prediction bound of earliness ratios by using the most recent 1 year of data and selecting the fifth smallest value of the most recent $n = 99$ earliness ratios if 99 ratios are available, otherwise the fourth smallest of the most recent 79 ratios if 79 are available, third smallest of 59 ratios, second smallest of 39 ratios, or smallest of 19 ratios. There was no association between date and earliness ratio for the 2 gastroenterologists (physician 1: Spearman rank correlation = −0.03, $n = 162$, 2-sided $P = 0.71$; physician 2: correlation = −0.04, $n = 161$, $P = 0.59$). Therefore, the 5% prediction bounds reported in the Results section are the fifth smallest of the most recent 99 earliness ratios for each physician.

Once the 5% lower prediction bound for the earliness ratio is known, the time at which each patient needs to be ready to enter his or her OR can be calculated from it by using a rearranged version of Eq. (1)[8]:

$$\begin{aligned}\text{Ready to Start Time} &= (\text{5\% Lower Prediction Bound for Earliness Ratio}) \times [\text{Scheduled Start Time} \\ &\quad - (\text{Start of Workday} + \text{Turnover Time})] \\ &\quad + (\text{Start of Workday} + \text{Turnover Time}). \qquad (2)\end{aligned}$$

As for Eq. (1), we use 8:00 AM for the start of the workday and 30 minutes for the turnover time. Equation (2) is applied at the studied facility to calculate the second and fifth columns of Table 1 from the first column of that table.

The arrival times are obtained from the "Ready to Start Time" by subtracting appropriate numbers of minutes and hours. To obtain suitable values for the arrival times given the clerks' and nurses' current practice at the facility, we used a convenience sample of $n = 38$ nonconsecutive patients on different weekdays. All patients (i.e., parents) were told to arrive at the facility 1.5 hours before the scheduled OR start time. There was no association between the instructed arrival time and how long it took between arrival and when the patient was ready in the holding area (Spearman correlation = 0.07, $P = 0.67$). Because the 94th percentile of preparation time was 30 minutes, patients were subsequently instructed to arrive 30 minutes before the Ready to Start Time.* This is seen in Table 1 from the third column being 30 minutes earlier than the second column and the sixth column being 30 minutes earlier than the fifth column. Mean absolute and percentage reductions in waiting times are reported in the Results section.

The NPO times for liquids are also obtained from the Ready to Start Time by subtracting appropriate numbers of minutes and hours. The clerks and nurses instructed all patients to be NPO to liquids starting at midnight. Among the $n = 19$ of the 38 children not having endoscopy at the start of the workday, actual NPO times for liquids were all >9 hours, with mean ± SEM of 12 hours ± 1 hour. Patients were subsequently instructed to be NPO for clear liquids for 3 hours before the Ready time. This is seen in Table 1 from the fourth column being 3 hours earlier than the second column and the seventh column being 3 hours earlier than the fifth column. Implementation is considered qualitatively in the first paragraph of the Discussion section.

## RESULTS

Decisions involving case-duration prediction generally involve 5 tasks, listed below in items 1 through 5.[1,2,5] Our first set of results involve determining which types of decisions might benefit from sophisticated analysis methods.

1. Case-duration prediction can affect whether a case is performed on a certain date and/or in a certain OR. For the studied cases, even perfect prediction of OR time would not substantively affect this decision, for 2 different reasons, 1a and 1b.
   - 1a. There was an average of only 1 minute of overutilized OR time per OR per workday (Table 2). This reason would be irrelevant scientifically if the anesthesiologist and OR nurses were inappropriately scheduled for the entire workday, as compared with half the day followed by different responsibilities. However, this was not the situation at the studied hospital—the relevant[6] (66th) percentile of the end of the workday was 5 hours 40 minutes after the start of the workday (Table 2), which is considerably longer than 4 hours. This reason would also be irrelevant scientifically if there was a lack of patient queues for endoscopy. However, this was not the situation at the studied hospital—the average wait for endoscopy was 4 weeks (Table 2), which is considerably longer than the 2 weeks' waiting time previously found to be desired by parents of gastroenterology patients[18] and all outpatient surgery patients.[19,20]
   - 1b. The absolute prediction error in case duration averaged only 13 minutes (Table 3). Understanding why this observation 1b is a reason for

