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Clinical Studies

Does body mass index influence intraoperative costs and operative times for open transforaminal lumbar interbody fusion? A time-driven activity-based costing analysis

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A R T I C L E I N F O

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A B S T R A C T

Background: The increasing prevalence of obesity has raised concerns about its impact on surgical outcomes and healthcare costs. This study evaluates the influence of Body Mass Index (BMI) on intraoperative costs and operative times during open Transforaminal Lumbar Interbody Fusion (TLIF) procedures using a Time-Driven Activity-Based Costing (TDABC) approach.

Methods: A retrospective analysis was conducted on 279 patients who underwent TLIF between 2019 and 2022. Patients were categorized into 5 BMI cohorts: healthy weight (BMI 18.5–24.99), overweight (BMI 25.0–29.99), Class I obese (BMI 30.0–34.99), Class II obese (BMI 35.0–39.99), and Class III obese (BMI >40). Intraoperative costs were calculated using TDABC methodology, with costs segmented into supply and personnel expenses. Operative times were measured in 3 phases: surgery time (incision to closure), OR time (patient entering to leaving), and turnover time. Multivariable regression models assessed the relationship between BMI and various intraoperative time and cost metrics, adjusting for potential confounders.

Results: BMI was significantly associated with increased operative times and personnel costs. Each unit increase in BMI corresponded to an additional 1.90 minutes in the operating room ($p = .01$) and a $25.72 increase in personnel costs ($p = .008$). However, no significant association was found between BMI and total or supply costs. Regression analyses indicated that obese patients did not significantly differ from healthy weight patients in terms of total intraoperative costs.

Conclusions: Higher BMI is associated with increased operative times and personnel costs in TLIF procedures, though it does not significantly impact total intraoperative costs when controlling for confounders. These findings suggest that BMI may not need to be a significant deterrent in patient selection for TLIF under bundled payment models.

Introduction

Since 1980, the prevalence of obesity has increased dramatically worldwide, with nearly a third of the global population now classified as overweight or obese [1,2]. In the United States, obesity prevalence among adults has risen from 14% to 42% over the same period [3] This trend has had a profound effect on the population's spine health, as current studies have shown an increase in body mass index (BMI) is strongly associated with disc degeneration, [4,5] disc herniation, [6] and spinal stenosis [6] within the lumbar spine. Several studies have identified that

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in addition to higher complication rates and slightly poorer functional outcomes in lumbar fusions, [7–9] patients with higher BMI undergoing lumbar fusions have significantly longer operation times [10,11]. Additionally, increased OR time results in increased costs of care for these patients. Limited research exists providing numerical values for these time-related costs for specific surgical approaches such as transforaminal lumbar interbody fusions (TLIF).

In response to the escalating expenses in healthcare provision, the medical field is pivoting towards a value-centered model. Time-driven activity-based costing (TDABC) is a methodology that enables precise monitoring of both direct and indirect expenses for specific care interventions, with a focus on individual patients. This approach assigns cost units to the various resources and compensation of staff involved in a patient's treatment journey. These units are then calculated based on the duration of each phase in the care process. The time-intensive nature of TDABC makes it particularly useful for accurately estimating the additional intraoperative expenses that might be linked to higher BMI patients, while eliminating potential bias that may arise from variable revenue-based hospital charges.

This type of analysis is especially pertinent in the setting of emerging payment structures such as bundled reimbursement models, where healthcare providers' compensation is tied to the total costs accrued during a patient's treatment episode. Given the aforementioned pay structure, healthcare institutions may find it valuable to determine if elevated BMI correlates with increased surgical expenses for patients undergoing the TLIF procedure. We present a novel use of TDABC for this purpose.

Methods

Patient population

This study was approved by the university's institutional review board under a universal Quality Improvement protocol. For more information on our institutional review board protocol, please contact the corresponding author. A retrospective review of the electronic medical record (EMR) was conducted for all patients who underwent neurosurgical open TLIF at our institutional enterprise between 2019 and 2022. All patients who received a TLIF were included in the study.

