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Derivation and out-of-sample validation of a modeling system to predict length of surgery

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Abstract

BACKGROUND: We performed a retrospective study to compare the precision of a regression model (RM) system with the precision of the standard method of surgical length prediction using historical means (HM).

METHODS: Data were collected on patients who underwent carotid endarterectomy and lower-extremity bypass. Multiple linear regression was used to model the operative time length (OTL). The precision of the RM versus HM in predicting case length then was compared in a validation dataset.

RESULTS: With respect to carotid endarterectomy, surgeon, surgical experience, and cardiac surgical risk were significant predictors of OTL. For lower-extremity bypass, surgeon, use of prosthetic conduit, and performance of a sequential bypass or hybrid procedure were significant predictors of OTL. The precision of out-of-sample prediction was greater for the RM system compared with HM for both procedures.

CONCLUSIONS: A regression methodology to predict case length appears promising in decreasing uncertainty about surgical case length.

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Cost incurred in the scheduling and operation of operating rooms (ORs) has 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 use is

one way of controlling health care costs, and providing optimal patient care.^{3,4}

Although scheduling is a primary determinant of surgical suite use, based on the time required to construct schedules as well as the quality of resulting schedules,^{5,6} evidence indicates that scheduling in practice often is performed poorly.⁷ In this study we hypothesized that a regression model (RM) that takes into account surgeon-, patient-, and technical surgery-specific variables will be more reliable in predicting the surgical length of carotid endarterectomy (CEA) and lower-extremity bypass (LEB), compared with the traditional method of prediction using historical means (HM). Our long-term goal has been to investigate whether or not individual procedures, which

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consist of the fundamental building blocks for OR scheduling, can be modeled reliably using an objective methodology. Such modeling could become a useful tool in optimizing OR scheduling and resource use.

Methods

Patient population

The study was conducted using a retrospective cohort design. Surgical length of 205 consecutive CEAs and 319 LEBs that occurred over a 3-year period were collected via queries of an electronic scheduling and timekeeping system. Surgical and patient-related variables that might influence the length of the intervention and were known preoperatively were collected from the medical record.

Regression modeling

For each procedure, patients were divided randomly into derivation and validation datasets using a random number generator. A linear regression model was created based on information of the derivation dataset, which also was used to calculate the overall historical means for performing each intervention. The parameter estimates of the model and the calculated historical means were used in the validation dataset to assess out-of-sample applicability and usefulness of the regression methodology. Generation of the regression model was initiated with univariate analysis that was performed using multiple simple linear regression equations to assess the relationship between the surgery length and variables that had been collected and were thought to be related to the surgical time. Predictors with a *P* value less than .05 were included in the final main-effects model. Given the natural tendency of surgeons to improve their performance over time, an interaction variable between surgeon and time was introduced to the model to assess the impact of the experience gained over time on the length of surgical intervention. Parameter estimates from the regression equation of the derivation dataset were applied in a validation dataset to calculate the expected length of surgery and assess the out-of-sample applicability of the model in being more accurate than the traditional predictive methodology of historical means. Because a surgeon's experience is a critical determinant of surgical performance, the 7 surgeons who were included in the study were divided for modeling purposes into 3 groups as follows: group A had at least 4 years of surgical experience; group B had more than 1 year but less than 4 years of surgical experience; and group C had less than 1 year of surgical experience at the time the study was initiated. Experience level of the main assistant also was included as a covariate; however, in our practice the attending surgeon typically dictates the pace of the surgery.

The historical mean for each surgery was calculated in the derivation dataset as the average surgical time. Admittedly, there is wide variation in the methodology used to calculate those means among hospitals. Averages per surgeon, per service, or per department all have been used.⁸ In addition, some facilities use averages that are updated infrequently, whereas other facilities use a sliding window approach to incorporate more recent data into their calculations. Averaging the time per procedure as we did was a neutral approach and incorporated data from all surgeons that were included in the study to facilitate a real-life comparison.

Outcomes

The primary outcome measure of the study was the accuracy in length of surgery, defined as the difference between the observed and predicted operative time for each patient of the validation dataset. The predicted surgery time length with the regression approach was calculated by applying the regression parameter estimates (calculated in the derivation dataset) to each patient's surgical characteristics. The predicted surgical time length with the HM approach was calculated as the mean surgical time for the particular type of intervention in the derivation dataset. The imprecision times for the RM and the HM measured in minutes then were compared using the *t* test with unequal variances. The distribution of predictors between the validation and distribution sets were assessed with the Fisher exact test for categorical variables, and the Student *t* test or Wilcoxon rank-sum test for continuous variables. Statistical analysis was performed using Stata software, version 12.1 (StataCorp, College Station, TX).

Results

Modeling of carotid endarterectomy

CEA modeling included a total of 205 patients (120 patients in the derivation dataset). The predictors we examined included the following. First, general predictors such as comorbidities (presence of diabetes mellitus, congestive heart disease, renal failure, chronic obstructive lung disease coded as binary variables; and revised cardiac risk index coded as ordinal variable I–IV), perioperative pharmacotherapy (β -blockers, statins, antiplatelet treatment, all coded as binary variables), body mass index, level of experience of the surgeon and assistant, and an indicator variable for the well-known July effect. Second, technical surgery-specific factors, including the presence of calcified plaque and the presence of a high carotid bifurcation. All these predictors were distributed similarly between the derivation and validation datasets. From the variables entered in the simple linear regression with surgical length as the dependent variable, only surgeon, time from the beginning of the study, the

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