Journal of Gastrointestinal Surgery (2019) 23:2054–2062
https://doi.org/10.1007/s11605-018-3889-4

ORIGINAL ARTICLE

Evaluating Surgeons on Intraoperative Disposable Supply Costs: Details Matter

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Received: 1 June 2018 / Accepted: 16 July 2018 / Published online: 10 August 2018

Abstract

Background Cost report cards have demonstrated variation in intraoperative supply costs and may allow comparisons between surgeons. However, cost data are complex and, if not properly vetted, may be inaccurate.

Methods A retrospective assessment of intraoperative supply costs for consecutive laparoscopic cholecystectomies (2013–2017) at a 4-facility academic center was performed. Using unadjusted data (akin to an auto-generated report card), surgeons were ranked and highest to lowest-cost ratios were calculated. Then, four stepwise adjustments were performed: (1) excluded non-comparable operations and low volume (< 10 cases) surgeons, (2) eliminated outlier cases based on instrument profiles, (3) stratified by facility, and (4) adjusted prices (assigned one price; corrected aberrant/missing prices). Surgeon rank and highest to lowest-cost ratios were then re-calculated.

Results The unadjusted data identified 1392 cases for 33 surgeons (range, 1–317 cases). The ratio between the highest cost and lowest cost surgeon was 4.13. Steps 1 and 2 excluded 272 cases and 15 surgeons. Facility sample sizes ranged from 144 to 621 (step 3). Adjusting prices (step 4) required manual review of 472 unique items: 45% had > 1 price and 16 had missing prices. After all adjustments, surgeons had different rankings and highest to lowest-cost ratios within sites were smaller (ratio range, 1.17–2.10).

Conclusions Evaluating surgeons based on intraoperative supply costs is sensitive to analytic methods. Surgeons who were initially considered cost outliers became the least expensive within a given site. Auto-generated cost report cards may require additional analyses to produce accurate comparative assessments.

Keywords Operating room · Surgery · Cost · Economics · Feedback · Supplies

Introduction

With rising US healthcare expenses, the importance of focusing on value—defined as quality over costs—is increasingly salient.[1,2] The estimated cost of running an operating room (OR) is over $2000 an hour, making the OR a prime target for value-based efforts.[3] While most OR costs are attributable to labor and indirect expenses, an increasingly studied, and potentially mutable component, are the supplies used by surgeons.[3] Preliminary evidence has demonstrated significant variation in supply use between surgeons and has suggested that higher costs may not be associated with improved clinical outcomes.[4–7]

Recently, studies have proposed the introduction of cost report cards—a receipt that documents the disposable supplies used by the surgeon and their costs.[8–15] Automation of these systems allows real-time cost feedback and also potentially offers a way to compare surgeons on their cost efficiency. Surgeons are accustomed to being evaluated on quality and are familiar with the challenges of accurate quality assessment. Cost measurement is equally complex, if not more so. Analyzing costs introduces new issues such as the time-value of money, and the intricacies of purchasing, contracts, and the supply chain.

The goal of this study was to assess whether automatically generated cost report cards offer a reliable and consistent way to compare surgeons on costs. We hypothesized that a number of factors may bias automatically generated cost data such as

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the inclusion of non-comparable cases as well as inaccurate or improperly adjusted cost data. To assess this, we conducted a detailed analysis of intraoperative supply data for one operation—laparoscopic cholecystectomy—at a 4-facility academic health center. The primary goal was to evaluate how a series of analytic steps changed cost estimates with a focus on how surgeons compared to one another.

Materials and Methods

Ethics Review and Data Sources

The University of California, Los Angeles (UCLA) Institutional Review Board approved this study and a waiver of informed consent was granted for retrospective electronic medical review. Data were included from a single academic health system with 2 distinct institutions each with 2 operative settings—a main OR used for both inpatient and outpatient (typically higher-risk) cases and a standalone ambulatory surgery center (ASC). Most data for this study were extracted from the perioperative data warehouse; the details of the construction and implementation of the data warehouse are described elsewhere.[16] Additional data were retrieved from the purchasing department and via manual chart review.

Financial Perspective

Cost in this study refers to the purchase price a hospital pays to acquire the supply/instrument from a vendor. This is distinct from charges (the amount a hospital bills a patient) and from reimbursement (the amount a hospital receives from a patient or insurer). These prices were taken directly from the hospitals' purchasing department, they were not estimated using cost-to-charge ratios or any other cost accounting systems.