General data collection

Data collection included baseline patient demographic information, such as age, race, sex, comorbidities, and smoking status. Additionally, procedural data was collected, including: the surgeon performing procedure, number of levels fused, staff utilized, and time associated with each procedure. Time was then more granularly split into the following categories: time of the surgery itself (defined as time from opening incision to closure), time spent in the OR (defined as the time from the patient entering the room to patient leaving the room), and turnover time (time from the patient leaving the room to the next patient entering the room).

Time-driven activity-based costing methodology

Cost data was collected using the TDABC methodology. The 2 major components of total cost using this methodology are: supply cost and personnel cost. To determine personnel cost, we first utilized the EMR to identify the exact personnel types documented in each surgical episode. Then, we contacted our institution's Human Resources department to determine the prototypical annual salary for each of these personnel types. Using these annual salaries, we then calculated the cost per minute per personnel type, which was then multiplied by the minutes spent in the OR. This constituted total personnel cost for each case.

To calculate supply cost, we queried the EMR to identify both implant-related surgical supplies (such as screws, plates, biologic tissue, and grafts) as well as consumables (such as sterile towels, drapes, and bipolar forceps) which were used intraoperatively. The cost associated with use of each of these resources was determined through consultation with our institution's business operations department. Supply cost were therefore an aggregate of implant related costs and consumables costs. A visual summary of the methodology used to calculate supply and personnel cost, the 2 primary drivers of total intraoperative cost, is shown in Fig. 1.

Through consultation with departments such as pharmacy and plant operations, we also extracted medication cost, sterilization cost, overhead cost, and turnover cost (defined as the cost associated with replacement of materials from 1 operation to the next for each procedure from the EMR. The total cost of surgery was therefore a composite of supply cost, personnel cost, medication cost, turnover cost, sterilization cost. and overhead cost.

Statistical analysis

We used the RStudio software (Version 2024.04.2+764) to conduct statistical analysis. Using the Centers for Disease Control classifications of BMI, we divided all patients undergoing TLIFs into 5 BMI-based cohorts: healthy weight (BMI of 18.5-24.99), overweight (BMI of 25.0-29.99), Class I obese (BMI of 30.0-34.99), Class II obese (BMI of 35.0-39.99), and Class III obese (BMI >40). We then performed descriptive statistics to identify the mean cost and duration of surgery associated with each of the different BMI cohorts. Then, we performed multivariable regression analyses to test how obesity influenced cost and duration of surgery with respect to the Centers for Disease Control-deemed "healthy" BMI (18.5-24.99).

We performed a similar regression analysis in which BMI was treated as a continuous independent variable. Time-based dependent variables of interest were the time of surgery itself, duration of OR time, and duration of time in the OR which was not spent operating (ie, preparatory time). In all regression models, we accounted for age, sex, comor-

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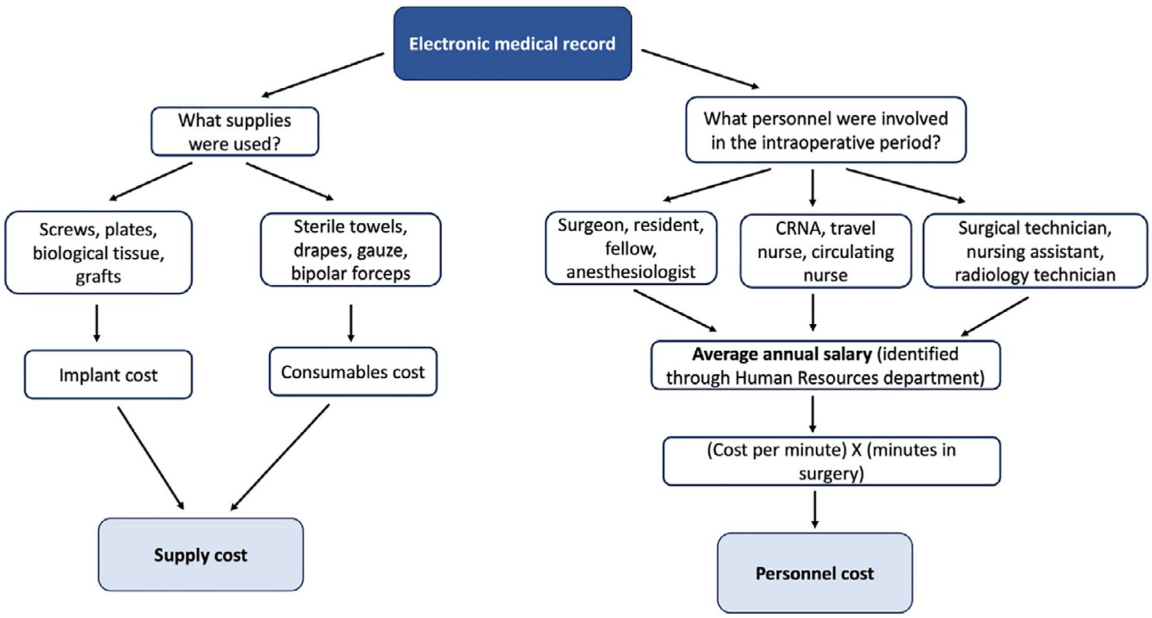

