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Predictive Analytics for Determining Extended Operative Time in Corrective Adult Spinal Deformity Surgery

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ABSTRACT

Background: More sophisticated surgical techniques for correcting adult spinal deformity (ASD) have increased operative times, adding to physiologic stress on patients and increased complication incidence. This study aims to determine factors associated with operative time using a statistical learning algorithm.

Methods: Retrospective review of a prospective multicenter database containing 837 patients undergoing long spinal fusions for ASD. Conditional inference decision trees identified factors associated with skin-to-skin operative time and cutoff points at which factors have a global effect. A conditional variable-importance table was constructed based on a nonreplacement sampling set of 2000 conditional inference trees. Means comparison for the top 15 variables at their respective significant cutoffs indicated effect sizes.

Results: Included: 544 surgical ASD patients (mean age: 58.0 years; fusion length 11.3 levels; operative time: 378 minutes). The strongest predictor for operative time was institution/surgeon. Center/surgeons, grouped by decision tree hierarchy, a and b were, on average, 2 hours faster than center/surgeons c-f, who were 43 minutes faster than centers g-j, all $P < 0.001$. The next most important predictors were, in order, approach (combined vs posterior increases time by 139 minutes, $P < 0.001$), levels fused (<4 vs 5–9 increased time by 68 minutes, $P < 0.050$; 5–9 vs ≤ 10 increased time by 47 minutes, $P < 0.001$), age (age <50 years increases time by 57 minutes, $P < 0.001$), and patient frailty (score <1.54 increases time by 65 minutes, $P < 0.001$). Surgical techniques, such as three-column osteotomies (35 minutes), interbody device (45 minutes), and decompression (48 minutes), also increased operative time. Both minor and major complications correlated with ≤66 minutes of increased operative time. Increased operative time also correlated with increased hospital length of stay (LOS), increased estimated intraoperative blood loss (EBL), and inferior 2-year Oswestry Disability Index (ODI) scores.

Conclusions: Procedure location and specific surgeon are the most important factors determining operative time, accounting for operative time increases <2 hours. Surgical approach and number of levels fused were also associated with longer operative times, respectively. Extended operative time correlated with longer LOS, higher EBL, and inferior 2-y ODI outcomes.

Clinical Relevance: We further identified the poor outcomes associated with extended operative time during surgical correction of ASD, and attributed the useful predictors of time spent in the operating room, including site, surgeon, surgical approach, and the number of levels fused.

Level of Evidence: 3.

Lumbar Spine

Keywords: adult spinal deformity, operative time, decision trees, predictive analytics

INTRODUCTION

The time to perform surgical correction of adult spinal deformity (ASD) can commonly be of protracted duration. ASD cohorts in the literature display average operative times ranging 257–390 minutes.[1–3] There is a wide variety of ASD pathologies and commensurate differential in the procedures required to correct them. Further variability exists among surgeons and institutions with respect to the management techniques employed. Each of these factors has an impact on the duration of surgery. Operative time is a primary concern for spine surgeons, as it has been associated with higher complications rates, longer hospital stays, higher costs, and higher operating room resource utilization.[4–7]

Operative time has been shown to independently correlate with complication incidence, particularly infection.[4,6] An independent, causal relationship between extended operative time and adverse events in ASD surgery is disputed, however, as it may be confounded by preoperative factors and deformity complexity, which may also result in extended operative time. ASD operative time has also been correlated with the extended length of hospital stay postoperatively, but similar methodological disputes over confounders have been postulated.[5] A general consensus, however, is that the risk for complication increases past a certain, undefined point, as the stress patients caused by anesthesia cannot be endured indefinitely.[8,9]

The value of operating room time is considerable. Operative times for long thoracolumbar reconstructions can vary from 3 to 14 hours and demand review in the current climate of measured healthcare economics.[1–3] Although operating room utilization and efficiency literature has historically focused on room turnover times, there has been no known analysis of the intraoperative efficiency of the surgical team. Improved understanding of specific determinants for extending operative time would be helpful in improving efficiency and reducing risk. This study seeks to identify and quantify the factors, which are most influential in affecting the duration of surgery.