Identification of Cases and Variables Extracted

The data warehouse was queried for all laparoscopic cholecystectomies performed between July 1st, 2013 and June 30th, 2017. The case list was derived using operation booking slips. Deriving the initial case list from booking slips was used to reflect how real-time supply receipts could be generated; reliance on post-procedure billing data would necessitate a significant time lag. However, as booking slips are sensitive but not specific to the actual case performed, we also extracted a list of billed CPT codes to validate the operation performed post hoc. For each case, detailed supply cost information was extracted as well as patient sociodemographic and case characteristics including age, gender, race/ethnicity, body mass index (BMI), tobacco use, American Society of Anesthesiologists (ASA) physical status score, case urgency, and in room and procedure times.

Calculating Intraoperative Disposable Supply Costs

Derivation of Auto-populated Cost Data

For costs, the data warehouse is able to extract a total supply cost—a single value for each operation which represents the sum of the costs of the disposable items used and wasted. The process of generating this total supply cost involves several steps. First, a list of the items used in the OR is generated. The surgeons' electronic preference card is loaded into the medical record at the time of surgery. This preference card guides the scrub and circulating nurses with retrieving and opening the necessary instruments before the case begins and serves as a template for intraoperative item usage. During the operation, as additional items are opened, the circulating nurse updates the list, either through barcode scanning or manual entry. The final report generated by the circulating nurse contains a list of item IDs/names, the number used, and the number wasted (opened but unused). The second step is the assignment of costs. A third-party purchasing system stores real-time instrument prices. This system is continuously updated by the purchasing department as new items are added, old items are reordered, and prices are re-negotiated. Price data from this system flows into the electronic medical record without transformation at the time of the operation. In other words, when a retrospective report is pulled, an items' price is based on the purchasing department's price at the time of the operation. Finally, the unit prices of each item are summed together to generate a total supply cost.

Generation of a Master Price List to Allow Assessment of Changing Costs over Time

To complete the analyses (described below), we extracted a more detailed list for each case including the itemized list of instruments, number used/wasted, and the individual item prices. This list aided with several analyses. First, it allowed the calculation of the number of unique and total number of instruments used during the operation. Second, because the cost of individual items changes frequently a single item may have different prices at different time points. One solution is to update costs using a national index—such as the consumer price index or medical component consumer price index. However, OR costs do not grow in-line with these indices and therefore this analytic strategy may bias estimates.[3] To evaluate the frequency and significance of these price changes, a "master price list" was generated including the item name/ID of every instrument used over the study time period with all prices assigned to that instrument.

Raw/Unedited Costs

Using the entire cohort of patients (based on booking slips) and the unedited cost data (the total supply cost), the mean and median intraoperative supply cost (case-level) and the median cost by surgeon (surgeon-level) were calculated. This represents the data that would be auto-populated from a surgical receipt system without any additional analysis. Surgeons were assigned a comparative rank based on this unedited data, labeled A (least costly) through AG (most costly). These labels were maintained throughout subsequent analyses to assess how each analytic step affected the surgeon's relative standing.

Four Stepwise Analytics

In the first analysis, cases were excluded based on post hoc billed CPT codes and if they were performed by surgeons with very low volumes (< 10 cases). The second analysis excluded cases based on outlier instrument profiles. The third analysis stratified results by site (site-level), including separating results by institution (institute 1, institute 2) and setting (main OR vs. ASC). Finally, in the fourth analysis, using the master price list, we assigned one cost (described to follow) to each item and fixed aberrant and missing costs. For items with minimal variation over time (ratio of highest to lowest price ≤ 2.0), the highest price was assigned to the item. For items with large variations (ratio > 2.0), we contacted our purchasing department for clarification. For these large variations, the issue was typically the assignment of a box versus an individual unit price (i.e., the price was for a box of endoloops instead of a single endoloop). Finally, a few items had missing prices, typically because the circulating nurse omitted the item ID, preventing the flow of cost information from the purchasing department into the medical record. These aberrant and missing data points were manually corrected.

Statistical Analyses

All estimates were adjusted to the case-level median from the unedited data, to avoid sharing proprietary dollar-value costs. Comparisons were made across analyses with respect to the case-level median and surgeon-level range (measured as a ratio between the highest and lowest cost surgeons). The five highest volume surgeons (labeled D, H, T, W, and Y) were identified to illustrate how the various analyses affected their relative standing. All statistical analyses were performed using STATA v.15.1. Descriptive data are presented as mean ± SD for normally distributed variables and median (IQR) for non-normally distributed variables. Non-parametric comparisons were made using rank-sum tests. An alpha of 0.05 and two-sided tests were used to determine statistical significance.

Results

Sample Characteristics

Case information was extracted from all 1392 laparoscopic cholecystectomies performed between July 1st, 2013 and June 30th, 2017 based on preoperative booking slips. Demographic and case information are presented in Table 1. The majority of patients were female and non-Hispanic white, with an average age of 50 years (± 18.3) and an average BMI of 28.9 (± 7.9). Slightly more than half (57%) of cases were performed at institute 2 with the rest performed at institute 1. Most cases (77%) were performed in the main OR with the remainder performed in a stand alone ASC. Just over half (56%) of cases were elective and most patients (70%) were relatively healthy (ASA ≤ 2).