Fig. 1. Time driven activity based costing methodology to calculate supply and personnel cost, the 2 major drivers of intraoperative cost.

Table 1
Demographic characteristics of patients.

Characteristic	n (%)	Mean	Range	SD
Number of levels fused		1.74	1–12	1.279
Age		66.0	28.5–84.6	10.4
BMI		30.0	18.5–60.2	6.43
Male	137 (49.3)			
Female	141 (50.7)			
Smoker	3 (1.1)			
Comorbidities				
Diabetes mellitus	52 (18.7)			
Osteoporosis	10 (3.6)			
Hypertension	153 (55.0)			
Dyslipidemia	139 (50.0)			
Race				
White or Caucasian	236 (84.9)			
Black or African American	28 (10.1)			
Hispanic	4 (1.4)			
Asian	7 (2.5)			
Unknown	1 (0.4)			

bidities (diabetes, hypertension, osteoporosis, dyslipidemia), surgeon, and number of levels fused. Variable selection process was based on clinical relevance. Results were considered significant if $p < 0.05$. Before inclusion in the final model, variables were tested for collinearity, and residual analysis was performed to ensure model assumptions were met.

Results

Descriptive statistics

A total of 279 patients underwent open TLIFs between 2019 and 2022. These procedures were performed by 13 surgeons. The study population's number of levels fused, mean BMI, and age was 1.74 +/- 1.279, 30.0 +/- 6.43 and 66.0 +/- 10.4, respectively. Further characteristics including comorbidities and race are shown in Table 1.

The overall mean total cost for all TLIF surgeries was $14921 +/- 7051. The mean total cost of surgery for each BMI-based cohorts was the following: $14576 +/- $6915 for healthy weight patients; $14577 +/- $6963 for overweight patients; $14848 +/- $7769 for Class I obese patients, $16104 +/- $5800 for Class II obese patients; $15716 +/- $7540 for Class III obese patients. There were no underweight patients observed within this cohort. More information about the mean cost and operative time associated with each BMI-based cohorts is shown in Table 2.

Additionally, the significant contributors to cost, consisting of supplies and personnel cost, among the BMI-based cohorts is shown in Fig. 2. A per-case cost comparison of the personnel types among the BMI-based cohorts is depicted in Fig. 3. Case volume and mean total cost for each surgeon is shown in Table 3.

Linear regression models

When examining the effect of BMI as a continuous independent variable on cost, regression analysis revealed that increased BMI was significantly associated with an increased personnel cost (B-coefficient: 25.72 +/- 9.58, p = 0.008). BMI was also significantly associated with minutes in OR (B-coefficient: 1.90 ± 0.74, p = 0.01), minutes in surgery (B-coefficient: 1.41 ± 0.66, p = 0.033), and minutes in OR not operating (B-coefficient: 0.49 ± 0.18, p = 0.007). There was no significant difference with total cost or supply cost when using BMI as a continuous independent variable. These results are summarized in Table 4. We further segregated supply cost into implant cost and consumables cost to examine whether healthy weight patients utilized fewer implant or consumables resources compared to obese patients (Table 5). No significant associations were found.

We also performed multivariate regression analysis to see how costs and operative times of obese patients compared to the "healthy BMI" cohort. In this scenario, total cost, supply cost, and personnel cost for obese patients were not significantly different from healthy BMI patients. (Table 6) Compared to healthy BMI patients, obese patients demonstrated no significant difference in time in the OR, time in surgery, or time in the OR not operating. (Table 7).