MATERIALS AND METHODS

Data Source

This study is a retrospective review of a prospectively collected, multicenter database of consecutively enrolled operative and nonoperative ASD patients from 11 sites across the country. Each site obtained Institutional Review Board approval and informed patient consent prior to patient enrollment. Inclusion criteria for the database are age ≥18 years at enrollment and presence of at least one spinal deformity marker: scoliosis Cobb angle ≥20°, sagittal vertical axis (SVA) ≥5 cm, pelvic tilt (PT) ≥25°, and/or thoracic kyphosis ≥60°. Exclusion criteria are spinal deformity secondary to neuromuscular, syndromic, autoimmune, infectious, tumor, or posttraumatic conditions. Additional inclusion criteria for the present study were as follows: patient enrolled into the surgical branch of the database, the operation was performed by a surgeon with <20 surgeries in the database, and complete baseline and 6-week radiographic, clinical, and patient-reported outcome measures.

Study Design

Conditional inference decision trees were used to identify potential factors that affect skin-to-skin operative time and the cutoff points at which they have a global effect. Patients undergoing staged procedures were excluded, as well as cases whose surgeons supplied fewer than 20 cases to the database.

Data Collection

Radiographic, demographic, clinical, and patient-reported outcome data were assessed. Radiographic measurements on full-length anteroposterior and lateral imaging (36-inch cassette) were completed by at least 2 independent physicians based on standard techniques using validated software (SpineView, ENSAM Laboratory of Biomechanics, Paris, France).[10,11] Demographic data included patient age, sex, body mass index (BMI), Charlson Comorbidity Index (CCI), years with spine problems, and previous spine surgeries. Surgical data included approach, number of levels fused, levels decompressed, osteotomy type and number, interbody type and number, and graft type. Complications were analyzed according to severity: adverse event (any deviation from protocol), minor complication (defined by Carreon et al 2003), major complication (defined by Carreon et al[12]), or reoperation complication (causing a reoperation). Correlations across the following parameters were investigated using Spearman correlation: estimated intraoperative blood loss (EBL), hospital length of stay (LOS), Oswestry Disability Index (ODI), Scoliosis Research Scoiety-22 (SRS), and EuroQol 5-dimensional (EQ-5D).[12–15]

STATISTICAL METHODS

R version 3.3.1 (The R Foundation for Statistical Computing) was utilized for preprocessing and analysis of the data; packages used include "party" and "rpart." Main analysis consisted of a random forest set of 2000 conditional inference trees (subsampling without replacement) utilized to identify potential factors that affect skin-to-skin operative time and the respective importance of each variable as a predictor. The top 15 predictors were chosen according to a variable-importance table (Gini Gain criterion) generated by the varimp() function in the R "party" package. An additional set of 15 conditional inference trees, which only compared our target variable against one of the 15 predictors previously mentioned, were run to find significant cutoff points at which these predictors had a global effect on our target variable. Results were confirmed by using means comparison and χ^2 tests for every partition in each of these trees. Kaplan-Meier curve