**Table 2. Overutilized Operating Room Time Among Series of Elective Cases**

| | Physician 1 | Physician 2 | Total |
|---|---|---|---|
| *N* series of cases | 67 | 61 | 128 |
| Overutilized OR time (min) | | | |
| Mean ± SEM | 0.0 ± 0.0 | 1.6 ± 1.2 | 0.7 ± 0.6 |
| Median | 0.0 | 0.0 | 0.0 |
| Scheduled end of series | | | |
| Mean ± SEM | 12:19 ± 0:12 | 12:28 ± 0:11 | 12:23 ± 1:36 |
| Median | 12:19 | 12:23 | 12:20 |
| 66th percentile | 13:17 | 13:02 | 13:09 |
| Weeks waiting | | | |
| Mean ± SEM | 3.5 ± 0.1 | 4.7 ± 0.2 | 4.1 ± 0.1 |
| Median | 3.4 | 4.7 | 3.9 |
| Cases per list | | | |
| Mean ± SEM | 4.0 ± 0.2 | 3.7 ± 0.2 | 3.8 ± 0.1 |
| Median | 4 | 4 | 4 |
| 80th percentile | 5 | 5 | 5 |

"Physician 1" and "2" refer to the pediatric gastroenterologists. The "*N*" refers to the number of consecutive series of cases. The 80th percentile is used in Table 6. The "SEM" refers to the standard error of the mean. The "overutilized OR time" refers to the minutes after 3:30 PM, where 3:30 PM was chosen because the start of the staffed workday is 7:30 AM. The "Scheduled end" refers to the scheduled end of the list of cases. The 66th percentile matters because if it were twice as expensive to finish late as early, 2/3rd of series should finish early.[6] The results show that if staffing could be planned for less than 8 h, and it could not based on staff scheduling rules at the facility, then the end of the workday planned should be 1:15 PM. The time of 1:15 PM is 5 h 45 min after the start of the workday. The "weeks waiting" refers to the weeks between the time that the case was scheduled and the child underwent the procedure. By definition, the weeks waiting underestimated the actual wait for the procedure, because it was from the time that the case was scheduled with the OR until the procedure(s) was performed. Because one patient's wait would generally be correlated to the wait of the next patient on the same day, the standard error of the mean for waiting time was obtained by calculating the mean for each list (series) and then calculating the standard error of the mean among the series' means. In other words, the sample size was considered to be the listed "*N*" series of cases. Nevertheless, when calculations were repeated by case, results were identical except for Physician 1's median wait being 3.0 weeks instead of the listed 3.4 weeks.

**Table 3. Absolute Prediction Errors in Minutes of Operating Room Times for All of the Pediatric Gastroenterology Procedures**

| | Physician 1 | Physician 2 | Total |
|---|---|---|---|
| *N* cases | 267 | 223 | 490 |
| Absolute error (min) | | | |
| Mean ± SEM | 14.3 ± 0.7 | 10.9 ± 0.8 | 12.7 ± 0.5 |
| Median | 11.3 | 7.3 | 9.3 |
| Absolute error (%) | | | |
| Mean ± SEM | 35.9 ± 1.7 | 23.4 ± 1.2 | 30.2 ± 1.1 |
| Median | 31.7 | 19.2 | 26.9 |
| Underestimate (min) | | | |
| Mean ± SEM | 3.3 ± 1.1 | 5.2 ± 1.0 | 4.2 ± 0.8 |
| Median | 3.3 | 3.3 | 3.3 |
| Operating room time (min) | | | |
| Mean ± SEM | 42 ± 1 | 43 ± 1 | 43 ± 0 |
| Median | 40 | 39 | 40 |
| SD ± SE | 17 ± 1 | 17 ± 1 | 17 ± 1 |