Discussion

To the authors' knowledge, this is the first study that has used a TDABC approach to understand the impact that BMI has on the intraoperative costs of open TLIF. Our findings demonstrate that each unit increase in BMI corresponds to an additional 1.90 minutes in the operating room (p = 0.01), which can create significant downstream effects on surgical scheduling and efficiency. When considering a full day's sur-

Table 2
Descriptive statistics for cost and time for all body mass index cohorts.

BMI cohort	n (%)	Total supply cost per case	Total personnel cost per case	Total cost of surgery	Minutes in surgery	Total minutes in the operating room	Total minutes in the operating room not operating
Healthy weight (18.5–24.99)	60 (21.58)	$10872 ± $5701	$3322 ± $1356	$14576 ± $6915	189 ± 95	257 ± 106	68 ± 19
Overweight (25.0–29.99)	93 (33.45)	$10917 ± $5999	$3184 ± $1010	$14577 ± $6963	190 ± 77	257 ± 89	68 ± 18
Class I Obese (30.0–34.99)	69 (24.82)	$10658 ± $6658	$3667 ± $1139	$14848 ± $7769	221 ± 90	296 ± 105	75 ± 20
Class II Obese (35–39.99)	34 (12.23)	$12118 ± $5141	$3952 ± $1564	$16104 ± $5800	237 ± 88	314 ± 98	77 ± 21
Class III Obese (>40)	22 (7.91)	$11016 ± $6650	$4181 ± $1748	$15716 ± $7540	222 ± 83	305 ± 108	83 ± 30
Total	278 (100)	$10994 ± $6040	$3506 ± $1296	$14921 ± $7051	206 ± 88	278 ± 101	72 ± 21

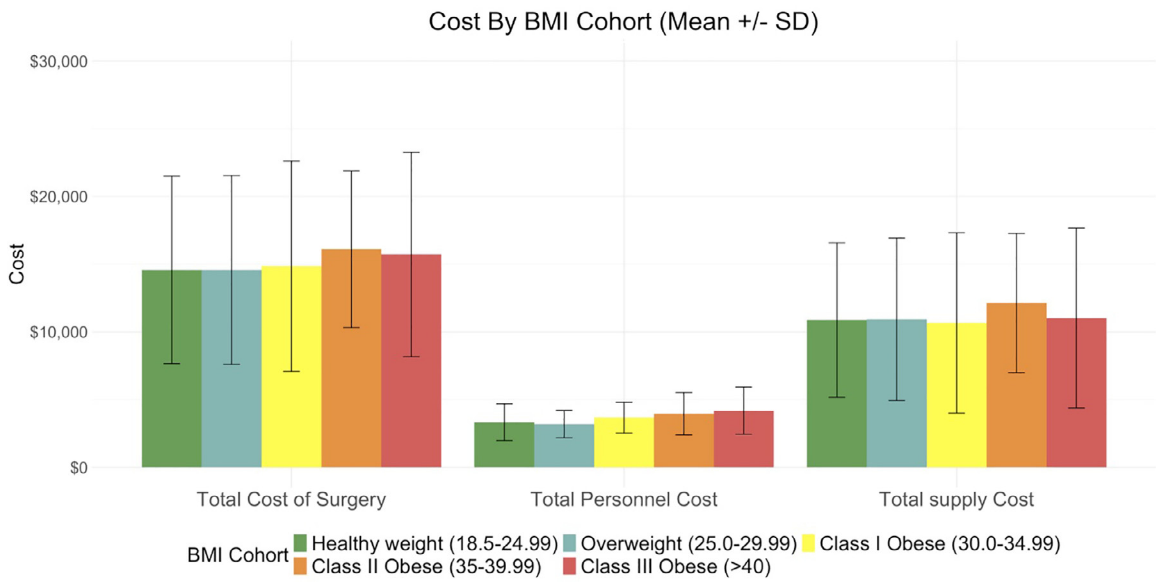

Fig. 2. Comparisons of the major drivers of cost among the BMI-based cohorts.

Table 3
Total cost and volume by surgeon.