Table 1 Descriptive data of the study cohort including patient demographics and case characteristics

Demographics			
		N = 1392	
		Frequency	Percent
Female		892	64.1
Race	Non-Hispanic White	649	46.6
	Non-Hispanic Black	84	6.0
	Non-Hispanic Asian	163	11.7
	Hispanic	397	28.5
	Other/unknown	99	7.1
Tobacco users		107	7.7
		Mean	SD
Age (years)		50	18.3
Body mass index[a]		28.9	7.9
Case characteristics			
		Frequency	Percent
Location	Main OR 1	450	32.3
	Main OR 2	621	44.6
	ASC 1	144	10.3
	ASC 2	177	12.7
Case status[a]	Elective	762	54.7
	Inpatient/urgent	592	42.5
ASA[a]	1	190	13.7
	2	788	56.7
	3	391	28.2
	4	20	1.4
		Mean	SD
Procedure time[a]		78.9	43.7
Room time[a]		120.3	44.3

ASA American Society of Anesthesiologists Physical Status Classification, *ASC* Ambulatory Surgery Center, *OR* operating room

[a] Missing data: BMI (*n* = 66), case status (*n* = 38), ASA (*n* = 3), procedure time (*n* = 5), room time (*n* = 1)

All proportions based on complete case (i.e., non-missing) data

Raw/Unedited Disposable Costs

The median case-level cost was set at 100% (IQR 68–132%). The mean cost was 139% (± 127%) of the median cost. Table 2 (first row) and Fig. 1a show the unedited distribution of median costs at the surgeon-level. Figure 2a shows a box plot for each surgeon and demonstrates the large number of outlier cases, with individual cases approaching 1500% of the median. Thirty-three surgeons contribute to these estimates, with 1 to 317 cases per surgeon. Median costs at the surgeon-level ranged from 53% to 220%, representing over a 4-fold difference between the most and least costly surgeons. The five highest volume surgeons (labeled D, H, T, W, and Y) had median costs ranging from 62% to 120%.

Step 1: Filtering Cases Based on Billed CPT Codes and Surgeon Volume

To generate a comparable cost dataset, 153 cases were excluded that did not have a post-procedure primary CPT code consistent with laparoscopic cholecystectomy, cases that included additional procedures (e.g., herniorrhaphy, bowel resection, appendectomy) and cases that were converted to open. Limiting the analysis to surgeons with 10 or more operations over the 4-year time period removed an additional 40 cases. This left 18 surgeons and 1199 operations. The median cost of the excluded cases was significantly higher than the included cases (excluded median 114% [IQR 88%–256%], included median 96% [IQR 66%–125%], p value < 0.001). However, after excluding these cases, the range of surgeon-level costs and the high-volume surgeon-level median costs remained largely unchanged (Table 2, row 2).

Step 2: Analyzing Instrument Utilization and Eliminating Outlier Cases

After excluding cases based on billed CPT codes and low-volume surgeons ($n = 1199$), we analyzed intraoperative instrument data to identify operations with outlier utilization. The mean number of unique instruments was 22.7 (± 4.9) and the mean number of total instruments was 31.2 (± 6.7). Histograms are presented in Fig. 3. A manual chart review of cases with very low unique items (less than the 5th percentile, fewer than 16 items) found that instrument logs were often missing one or more items described in the operative note such as trocars, endocatch bags, and clip appliers. Cases with

Table 2 The effect of stepwise analytics on patient and surgeon sample size, overall median costs, and surgeon-specific costs

	Case-level cost data		Surgeon-level cost data							
	Sample size	Case-level median, as percentile[a]	Number of surgeons	Range (low-high)	Ratio of highest to lowest	High-volume surgeons D	H	T	W	Y
Raw/unedited data	1392	100%	33	(53%–220%)	4.13	62%	74%	107%	118%	122%
Step 1: limiting to comparable cases and surgeons with ≥ 10 cases	1199	96%	18	(51%–214%)	4.20	62%	74%	105%	118%	120%
Step 2: eliminating outlier cases based on instrumentation	1123	96%	18	(51%–204%)	4.01	61%	71%	113%	118%	120%
Step 3: stratification by site										
Across all sites	1118[c]	95%	18[b]							
Main OR 1	342	76%	11	(67%–165%)	2.48	67%	74%	–	–	82%
Main OR 2	481	120%	8	(67%–246%)	3.69	–	67%	118%	118%	123%
ASC 1	140	53%	3	(46%–59%)	1.28	59%				
ASC 2	156	73%	5	(61%–104%)	1.70	–	–	82%	104%	61%
Step 4: cleaning costs (assigning one price, fixing aberrant/missing prices)										
Across all sites	1118	91%	18[b]							
Main OR 1	342	80%	11	(71%–100%)	1.41	73%	83%	–	–	92%
Main OR 2	481	124%	8	(71%–148%)	2.10	–	71%	123%	119%	129%
ASC 1	140	58%	3	(53%–62%)	1.17	62%	–	–	–	–
ASC 2	156	75%	5	(67%–91%)	1.35	–	–	75%	91%	67%