"Physician 1" and "2" refer to the pediatric gastroenterologists. The "*N*" refers to the number of cases, all of which are part of the sequences in Table 2. The "Absolute error" refers to the absolute difference between the actual and scheduled operating room (OR) time. The absolute percentage error was calculated relative to the true OR time. The "SEM" refers to the standard error of the mean while the "SE" after standard deviation refers to the standard error of the standard deviation.

excluding decision 1 depends on previous findings from different facilities. An outpatient surgery center's cases had absolute prediction errors twice as large.[1,21] Cases were rescheduled using the original scheduled OR times and then using the final actual OR times. Even with absolute prediction errors twice those of Table 3, the outpatient surgery center had only 1.0 minute of incremental overutilized time per OR per day compared with perfect predictive knowledge of OR times.[1,6,21] There are 2 reasons for this: (1) short cases have small absolute errors relative to the mean absolute differences among workdays in total hours of cases scheduled,[11] and (2) short cases pack well[1,19,21–23] into whatever OR time is available for them. An appropriate scientific concern would be that the prediction errors of Table 3 are unusually small for endoscopy. However, this is unlikely. Table 4 gives SDs for combinations of gastroenterologist and procedure(s), which can be compared with those reported by Combes et al.[11] in their Tables 2 and 3. Whereas their maximal SD of 15 minutes was no larger than that of our studied suite, 5 of their 10 SDs were less than the 11 minutes minimum observed at our studied suite.[11] Thus, our studied suite had larger variability in OR times than the other studied endoscopy suite, even though the variability was so small that its elimination was insufficient to change the decision 1 (i.e., the day and the OR in which each case was performed).

2. Calculating the probability that 1 case will last longer than another is useful for sharing equipment or personnel between ORs.[1,2,24] However, the use of such calculations is unnecessary when absolute prediction errors are as small as the 13 minutes of Table 3. The errors were not small because of good predictive ability of the gastroenterologists and schedulers. Their average absolute percentage error rate was large, 30%, effectively the same as the 29% rate previously observed for a tertiary surgical suite (Table 3).[10] Rather, the absolute prediction errors were small because the mean OR times were so brief (40 minutes) (Table 3).[11]
3. Knowing the longest time that a case might take is useful for filling holes in an OR schedule, swapping cases among 2 ORs, and, especially, to estimate the time remaining in ongoing cases.[1,5,25] However, these methods are useful for the 5-hour general thoracic surgery case that has been ongoing for 4 hours and could have 10 minutes to 2.5 hours to go. For such cases, a 30% mean absolute prediction error corresponds to a mean absolute error of 1.5 hours. However, the endoscopy cases had mean prediction errors of only 13 minutes because they are short cases.
4. The sequence of each gastroenterologist's list of cases on each day can be chosen to reduce the peak phase I postanesthesia care unit (PACU) staffing (4a) and/or the average patient waiting times from scheduled start times (4b).[2,26]
   4a. Case sequencing influences the peak numbers of patients in the PACU by affecting the arrival

**Table 4. Standard Deviations in Minutes of Operating Room Times for the Common Pediatric Gastroenterology Procedures**

| | Physician 1 | Physician 2 | Total |
|---|---|---|---|
| Colonoscopy | 11 ± 2, *N* = 14 | 14 ± 2, *N* = 39 | 14 ± 1, *N* = 53 |
| Colonoscopy esophogastroduodenoscopy | 15 ± 1, *N* = 86 | 15 ± 2, *N* = 37 | 15 ± 1, *N* = 123 |
| Colonoscopy esophogastroduodenoscopy, 24 h pH monitor | 11 ± 2, *N* = 20 | 14 ± 3, *N* = 14 | 13 ± 2, *N* = 34 |
| Esophogastroduodenoscopy | 12 ± 1, *N* = 68 | 13 ± 1, *N* = 60 | 13 ± 1, *N* = 128 |
| Esophogastroduodenoscopy, 24 h pH monitor | 11 ± 1, *N* = 67 | 13 ± 1, *N* = 66 | 12 ± 1, *N* = 133 |