Surgeon	Case volume	Mean	Standard deviation
1	10	$11832	$1799
2	14	$11515	$3011
3	1	$28402	N/A
4	1	$14019	N/A
5	10	$23714	$16757
6	2	$14133	$248
7	8	$27441	$8368
8	2	$16601	$4953
9	2	$19197	$440
10	113	$11509	$2797
11	17	$13328	$6469
12	97	$17637	$6589
13	1	$31674	N/A
Total	278	$14921	$7051

Table 4
Multivariate regression with BMI as continuous variable.

Variable	B-coefficient	p-value
True supplies cost per case	-35.47 ± 44.01	.4210122
Total personnel cost per case	25.72 ± 9.58	**.0077434**
Total cost per case	-17.30 ± 49.39	.7263682
Minutes in OR	1.90 ± 0.74	**.0110561**
Minutes in surgery	1.41 ± 0.66	**.0331147**
Minutes in OR not spent operating	0.49 ± 0.18	**.0072522**

Table 5
Results of multivariable regression models for subcomponents of supply cost.

Variable	B-coefficient	p-value
Implant cost	-334 ± 651	.609
Consumables cost	-182 ± 401	.65

Table 6
Results of multivariable regression models for total cost, supply cost, and personnel cost.

Variable	B-coefficient	p-value
Total cost	-91 ± 741	.902
Supply cost	-181 ± 679	.79
Personnel cost	209 ± 171	.223

gical schedule, these cumulative delays can lead to increased staff overtime costs, potential cancellation of later cases, and reduced overall OR utilization efficiency. These cascading effects have substantial financial implications for healthcare facilities, particularly in the context of bundled payment models where efficient resource utilization is crucial.

A similar trend regarding time in the OR was seen in a similar TDABC study assessing the impact of BMI on intraoperative costs and operative times for anterior cervical discectomy and fusions [12]. Additionally, there was a significant association between increase in BMI and increase in minutes in the OR not operating as well as in performing surgery. Higher BMI patients often require additional preparation time for proper positioning, careful transfer between hospital beds and operating tables, and more complex anesthetic considerations. These factors contribute to the extended non-operative periods and highlight the importance of considering BMI in surgical planning and resource allocation.

The intraoperative challenges associated with higher BMI patients extend beyond just positioning and transfer. These patients often require

