JOURNAL OF SURGICAL RESEARCH 201 (2016) 306–312

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.JournalofSurgicalResearch.com

Use of simulation to assess a statistically driven surgical scheduling system

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ARTICLE INFO

Article history:
Received 28 July 2015
Received in revised form
22 October 2015
Accepted 29 October 2015
Available online 6 November 2015

Keywords:
Simulation
Statistical modeling
Effectiveness

ABSTRACT

Background: To maximize operating room (OR) utilization, better estimates of case duration lengths are needed. We used computerized simulation to determine whether scheduling OR cases using a statistically driven system that incorporates patient and surgery-specific factors in the process of case duration prediction improves OR throughput and utilization.
Methods: We modeled surgical and anesthetic length of vascular surgical procedures as a function of patient and operative characteristics using a multivariate linear regression approach (Predictive Modeling System [PMS]). Mean historical operative time per surgeon (HMS) and mean anesthetic time were also calculated for each procedure type. A computerized simulation of scheduling in a single OR performing vascular operations was then created using either the PMS or the HMS.
Results: Compared to HMS, scheduling the operating room using the PMS increased throughput by a minimum of 15% (99.8% cumulative probability, $P < 0.001$). The PMS was slightly more likely to lead to overtime (mean 13% *versus* 11% of operative days during a calendar year, $P < 0.001$). However, the overtime lasted longer in the HMS group (mean 140 *versus* 95 min per day of overtime, $P < 0.001$). PMS was associated with lower OR underutilization rate (mean 23% *versus* 34% of operative days, $P < 0.001$) and less lengthy OR underutilization (mean 120 *versus* 193 min per day of underutilization, $P < 0.001$).
Conclusions: This computerized simulation demonstrates that using the PMS for scheduling in a single operating room increases throughput and other measures of surgical efficiency.
Published by Elsevier Inc.

1. Introduction

Costs incurred in the scheduling and operation of operating rooms (ORs) have been important to hospital administrators, particularly because surgical suites comprise one of the most costly functional areas in the hospital [1,2]. Typically, more than 60% of patients admitted to a hospital are treated in the OR. Therefore, access to surgical services depends on the efficient use of limited and costly OR resources. In this context, maximizing OR utilization is one way of controlling health care costs and providing optimal patient care. [3,4].

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0022-4804/$ – see front matter Published by Elsevier Inc.
http://dx.doi.org/10.1016/j.jss.2015.10.043

We have previously shown that the operative length (time from skin incision to skin closure) of carotid endarterectomy and lower extremity bypass graft operations can be modeled using a regression-based approach, using operative, surgeon, and patient characteristics as predictors [5]. We have also demonstrated that forecasts of operative time length that are based on these models have superior accuracy in predicting operative time out of sample when compared to predictions made using historical means [5]. Furthermore, we have shown that the length of presurgical and postsurgical anesthetic time can be similarly modeled for all major types of vascular surgical operations [6]. However, the practical significance of the incremental benefit in precision gained from this modeling remains unclear. Specifically, we do not know whether the ability to more accurately predict individual case length is adequate to meaningfully increase the number of cases performed in the operating room during an operative day that has fixed length and fixed hours of regular-wage staffing.

In this study, we hypothesized that scheduling vascular surgical cases in a single operating room by using the regression-based predictive modeling system (PMS) will improve throughput without leading to excessive over- or underutilization of the operating room. We compared the PMS to a scheduling methodology that uses historical means per surgeon (HMS), which is a common strategy used by hospitals to estimate operative length for allocating OR time to individual cases. To compare the two approaches we conducted a computerized simulation of elective surgery scheduling in a single operating room. Our findings indicate that the regression modeling approach holds promise in improving throughput of elective vascular surgical cases.

2. Methods

2.1. Patient population

Using a retrospective cohort design, we extracted via queries of electronic scheduling and timekeeping system information on 3245 open and endovascular vascular surgery operations that were performed over a 4-year period. We categorized these surgical cases in distinct procedure types on the basis of anatomic and operative characteristics. Most of the procedures, we examined incorporated more than one current procedural terminology (CPT) codes, which is fairly typical in a complex Vascular Surgery practice setting. Technical operative and patient-related variables that might influence the length of the intervention were collected from the medical record. As the objective was to use this information to model the length of the operative interventions, only variables that were known preoperatively were collected.

2.2. Regression modeling

Our group has previously described details of operative case modeling [5,6]. Briefly, we divided all vascular operative procedures that are performed in our institution in groups based on common anatomic and technical factors. This grouping was used in lieu of the most commonly reported grouping in the literature, which is based on primary CPT codes. This different classification allowed us to circumvent CPT-related precision limitations and to account for the fact that most of the surgical procedures we examined included multiple CPT codes. To model operative time within each procedure group, we conducted multiple univariate regression analysis with the operative time as dependent variable and patient or surgery-specific factors as right-hand variables. To assess model stability, we fit two separate regressions per procedure type. Specifically, we used either a) robust linear regression with dependent variable the operative time, or b) linear regression, with dependent variable the natural logarithm of the operative time. Variables with P value <0.15 were subsequently entered in a multivariable regression model. Regressors with P values <0.05 were included in the final main effects model, for which parameter estimates were calculated and used to make operative time predictions. This methodology enabled to obtain hospital-level and procedure-specific "mathematical signatures" of operative time length for all the vascular operations performed in our facility. Table 1 lists the procedure types we examined and the statistically significant predictors of surgical length for each one of them. Both sets of models (robust regression or linear regression with logarithmic transformation of the dependent variable) yielded similar statistically significant regressors. The robust regression parameter estimates were finally used for duration prediction purposes.

A similar approach was taken to predict anesthetic times that were modeled as the sum of preoperative anesthetic (time from entry to the room until skin incision) and postoperative anesthetic (time from skin closure to patient exit from the room) times. Room turnover time was also modeled but was found to be random and not associated with particular procedure types.

2.3. Calculation of historical means per surgeon

The historical average length for each type of operation per surgeon was calculated as the average operative time for this procedure over the entire span of our data collection. There is a wide variation in the methodology used to calculate the expected length for a given operation among hospitals. These include averages per surgeon, service, or department; surgeon's or scheduler's estimate; department, hospital, or national averages; or, uncommonly, estimates derived proprietary formulas of the operating room–scheduling package [7]. We took the approach of averaging the time per procedure per surgeon, as surgeon's effect on operative time has been well established in our work, as well as the work of others [8,9]. Furthermore, using this benchmark for operative duration predictions provides a robust point of reference, as there are very few facilities, if any, that use a more granular approach in operative time predictions when constructing their OR schedule.

2.4. Simulation

To compare the PMS *versus* the HMS scheduling methodologies, we conducted a computerized simulation of scheduling vascular surgical cases in a single operating room. We used the operative day as unit of observation and analyzed