ASC Ambulatory Surgery Center, *OR* operating room

[a] To protect disclosure of proprietary cost information, all dollar values were adjusted to the median case-level price of the raw/unedited data; for example, the median case-level cost after "Step 1" was 96% of the median case-level cost of the raw/unedited data

[b] Numbers do not sum as surgeons can operate at more than one location

[c] Sample size smaller than previous step due to exclusion of surgeons with < 5 cases at a given site

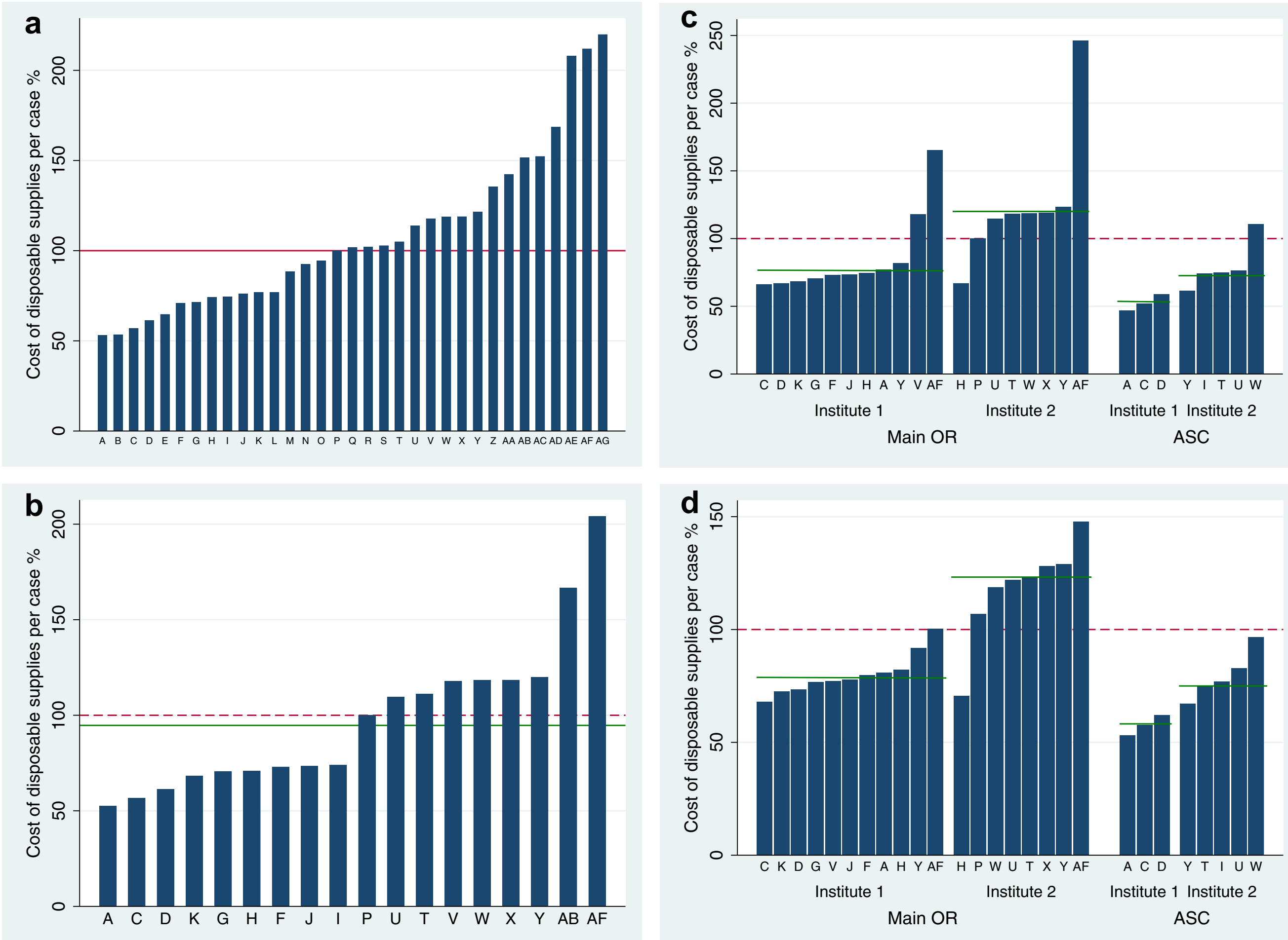

Fig. 1 Median surgeon-level intraoperative costs. **a** Raw/unedited. **b** After exclusion of non-comparable cases and low-volume surgeons (steps 1 and 2). **c** After stratification by site (step 3). **d** After correction of item prices (step 4). *Note*: Surgeons are ranked from least costly (A) to most costly (AG) based on Figure 1a. These rankings/letters are retained through the subsequent panels. The solid line in Figure 1a represents the unedited case-level median. This is maintained as a dashed line in the subsequent panels. Solid lines in Figures 1b-1d represent the "new" median after each analytic step

very high unique items (above the 95th percentile, greater than 30 items) identified unusually challenging cases, such as those of patients with previous cholecystectomy tubes or adjacent tumor deposits, requiring, for example, electrothermal devices or staplers. Excluding these outliers resulted in the loss of 76 cases. The median