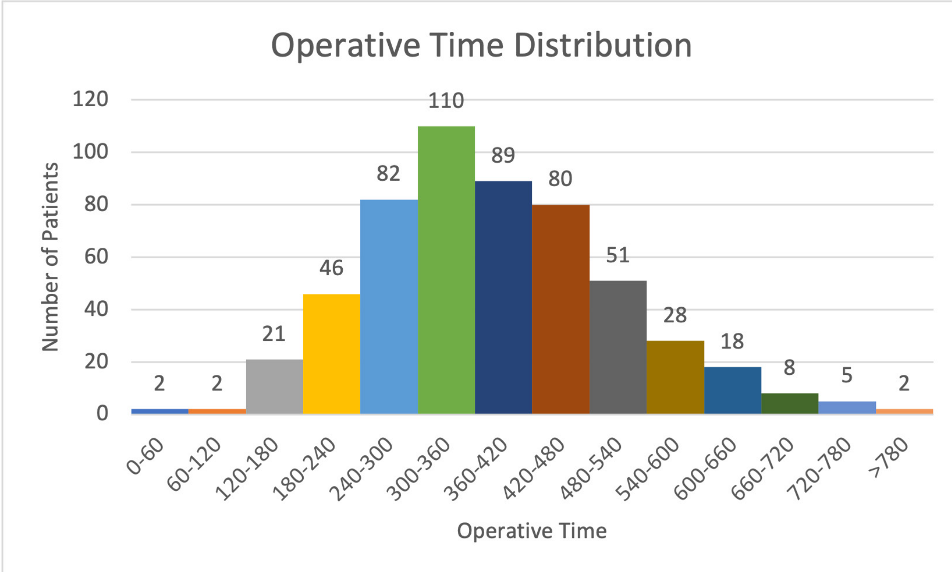

Figure 1. Distribution of operation times in the adult spinal deformity cohort (*N* = 544). Operative times are shown in minutes.

analysis was utilized via IBM SPSS Statistics software to estimate rates of intraoperative complications in relation to increasing operative time.

RESULTS

A total of 544 patients underwent spinal fusions for correction of ASD. Average operation time was 377.56 minutes, ranging from 22 to 836 minutes (Figure 1). Patient demographics and information on procedures performed are available in Table 1.

Global Effects

The strongest predictor for operative duration was the global variable: institution/surgeon (Table 2). Center/surgeons, grouped by decision tree hierarchy, a and b were, on average, 2 hours quicker than center/surgeons c-f , who were 43 minutes faster than centers g-j (all $P < 0.001$).

Table 1. Summary of demographics and surgeries performed in adult spinal deformity patients.

Demographics	***N* = 544**
Woman, %	75.4%
Age, y, mean	58.1
Body mass index, mean	28.1
Charlson Comorbidity Index	1.6
Smoker, %	7.2%
Previous fusion surgery, %	37.0%
Surgeries performed	
Mean number levels fused	11.4
Approach, %	
Anterior	0.5%
Posterior	85.4%
Anterior then posterior	13.9%
Three-column osteotomy	49.4%

Patient Profiling

Adverse patient demographics strongly predicted longer operative times (Table 2). Age (age <50 years increases time by 57 minutes, $P < 0.001$) and a summative patient frailty (score <1.54 increases time by 65 min, $P < 0.001$) showed the strongest effect.

Procedure

Table 2 also summarizes the minute effect of each procedure commonly employed by spine surgeons in this database. Procedures utilizing both anterior and posterior approaches, greater number of vertebra levels fused, and including the placement of an interbody device had significantly increased operative times. Important operative time determinants included approach (combined vs posterior increases time by 139 minutes, $P < 0.001$) and number of levels fused (<4 vs 5–9 increased time by 68 minutes, $P < 0.050$; 5–9 vs ≤10 increased time by 47 min, $P < 0.001$).

Intraoperative Events

A 10.8% of patients sustained a major complication, and 19.6% of patients sustained a minor complication. Major and minor complications were both associated with increased operative time by an average 65 minutes (both $P < 0.001$); however, both adverse event and "reoperative" complication categories did not reach significance.

Table 2. Predictive analytics utilizing decision trees in determining significant clincial variables affecting operative time in adult spinal deformity corrective surgery.

Significant Clinical Variables Affecting Operative Time				
Overall Rank	**Variable Name**	**Groups Compared**	**Difference**	***P* Value**
Global				
01	Surgery site	Centers a,b vs centers c-f	120.906	0.000
		Centers c-f vs centers g-j	42.656	0.000
Procedural				
02	Approach	Comb. vs post.	139.034	0.000
03	Levels fused	≤4 vs 5–9	68.207	0.014
		5–9 vs 10+	47.613	0.000
04	Interbody device	0 vs <0	44.710	0.000
11	Number of pedicle screw osteotomies	≥1 vs 0	32.858	0.027
08	Number of 3-column osteotomies used	≥1 vs 0	35.269	0.005
09	Decompression technique used	Decmp. vs none	48.651	0.000
Patient Characteristics				
05	Frailty index	< 1.5 vs ≥ 1.5	78.375	0.000
06	Charlson Comorbidity Index	0 vs <0	66.054	0.000
07	Scoliosis Research Scoiety-22-Schwab Global Alignment	0 vs +	30.196	0.025
		+ vs ++	34.963	0.016
10	Scoliosis Research Society-Schwab PI-LL	0 vs (+ & ++)	46.164	0.000
14	Body mass index	<25 vs 25–30	34.382	0.007
		25–30 vs ≥30	29.854	0.027
Intraoperative Complications				
12	Minor	≥1 vs 0	66.520	0.001
13	Major	≥1 vs 0	66.552	0.001