"Physician 1" and "2" refer to the pediatric gastroenterologists. The other combinations of procedures performed during the 21 months studied were each performed 6 times or fewer by the two gastroenterologists combined (Table 5). The data are reported as SD ± standard error of the SD. The sample size is listed second. The SDs do not differ significantly among combinations of physician and procedure(s) by Levene's test[15] without ($P = 0.24$) and with ($P = 0.10$) logarithmic transformation.

time of patients into the PACU.[27–29] For example, the peak number of patients in the PACU is larger if every surgeon schedules his or her list with the longest case of the day first versus each surgeon choosing the sequence using whatever criteria he or she happens to use, resulting in a nearly random pattern of arrival into the PACU.[29] Readers can refer to Tables 1, 2, 4, and 6 in Ref. 29. Nevertheless, case sequencing cannot substantively affect PACU staffing for the pediatric endoscopy cases, because the SD of OR times among cases is only 17 minutes (Table 3). The endoscopy cases essentially all took about the same amount of time, as compared with problems such as sequencing an inguinal herniorrhaphy and a Wilms tumor resection.

4b. Case sequencing generally affects patient waiting time. Continuing the preceding example, suppose that the patient to undergo the Wilms tumor resection has surgery after the patient undergoing inguinal herniorrhaphy and has a scheduled start time of 9:30 AM. Then, the earliest possible start time might be 9:15 AM and the latest possible start time 10:00 AM. The differences in time are relatively small (45 minutes) because the SD of OR times for the surgeon to perform inguinal herniorrhaphy is small (e.g., 11 minutes). In contrast, suppose that the patient undergoing Wilms tumor resection has surgery first. If the scheduled start time of the inguinal herniorrhaphy was 12:30 PM, the earliest possible start time might be 11:00 AM and the latest possible start time 2:30 PM. The time differences are relatively large (3 hours 30 minutes) because the SD of the OR times for Wilms tumor resection is large (e.g., 1 hour). The example shows that average patient waiting from the Ready to Start Time (Table 1) and from the scheduled start time is reduced by scheduling cases with the smallest predictive variability earlier in the day and the more unpredictable cases later.[2,26] However, Table 4 shows that this principle is not of benefit for endoscopy cases. The reason is that the SDs of OR times differ negligibly (<5 minutes) if at all ($P = 0.24$) among procedure(s).

5. The shortest times that preceding cases in an OR may take can be used to choose the time at which the next patient needs to be ready. This decision is especially important for the gastroenterology patients because there are so many cases.[30] At an outpatient facility that averaged 4.0 cases per day,[30] similar to the gastroenterologists (Table 2), there was 52% more total patient waiting than at a tertiary suite with 2.1 cases per OR per day,[30] the US national average.[31] The reason was simply that there were more cases after the first case of the day.

Summarizing the preceding results, the 5th issue is of importance, but not the others. Therefore, the remaining results focus on choosing the times at which patients need to be ready for their anesthetics. The simplest[2,5,8,16,17] statistical method is to model the relationship between scheduled and actual start times (Eq. 1) and to use the model to calculate a ready time for each scheduled start time (Eq. 2) while assuring an overall 5% incidence of OR waiting for the patient.[8] As the day progresses, the average number of minutes that a case may start early increases progressively.[30] Figure 3 (of Ref. 30) shows this result for 2 suites, 1 with brief cases, and Table 1 of this article shows the consequence. Patients scheduled to start earlier in the day need to be ready fewer minutes ahead of their scheduled start times than patients scheduled to start later in the day (Table 1). Patient waiting is uninfluenced[32] by bias[3,4,6,33] that surgeons and schedulers may have when estimating OR times because Eq. (2) corrects for such bias, if present.