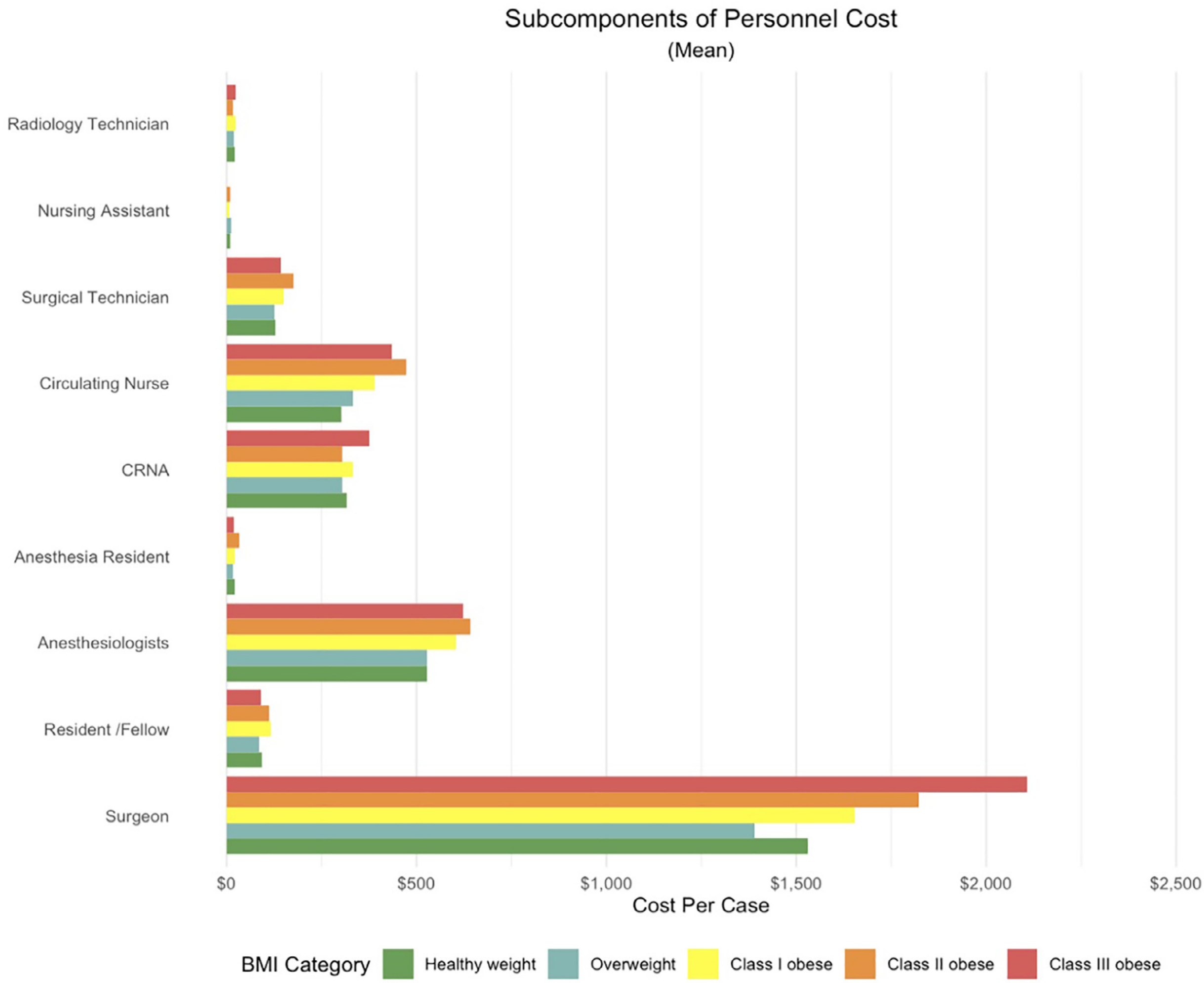

Fig. 3. Subcomponents of personnel costs.

Table 7
Results of multivariable regression models for time of surgery and subcomponents of time.

Variable	B-coefficient	p-value
Time in the OR	17 ± 12	.151
Time in surgery	12 ± 11	.275
Time in OR not operating	5 ± 3	.0707

specialized equipment, modified surgical approaches to ensure adequate exposure, and careful consideration of wound closure techniques.

Additionally, the deeper surgical field can necessitate specialized retractors and longer instruments, while potentially limiting visualization. These technical challenges contribute to the increased operative times observed in our study.

As shown in Table 3, there was a great variability in both cost and case volume for the surgeons in our study. It is interesting to note that Surgeon 10, the surgeon with the most amount of cases (n = 113), incurred the least amount of average cost. Additionally, surgeons that performed less than 10 cases experienced the highest amount of costs. To minimize the impact of surgeon-level variability, we included surgeon as a confounder in our multivariable regression analysis. Although further investigation on this relationship was not performed, it is a finding that can potentially be explored in future studies.

Additionally, we found that obesity was not associated with supply cost or total cost of surgery. The average total cost per case for all patients that underwent an TLIF was $ $14921 +/- $7051, which was driven primarily by supply cost ($10994 +/- $6040, 73.6%) and personnel cost ($3506 +/- 1296; 23.5%) Remaining sources of cost per case could be attributed to medication cost, sterilization cost, turnover costs, and hospital overhead cost ($433; 2.9%). Surgeons and anesthesiologists were involved in every case, which is why they comprised the highest proportion of total personnel cost per case as shown in Fig. 3. In contrast, radiology technicians, nursing assistants, and anesthesia residents were the least utilized personnel intraoperatively, which explains their low cumulative contribution to personnel cost per case. There was also no significant variance in supply cost as BMI increased. Supply costs included implants, plates, screws, instruments, and sterilization costs. With 73.6% of the mean TLIFs cost being driven by supplies, our findings reinforce the importance of implant selection for these procedures.