Determining an Operative Time Threshold for Complications

Major complication incidence occurred at a relatively steady rate with respect to surgery time from the 4 hours mark onward (Figure 2). Patients who reached 10 hours under anesthesia had a 68% survivorship rate of experiencing major complications. Minor complication incidence had a sharper increase from the 4 hours mark with respect to surgery time. Patients who reached 10 h under anesthesia had a 38% survivorship rate of experiencing a minor complication.

A 8.1% of patients sustained an infection. Survivorship analysis showed infection incidence to increase after 7 hours, with the great majority of patients sustaining infections undergoing surgeries lasting 7–11 hours. Cardiopulmonary complications occurred in 11.3% of patients; 91.1% of these complications appeared between 6 and 11 hours.

An additional Kaplan-Meier study utilizing SPSS software mirrored the previous survivorship analysis and found that patients exceeded a 50% estimated chance of developing a major intraoperative complication if their operative time was longer than 380.0 minutes (95% CI, 329.71–420.29, Figure 3). Indeed, patients who had an operative time greater than 380.0 minutes had significantly higher major intraoperative complication rates (12.1%) compared to those with a lower operative time (7.47%, $P = 0.055$). For minor complications, the estimated time was 670.0 minutes until patients experienced an estimated prediction greater than 50% (95% CI, 572.70–767.31, Figure 4). The mean estimated operative time for major intraoperative complications was 396.3 minutes (95% CI, 363.79–428.89) and 641.9 minutes for minor (95% CI, 572.69–767.31).

Correlation With Clinical Outcomes

Table 3 describes relationships between clinical variables and operative time. Estimated blood loss and hospital LOS both showed high correlation with operative time. Longer operative times correlated with worse ODI scores at 2-year follow-up.

DISCUSSION

The duration of an operation has important clinical and economic consequences. ASD correction typically requires considerable time for completion. Therefore, efficiency is paramount in optimizing surgery outcomes and a hospital's bottom line. This study, therefore, described operative duration as a function of patient characteristics and surgeon decision-making in 544 long spinal fusions for ASD.

The most important factor predicting operative time was the institution at which the surgery was performed. Centers a and b were 120 minutes faster than c-f, which were 42 minutes faster than centers g-j. Because all but one center contributed a single surgeon, the specific surgeon variable cannot be isolated from expediency of the hospital center. Because of the institution and surgeon factors being indistinguishable from one another in the analysis, it is difficult to separate the influence of OR/team efficiency from the surgeon's