This methodology[8] ignores knowledge of the preceding procedure(s) in the OR and thus likely results in overall longer average patient waiting times than if more information was used.[2] For tertiary suites, this disadvantage is of negligible importance because approximately 47% of cases at such suites are scheduled by the surgeon fewer than 9 times in 3 years (i.e., historical sample sizes are so small that little information is unused).[34] Even after pooling data among 4 tertiary facilities, 20% of cases were of a procedure(s) performed fewer than 9 times in 1 to 3 years.[35] In contrast, we expected a small percentage for the gastroenterologists, and indeed found only 3% of cases were performed 6 or fewer times in 1.5 years by each physician (Table 5). Nevertheless, using that information[1,16,25] turned out to be impractical because the probability that a list of cases contains at least 1 case of a rare procedure increases exponentially with the number of cases minus 1. The 3% of cases calculation resulted in 13% of series having a rare procedure (Table 5), and thus the problem could not be ignored. The probability distributions for OR times of rare procedures are known[2,5] and can be used for the arrival time decision by calculating and storing versions

**Table 5. Incidence of Uncommon Pediatric Gastroenterology Procedures and Distribution Among Series of Gastroenterologists' Cases**

| Incidence of the procedure | Example of procedure with listed incidence | Inclusion in how many of the 128 series? Physician 1 | Physician 2 | Total |
|---|---|---|---|---|
| $N = 1$ | G-tube placement | 2 | 3 | 5 |
| $N = 2$ | Anoplasty, colonoscopy | 4 | 4 | 8 |
| $N = 6$ | Esophogastroduodenoscopy, flexible sigmoidoscopy | 6 | 0 | 6 |
| $N \leq 6$ | Counting only 1 such procedure per list | 10 | 7 | 17 (13%) |
| $N \leqq 34$ | All listed in Table 4 | 67 | 61 | 128 |

The right-most column's 5 + 8 + 6 = 19 cases of uncommon procedures were distributed among 17 series of cases. The ratio of 19 cases to the total of 490 cases (Table 3) equals 3.4%. The "13%" refers to the percentage of the overall 128 series (Table 2) that include at least 1 uncommon procedure.

**Table 6. Incidence of Combinations of Gastroenterologist and Procedure(s) Among Preceding Cases of Gastroenterologist on Same Day**

| Incidence of combination among preceding cases | Percentage of the 182 observed combinations | Percentage of the 330 estimated combinations |
|---|---|---|
| 7 | 1 | 0.3 |
| 6–7 | 2 | 1 |
| 5–7 | 3 | 2 |
| 4–7 | 7 | 4 |
| 3–7 | 15 | 8 |
| 2–7 | 30 | 17 |
| 1 or more | 100 | 55 |

The value of 330 equals the number of combinations with replacement obtained by selecting 4 cases from 8 procedure(s). The 4 cases equal the 80th percentile of list length (5 cases from Table 2) excluding the last case of the list. The 8 procedure(s) was obtained from Tables 4 and 5. Because the 80th percentile was used, not the maximum of 8 cases, and because the number of observed procedure(s) likely under-estimates the actual list of procedures,[35] the values in the third column likely are overestimates. The analysis was based on combinations with replacement rather than permutations because the sequence of the preceding combinations of procedures does not matter. For example, suppose that the first case of the day were colonoscopy, and the second case were a combination of esophogastroduodenoscopy and 24 h pH monitor. The 5% prediction bound for the time that the third patient would need to be ready would likely be the same as if the sequence of the first and second case were switched.