cost of excluded cases was higher than the included cases (excluded median 102% [IQR 91%–151%], included median 96% [IQR 65%–124%], $p < 0.001$). Expanding the filter to the top and bottom 10% did not significantly change estimates. Therefore, to maximize sample size, the filter was maintained at the 5th and 95th percentiles. Figures 1b, 2b, and Table 2 (row 3) show costs for the cohort after steps 1 and 2.

Step 3: Stratification by Site

Figures 1c, 2c, and Table 2 (row 4) present data stratified by site. Median site-level costs ranged from 53% at the cheapest site to 120% at the most expensive site. The range of surgeon-level costs was small within the surgery centers. For example, the most and least costly surgeon varied by only 13 percentage points in ASC 1. The main ORs retained significant surgeon-level variation.

Step 4: Cleaning Cost Data and Generation of Final Estimates

Figures 1d, 2d, and Table 2 (row 5) present the final data after cleaning instrument prices. Over the 4 year study time period, 472 unique items were used and were included in the master price list. Almost 45% of items had more than one price with items having as many as 17 unique prices. Sixteen items had missing prices. Among items with more than one price, most items had minimal variation over the study time period (median ratio of maximum to minimum cost was 1.07 [IQR 1.03–1.25]). However, 17 items had large variations (max/min ratio ≥ 2) requiring manual correction with the purchasing