Previous studies examining BMI

Currently, there have been mixed results on the impact of BMI on operating room times and outcomes in patients undergoing TLIFs [13–16] Rosen et al. (2008) found no significant relationship between BMI and operative time, length of hospital stay, or complications in patients undergoing minimally invasive TLIF [14]. This was later supported by Villavicencio et al. (2019), who found that BMI did not have a statistically significant effect on surgical and non-operative OR times in patients undergoing 1- to 2-level elective TLIF procedures [16]. However, more recent literature begins to suggest a relationship; Tang et al. (2024) conducted a systematic review and meta-analysis, revealing that obese patients had slightly longer operative times compared to normal-weight patients, with a mean difference of 14.87 minutes [15]. Morbidly obese patients had even longer operative times, with a mean difference of 21.44 minutes [15]. Krüger et al. (2019) reported that morbidly obese patients (BMI > 40 kg/m?) undergoing minimally invasive TLIF had significantly longer operative times (235 vs 168 minutes) and longer hospital stays compared to normal-weight patients [13].

Implications for bundled payments

These findings have significant implications for healthcare policy. Traditionally, the U.S. healthcare system emphasized fee-for-service models, where surgeons were compensated based on the number of procedures performed, with little regard for outcomes. In contrast, value-based models like bundled payments aim to prioritize high-quality care at reduced costs. Under bundled payment models, healthcare providers receive a single, comprehensive payment that covers all services related to a specific episode of care. This payment structure incentivizes providers to coordinate care efficiently and prevent costly complications. A crucial element of these newer models is a precise understanding of expenses, which can be obtained through TDABC.

Total joint replacement surgery has been a prime example for bundled payment implementation, demonstrating potential cost reductions for hospitals. However, critics argue that such models might discourage treatment of "high-risk" patients, including those with multiple health issues, complex medical histories, or in this case, patients with high BMI.

Our research indicates that BMI does not significantly impact intraoperative cost variability when accounting for patient and surgeon-specific factors as well as the number of spinal levels fused. Our data revealed that when controlling for confounding variables in regression analysis, there is no significant difference for average intraoperative costs and BMI.

Limitations

This study has several limitations. Its retrospective nature, relying on electronic medical record (EMR) review to determine resource usage and event sequencing during surgery, may introduce inaccuracies. Potential errors could arise from imprecise documentation of staff presence and event timing.

While our TDABC methodology provides valuable insights into intraoperative costs, the exclusion of postoperative expenses significantly limits the generalizability of our findings to bundled payment models. Specifically, our analysis does not capture crucial post-surgical costs such as emergency department visits, readmissions, extended rehabilitation requirements, wound care, follow-up visits, and management of obesity-related complications. Notably, obesity's strong association with conditions like diabetes, hypertension, and cardiovascular disease puts higher BMI patients at increased risk of postoperative complications, potentially leading to elevated care costs.

Additionally, our multivariate regression analysis doesn't account for patient insurance type, a potential confounding factor that future costing studies should consider.

While we've demonstrated TDABC feasibility, its widespread adoption faces challenges. This micro-costing approach requires meticulous identification of all material resources used during surgery, a particularly complex task in neurosurgery due to the involvement of multiple hospital departments. To address this, we collaborated with our institution's Information Systems and Technology team to automate data extraction from the EMR. However, this process took over a year, which may deter other institutions from undertaking such a time-intensive project.

Nevertheless, understanding true costs and outcomes is crucial for assessing value in neurosurgery. Without accurate procedure cost data, hospitals will struggle to participate effectively in bundled payment models. Moreover, surgeons may remain incentivized to prioritize volume over value in patient care.

Conclusion

Our TDABC analysis of TLIF procedures reveals that while increasing BMI correlates with longer OR times and higher personnel costs, it does not significantly impact total intraoperative costs when accounting for confounding factors. This finding challenges the assumption that higher BMI patients necessarily incur greater intraoperative expenses, which has important implications for bundled payment models in spine surgery.

The observed variability in costs among surgeons highlights potential opportunities for improving efficiency and reducing expenses. However, our study's focus on intraoperative costs limits its scope, and further research is needed to assess BMI's impact on postoperative outcomes and long-term expenses.

While TDABC implementation presents challenges, it provides valuable insights into procedural costs. As healthcare shifts towards value-based models, accurate cost analysis becomes increasingly crucial. Our findings suggest that BMI alone should not deter patient selection for TLIF procedures under bundled payment models. Future research should aim to comprehensively evaluate the entire episode of care, supporting the development of reimbursement models that promote high-quality, cost-effective care for all patients, regardless of BMI.

Declarations of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.xnsj.2025.100583.

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