**Table 7. Incidence of Cases Preceded by At Least One Cancelled Case**

| | Physician 1 | Physician 2 | Total |
|---|---|---|---|
| Scheduled cases | | | |
| Counts | 25/325 | 25/268 | 50/593 |
| Percentage | 7.7 | 9.3 | 8.4 |
| Series with ≥1 cancellation | | | |
| Counts | 25/79 | 25/68 | 50/147 |
| Percentage | 32 | 37 | 34 |
| Affected/scheduled cases | | | |
| Counts | 52/300 | 38/243 | 90/543 |
| Percentage | 17 | 16 | 17 |

"Scheduled cases" gives the percentage of scheduled cases that are cancelled. The series of cases are different from those in Table 2 because cancellation of the first or second case in the list results in the cases not appearing in the other Tables. The value of 34% in the fourth row and third column of numbers is reasonable, given that for an 8.4% cancellation rate, the expected probability of 4 cases with no cancellations equals 30%. The choice of 4 cases equals both the median from Table 2 and the 80th percentile for cases in the list excluding the first case of the day. Although cancellations may cluster (e.g., physician sick resulting in all cases being cancelled), that would not be observed with the data, and so the assumption of independence is expected.

of Table 1 for each combination of procedure(s) that may precede each patient's case. However, there are at least 330 such combinations (Table 6). Not only is 330 too many to be viewed easily on paper by a scheduler, but also combinations of procedure(s) are combinations of text and difficult for schedulers to choose from in computer dropdowns. Having a computer calculate ready times once all cases are scheduled solves that problem but is useful only if there are not changes to the schedule.[8,29] Yet, there are indeed changes to the schedule. There was at least 1 case cancellation for 34% of the series of cases (Table 7).

Applying the empirical method[8] that uses only scheduled and actual start times to choose patient ready times, the probability distributions of earliness ratios (Eq. 1) differed between gastroenterologists ($P < 0.0001$). Figure 1 shows the surgeons' earliness ratios. An unbiased and nonparametric estimator of the 5% prediction bound of the earliness ratio was calculated by using each physician's fifth smallest of the most recent 99 earliness ratios: 0.667 and 0.867, respectively (Fig. 1).* Those 2 numbers were used in Eq. (2) to create the second to fourth and fifth to seventh columns of Table 1.

The facility previously instructed all patients (parents) to arrive 1.5 hours before the scheduled start of the procedure (Fig. 2). This approach failed to distinguish between the scheduling patterns and cancellation rates of the 2 gastroenterologists, with "physician 2" patients able to come <1.5 hours ahead (Fig. 2). This approach also neglected that, for "physician 1," with a relatively small earliness ratio, patients can wait < 1.5 hours in the morning, whereas later in the day, patients need to wait longer than 1.5 hours (Fig. 2). Use of Table 1 would have reduced the waiting time of patients by an average of 23 minutes or 30% (Table 8). The average and peak numbers of endoscopy patients in the holding area would have decreased approximately proportionately.[36,37]

## DISCUSSION

The studied facility implemented changed arrival and NPO times (Table 1) the week after data analysis was complete. The series of endoscopy cases served as a model system to explore the usefulness of different statistical methods of case-duration prediction for problems involving short pediatric anesthetics. Only calculation of patient ready times was found to be relevant and useful (Table 8). Because Tables 2 through 7 represent observational data, and, in many circumstances, we were able to identify other articles for comparison to assure that our results are likely typical,