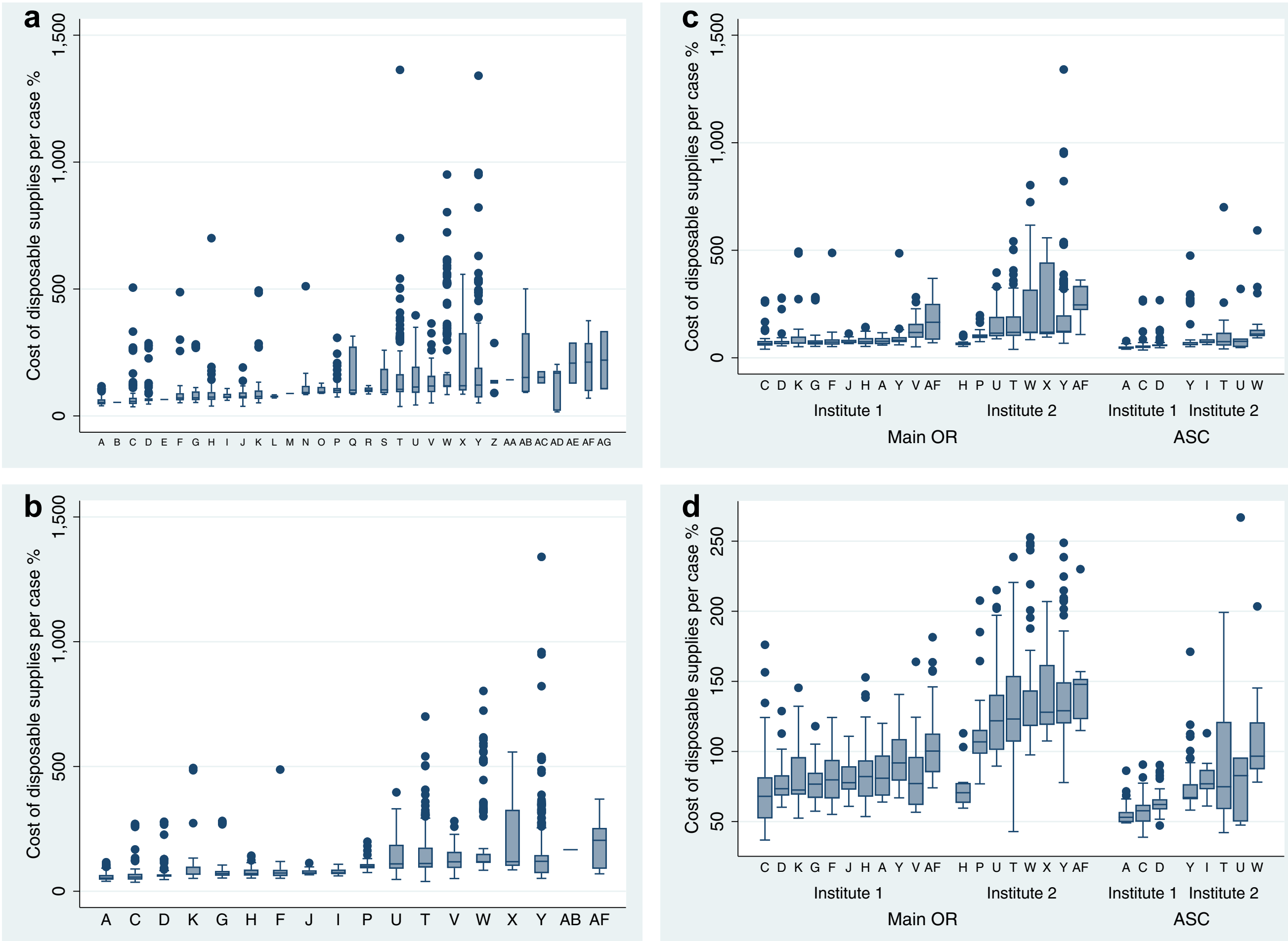

Fig. 2 Box-plot of surgeon-level intraoperative costs. **a** Raw/unedited. **b** After exclusion of non-comparable cases and low-volume surgeons (steps 1 and 2). **c** After stratification by site (step 3). **d** After correction of item prices (step 4). *Note*: Surgeons are ranked from least costly (A) to most costly (AG) based on Figure 2a. These rankings/letters are retained through the subsequent panels

department. After assigning final prices, the patient-level median cost was 91% (IQR 70%–123%) of the original raw/unedited value. Median cost by site ranged from 58% to 124%. The ratio of the highest-cost surgeon to the lowest-cost surgeon, within a site, ranged from 1.17 to 2.10. The change in the surgeon-level median after each analytic step is presented for the 5 highest volume surgeons in Fig. 4.

Comparison of Final Supply Costs and Procedure Time

Median surgeon-level procedure times are illustrated in Fig. 5. The *X*-axis retains the final surgeon rankings based on supply cost. As expected, median OR times were longer in the main ORs than the ASCs (67 min [IQR 51–88] vs. 52 min [IQR 43–64.5; $p < 0.001$). However, there was no clear trend between median surgeon-level costs and surgeon-level procedure times. For example, of the two surgeons with median procedure times > 100 min, one was the most expensive within their facility and one was almost the cheapest within their facility.

Discussion

Evaluating surgeons based on intraoperative supply cost is highly sensitive to analytic methods, especially factors unique to cost data. Surgeons who would have otherwise been considered high outliers with respect to cost were actually the least expensive within a given site. Similar to assessing surgeons on quality, assessing volume is critical, but the introduction of cost data introduces additional challenges.

The first two steps of this analysis were designed to generate a comparable set of cases for a comparable set of surgeons—akin to case-mix adjustment when one considers quality assessment. Interestingly, while this restriction eliminated 15 low-volume surgeons and over 200 cases, the effect on costs was minimal. The overall median dropped by 4 percentage points, the surgeon-level range was essentially unchanged, and a number of outlier cases still existed. Therefore, significant risk adjustment may not be required to allow accurate ranking of surgeons provided they have sufficient volume to generate reliable estimates of the median.