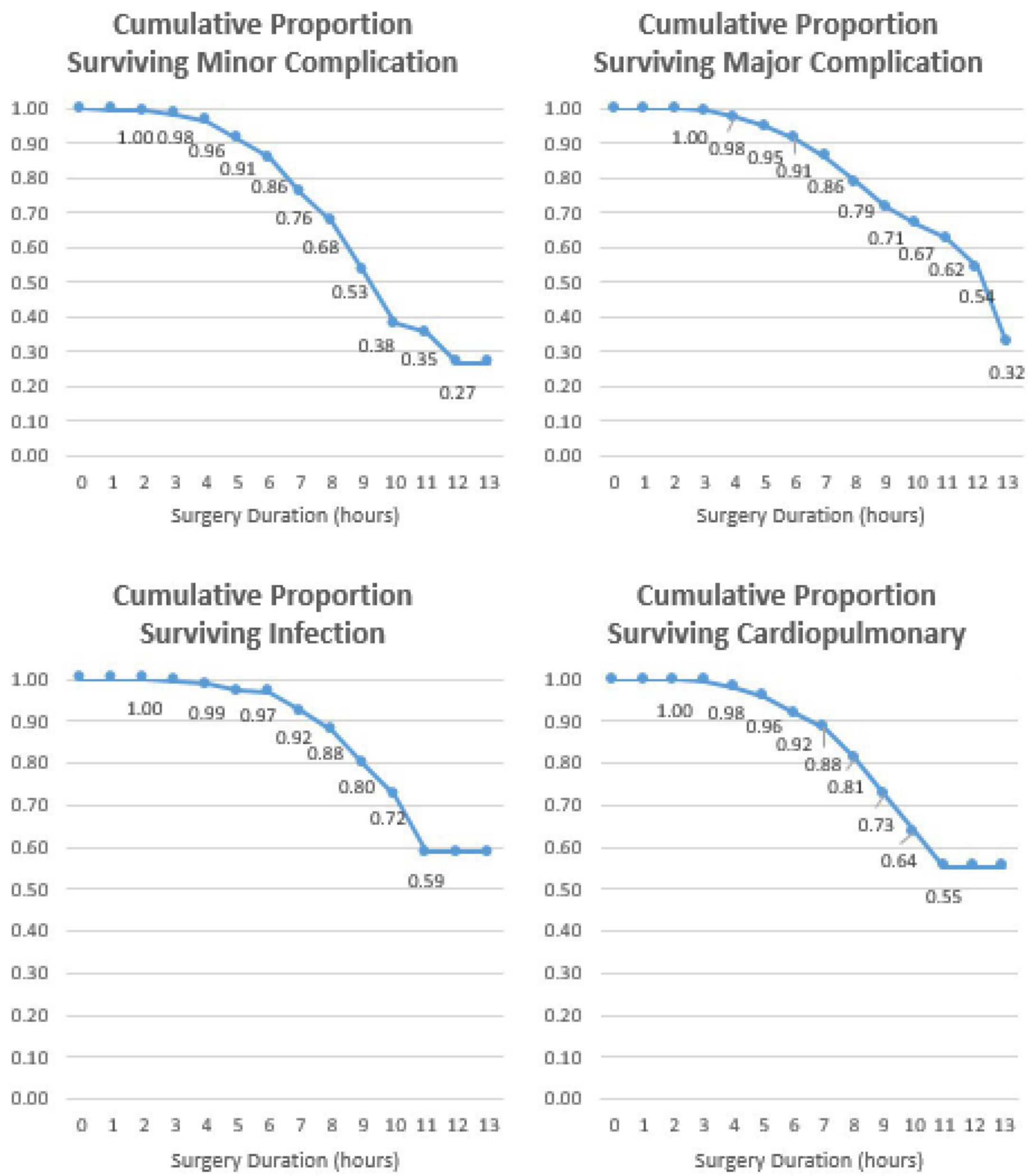

Figure 2. Survivorship curves for intraoperative infection, cardiopulmonary, and major and minor complications, respectively.

specific impact. In a recent article examining the effect of 1 vs 2 attending surgeons in adult scoliosis surgeries, Ames et al found a significant difference in operation duration between 1 and 2 attending surgeon teams ($P = 0.745$).[16] The present study corroborates the finding that changes in surgeon protocol, whether it be adding a surgeon or other undetermined factors, have a significant effect on operation duration.

In every quantifiable measure, more comorbid patients required longer operative times. This indicates that surgeons are more diligent in patients with higher risk of complication. Comorbidity has a well-established link to complications and indirect cost. The current study adds further understanding to higher comorbid patients' burden on hospital resources: a CCI <0 increased operation time by over an hour. CCI has already shown strong prediction of complications,[17] LOS,[18] and worse overall outcomes[19] in ASD correction. The current study's finding emphasizes the importance of patient selection in the context of resource usage. In analyzing time added when managing worse deformities, increasing SRS modifiers describing worse "Global Alignment" and "PI-LL Mismatch" contributed 30–35 and 45 minutes added operative duration, respectively. This time most likely consists of time for positioning and turnaround between additional procedures