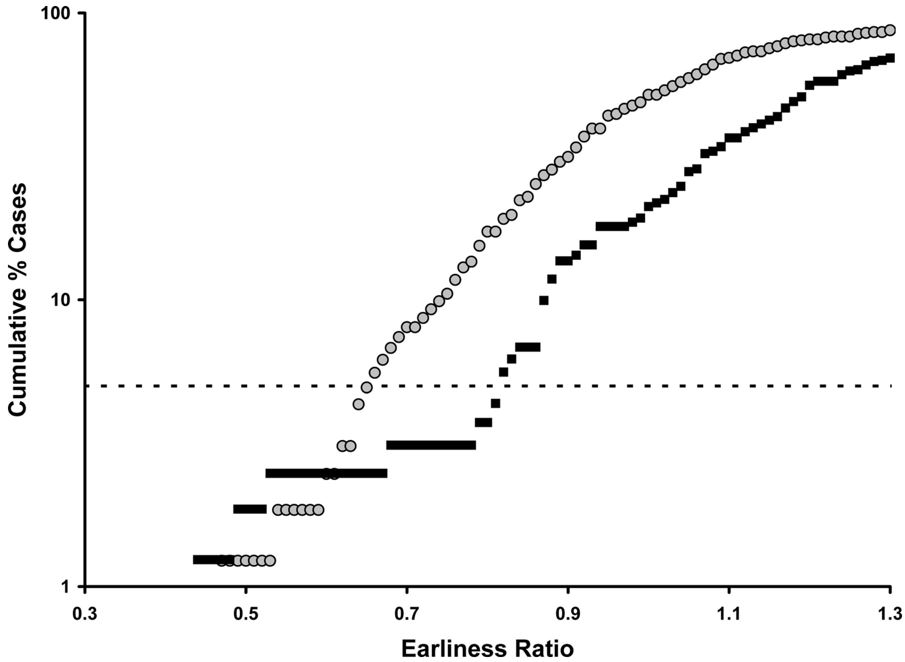


**Figure 1.** Cumulative probability distributions of earliness ratios differ between the 2 pediatric gastroenterologists. The earliness ratios were calculated as described in the Methods section equation (1), using the actual versus scheduled time of entry into the operating room. The 5th percentile is shown by the dotted line. Physician 1 data from the tables are represented by the gray circles and physician 2 data are represented by the black squares.

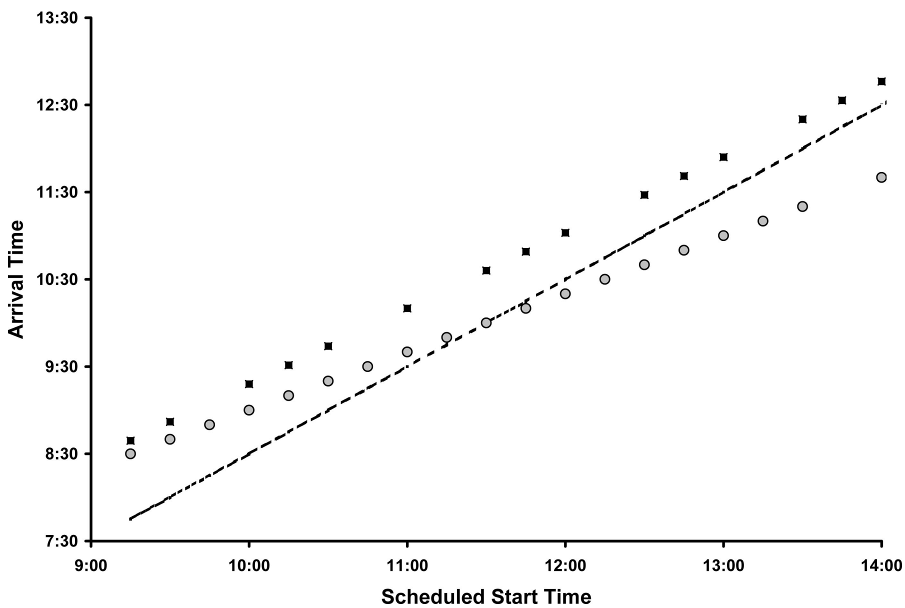


**Figure 2.** Comparison of arrival times of the pediatric gastroenterologists' patients based on earliness ratios versus constant interval before scheduled start time. Data are plotted for the 294 cases that were not scheduled to be first case of the day starts (Table 8). Physician 1 data from the tables and Figure 1 are represented by the gray circles and physician 2 data are represented by the black squares. For physician 1, the earliness ratio used was 0.667, resulting in patients undergoing procedures in the morning arriving 40 minutes to 1.5 hours early and those having procedures in afternoons arriving 1.5 to 2.3 hours early. For physician 2, using a larger earliness ratio, early in the morning the patients arrived 35 minutes early, whereas in the late afternoon the interval is 1.3 hours early. Both are shorter than the facility's previous policy of the patients arriving 1.5 hours before the scheduled start time (dotted line).

this portion of our results is essentially a qualitative systematic review. However, the fact that qualitative review would be sufficient to draw conclusions was evident to us only in retrospect. We are unaware of any prior study that has systematically organized the existing knowledge for short pediatric cases.