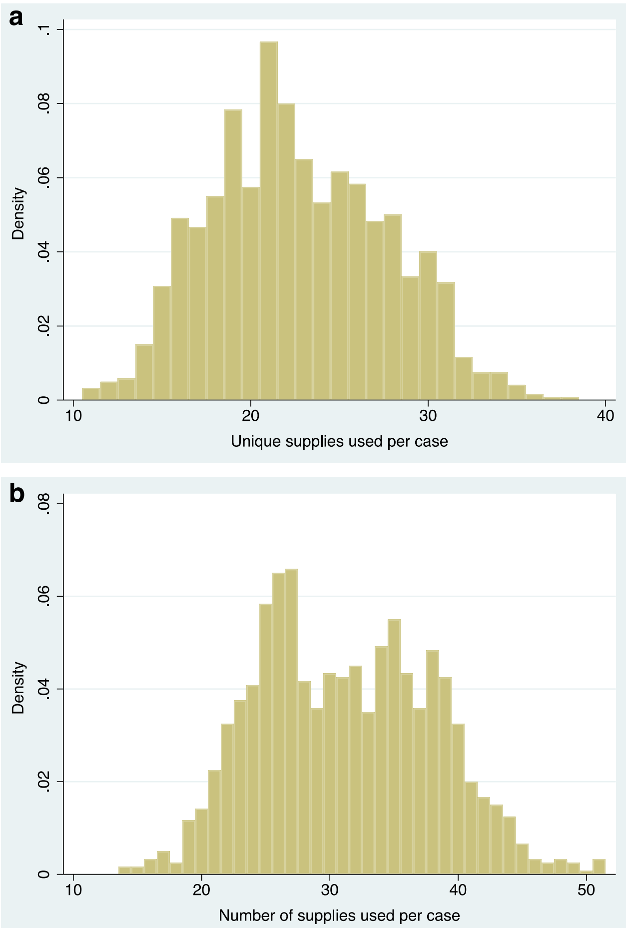

Fig. 3 Items used per case. **a** Unique items. **b** Total items

However, when adjusting for factors unique to cost—stratification by site, price changes over time, and cost errors—we identified significant changes in cost estimates. These steps reduced the surgeon range from 4-fold to, at most, 2-fold. After all steps were complete, the amount of variability between sites was similar to the variability between surgeons within a site. This difference across sites existed despite overlapping faculty. In other words, a surgeon operating at one site may go "across the street" and perform the same operation at significantly higher cost. This suggests that surgeons are capable of using a cheaper combination of supplies, but the infrastructure may not support it. Even if generating uniform preference cards across surgeons is not tenable, a single preference card for one surgeon should be reasonable. When using cost report cards to evaluate surgeons, data must be stratified by institution and facility and some attempt must be made to correct missing and aberrant prices. Partnerships with the purchasing department are essential to resolve these discrepancies.

Another unexpected finding was the number of instrument combinations available to surgeons—despite the fact that, on average, only 23 unique items were required to complete a laparoscopic cholecystectomy, 472 different items were used over the study time period. Put another way, for any given item required to remove a gallbladder, this study identified an average of 20 alternative items that may be chosen by a surgeon. Even if variation in cost is less than previously reported, variation in utilization is excessive and should be a focus of future research.

The literature describing surgeon-level intraoperative costs, especially in general surgery, is sparse. The largest study to date was conducted in 2015 and analyzed intraoperative supply costs for 2178 laparoscopic cholecystectomies across 55 surgeons at 7 US medical centers.[4] Median surgeon-level supply costs varied by a factor of 2 (~ $300–$650). However, the study did not address a number of the issues presented here. For example, they included surgeons with very low volumes (as few as 2 cases) and did not describe in sufficient detail the

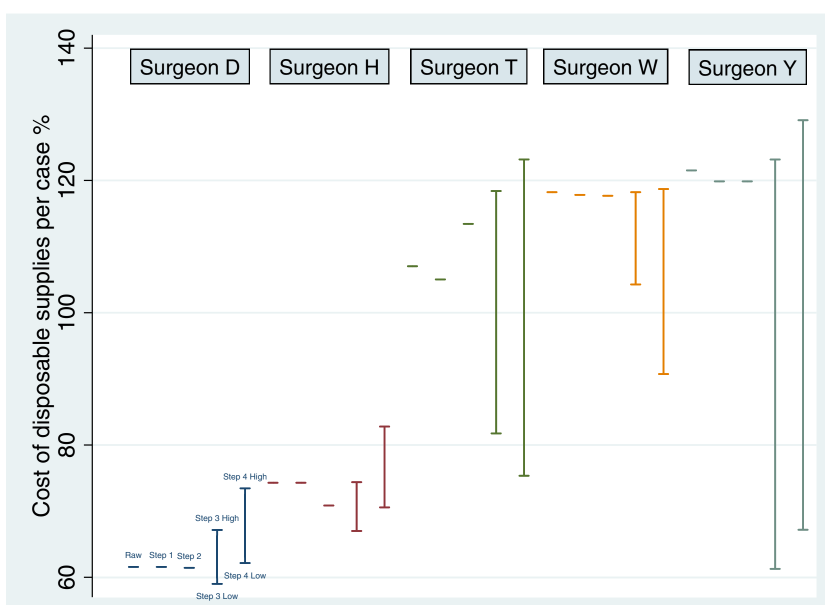

Fig. 4 Median surgeon-level cost across each analytic step for the 5 highest volume surgeons. *Note*: Steps 3 and 4 show the range of the highest and lowest site-specific median cost for that surgeon