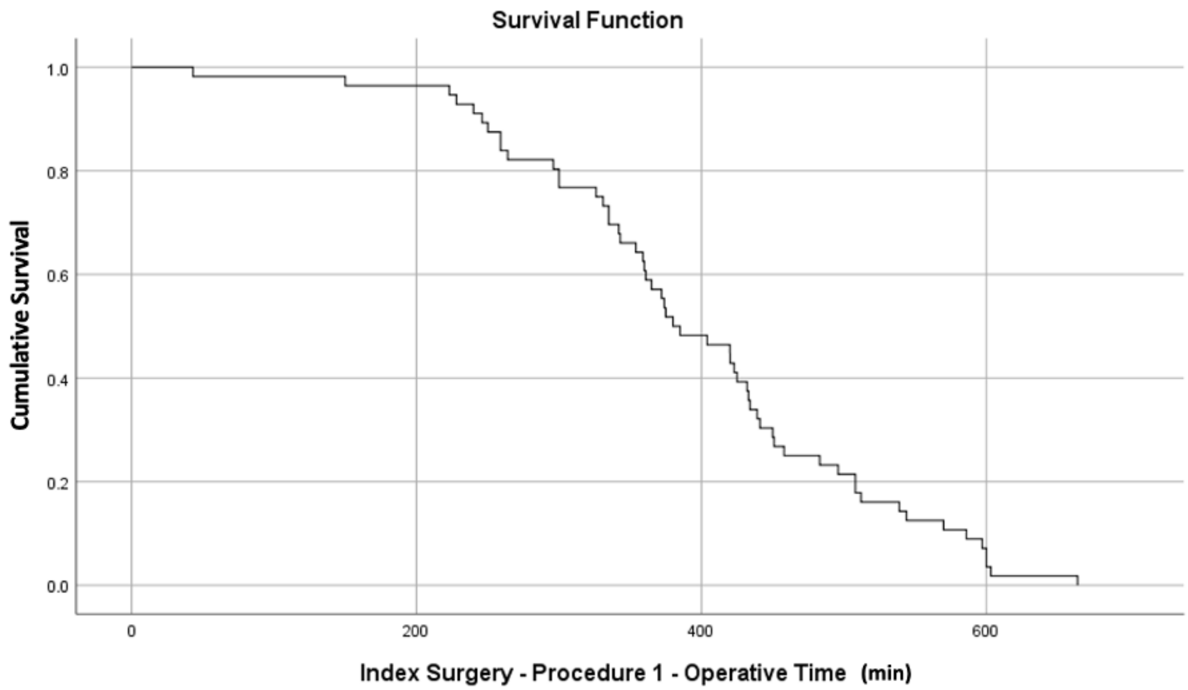

Figure 3. Kaplan-Meier curve utilizing operative time and major intraoperative complications as the status event.

needed for corrections that are more complex. Finally, patient BMI added significant time to operation duration, with patients in "overweight" adding 34 minutes, and "obese" category patients adding an additional 30 minutes. Given the increased complications frequently attributed to both more deformed and higher BMI patients, these findings agree that more comorbid take significantly longer.

Procedures that are more complex will typically result in longer operative times. Table 2 gives a detailed breakdown of operative time differential in patients relative to specific surgical procedures. Of