Tables 2 through 4 give important new results about case-duration prediction for pediatric endoscopy. This evaluation of the usefulness of predictive methods likely can be extrapolated to other brief pediatric anesthetics in ORs, regardless of the type of anesthesia. However, the evaluation likely does not apply to case-duration prediction for diagnostic and interventional radiological procedures (including cardiology), principally because different types of scheduling information systems are used at such sites.[7,38] In contrast, our results for choosing the ready times of patients (Table 1, Eqs. 1 and 2, and Figs. 1 and 2) do apply to those sites, including endoscopy suites distant from ORs.[8,39]

A limitation of our work is that it is from 1 facility. However, estimated statistical parameters for patient arrival times were similar at another pediatric hospital.* Also, our finding of a 30% reduction in waiting time with a negligible increase in overutilized OR time can be compared with discrete event simulation results from an adult endoscopy suite, with 4 gastroenterologists working in 8 ORs.[40] Their finding was a 44% decrease in patient waiting by applying statistical methods for choice of arrival, while constraining the

**Table 8. Differences in Predicted Waiting at the Facility Between (1) Patients Arriving 1.5 h Before the Scheduled Start Time as Used Originally and (2) Patients Arriving Based on Table 1**

| | Physician 1 | Physician 2 | Total |
|---|---|---|---|
| Time reduction (min) | | | |
| *N* cases | 165 | 129 | 294 |
| Mean ± SEM | 10 ± 2 | 40 ± 1 | 23 ± 1 |
| Median | 15 | 40 | 30 |
| Time reduction (%) | | | |
| *N* series (lists) | 64 | 54 | 118 |
| Mean ± SEM | 20% ± 3% | 43% ± 2% | 30% ± 2% |
| Median | 20% | 42% | 30% |

"*N* cases" refers to the number of cases that were scheduled to start on or after 9:15 AM. Time reduction (%) was analyzed after batching by series of cases to prevent 0 in a denominator.

increase in overutilized OR time to <1%.[40] The results are consistent in showing that opportunities exist to reduce waiting by applying operations research (statistical) methods.

Another limitation is that we considered liquid restrictions but not restrictions on solids. The pediatric gastroenterology patients are kept NPO for solids for 8 hours before the start of anesthesia. Given the patients' medical conditions, we are unaware of applicability of consensus guidelines to these patients for fasting intervals <8 hours. Referring to the second and fifth columns of Table 1, only patients scheduled to have surgery starting after 2:00 PM would be able to eat after 5:00 AM. This seems an impractical reduction in time as compared with having children eat before going to sleep.

## AUTHOR CONTRIBUTIONS

Both authors participated in study design and manuscript preparation. BS organized the data acquisition and observational study. FD performed the data analysis.

## RECUSE NOTE

Franklin Dexter is section Editor of Economics, Education, and Policy for the Journal. The manuscript was handled by Peter J. Davis, section Editor of Pediatric Anesthesiology and Dr. Dexter was not involved in any way with the editorial process or decision.

## DISCLOSURE

The University of Iowa performs statistical analyses for hospitals and anesthesia groups, including the methods used in the article. Dr. Dexter receives no funds personally other than his salary from the State of Iowa, including no travel expenses or honoraria, and has tenure with no incentive program. Dr. Smallman has no productivity based incentive program (i.e., compensation) affected by study results or implementation.


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