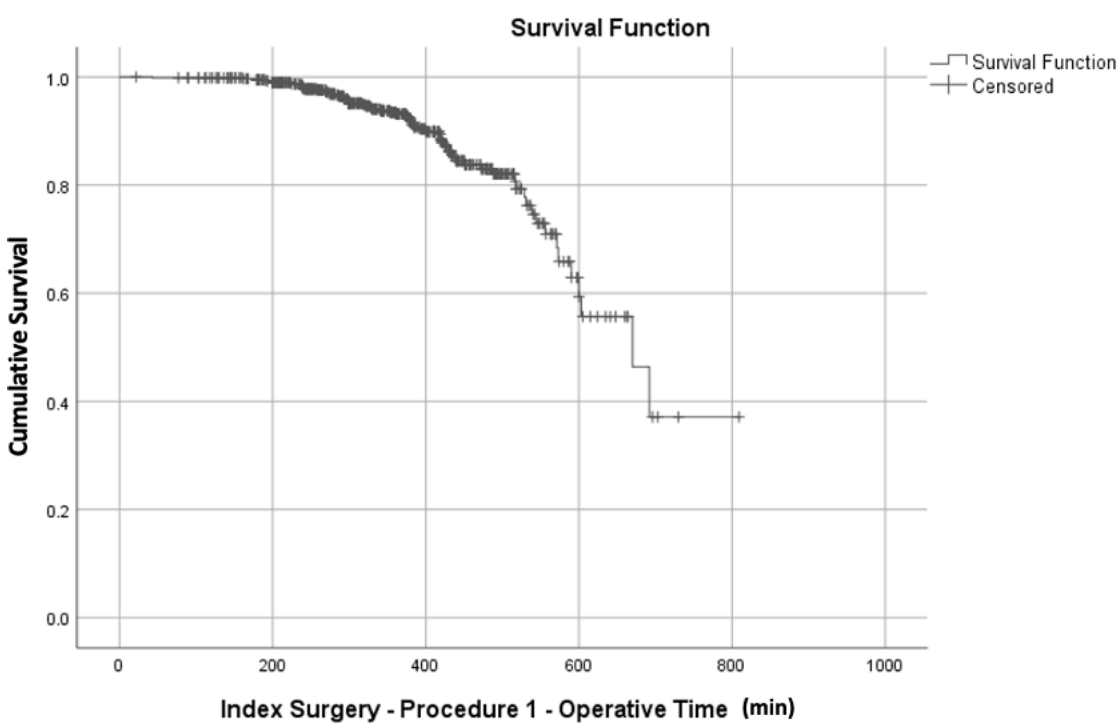

Figure 4. Kaplan-Meier curve utilizing operative time and minor intraoperative complications as the status event.

Table 3. Spearman correlations determining significant correlations between clinical variables and operative time in adult spinal deformity surgical patients.

Correlation Between Clinical Variables and Operative Time		
Variable	Prediction Accuracy (Spearman Coefficient)	Significance (2-Tailed)
EBL	0.331	<0.001
LOS	0.263	<0.001
2-y ODI	0.141	0.015
2-y SRS-22	–0.069	0.232
2-y EQ-5D	–0.023	0.808

Abbreviations: EBL, estimated intraoperative blood loss; EQ-5D, EuroQol 5-dimensional; LOS, hospital length of stay; ODI, Oswestry Disability Index; SRS, Scoliosis Research Society-22.

significance, a secondary surgical approach added an average 139 minutes to the procedure. Staged procedures performed on 2 different days were excluded from this analysis, but are a relatively common method to ease the physiologic stress of extended operative time in combined approaches. The number of levels fused, the application of osteotomies, the performance of direct neural decompression, and the utilization of interbody fusion/devices all increased operative duration, as expected.

The occurrence of minor and major complications was associated with an average increase in operative time of 67 minutes. Individual complications did not occur with enough frequency to allow for a powered analysis of the operative time increases by specific complication. Surgeries extending beyond 300 minutes were associated with an increase in the rate of minor complications. Infection and cardiopulmonary complication risk increased after the sixth and seventh hour, respectively. Alternatively, major complication risk did not increase until surgeries went beyond 500 min.

The field of ASD has almost no literature evaluating operative time optimization, largely due to the heterogeneity and lower frequency of such surgeries. The current study shows that institutional practices have the largest impact on operative time: over 90 minutes to 2 hours in comparing 9 different hospital centers. After a global effect of the institution/surgeon, patient profiling, procedures performed, and intraoperative adverse events all had quantifiable, important impacts extending operation duration. This data do not attempt to alter protocol, but do stress justification for usage of more complex procedures, as they may, in addition to direct costs associated with the procedure, increase operation time. Finally, this study found that procedures predicted to extend greater than 300 minutes, complication rates increase. In cases predicted to surpass this threshold, alternative approaches such as dual surgeon or staging the procedures should be consider as much as possible.

Limitations

This analysis recognizes several limitations to its methods. The ranking methodology does not allow the examination of variables that did not reach significance, as well as the effect of clustered variables that may affect operative time when combined and not only partitioned. Additionally, branching logic limited the analysis of variables with more scarce information as it reduces samples by the size of subsequent partitions.

CONCLUSION

The location/institutional setting at which surgery is undertaken is the most important factor determining operative time, and this accounted for duration variability of greater than 2 hours. The type of surgical approach and the number of levels fused were the second and third most important factors influencing operative time, respectively. Further study on the clinical relevancy of these findings is necessary.

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