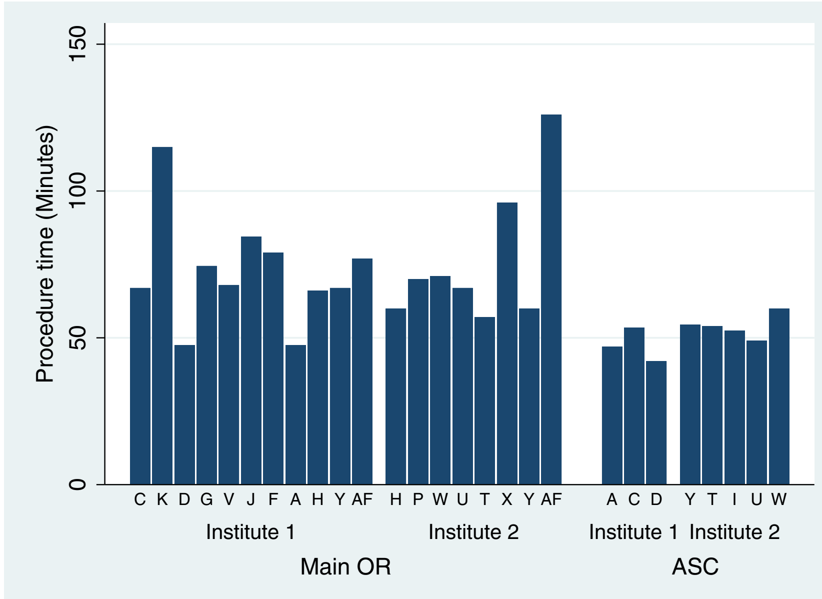

Fig. 5 Median surgeon-level procedure time, organized by median supply cost. *Note*: Procedure time calculated from procedure start to procedure end and does not include pre-incision or post-dressing time. The order of surgeons reflects the cost rankings based on the final data, as seen in Fig. 1d or 2d

process of assigning costs and fixing aberrant or missing prices. It is unknown how the steps outlined in this study would have affected their conclusions.

The results of this current analysis demonstrate how sensitive cost estimates are to analytic steps. This implies that supply costs must be interpreted in light of how the data were analyzed. Studies evaluating interventions to reduce supply costs are published frequently.[7–15] Perhaps the most robust study to date provided supply scorecards to 3 service lines at a major academic health system while using the remaining 7 service lines as controls.[15] Using 2012 to 2014 data as the pre-intervention and 2015 as the post-intervention, they found a median decrease in supply costs of $91 per case in the intervention group, compared to an increase of $53 in the controls. The authors attempted to adjust for cost and patient variation using the consumer price index and case mix index, respectively. However, given how sensitive costs are within just one operation (laparoscopic cholecystectomy), it seems likely these biases will only be magnified when comparing across operations, let alone service lines.

It appears that there is much to learn when comparing surgeons' intraoperative supply costs. It is likely that the analytic steps outlined in this study are necessary but may not be sufficient to generate usable data. Institutions analyzing their own data will likely encounter additional, not yet described, challenges. Future studies evaluating supply costs should utilize standardized reporting metrics such as the CHEERS[17] checklist. Modified versions addressing the concerns identified in this study may be needed. If clinicians are to consider costs in the decisions they make, detailed understanding of hospital processes and finances must be a part of standardized curricula, ideally during medical school or residency.

This study has a number of limitations. First, all data were obtained from a single health system that utilizes a common purchasing department. Multi-system studies will undoubtedly encounter additional challenges—such as differential pricing for the same item and the existence of non-disclosure agreements by medical device companies. The challenges in our system may also not be the dominant factors at play in others. Second, we only analyzed one operation. The importance of these analytic steps may not generalize to other operations. Finally, it is important to keep the larger picture in mind. We only analyzed intraoperative disposable supply costs—likely a small fraction of total OR costs and an even smaller fraction of the total cost of a surgical patient. Thus, even wide variations in cost in this analysis may not make a large difference when looking at the overall operative period. While this is a significant limitation, our understanding of surgical costs is very much in its infancy, and starting with a narrow and tangible area such as supply costs is a good first step. Additionally, given the thin margins hospitals run on, even small reductions in cost may prove significant.

Conclusions

Increasing value requires improving quality, decreasing costs, or ideally, both. There has been an exponential increase in effort to understand and ultimately decrease intraoperative supply cost variation. However, working with costs introduces novel challenges, and if not properly accounted for, may lead to inaccurate conclusions. This study demonstrates that for a seemingly standardized operation, laparoscopic cholecystectomy, supply costs are highly sensitive to small perturbations in the analytic approach used to assess them. Cases must be comparable in scope and complexity, volumes must be sufficiently large, estimates must be stratified by site, and prices must be assigned consistently and accurately. Only when all of these steps are met can we attribute costs to surgeons and consider evaluating surgeons not only on their quality, but also on their value.

Authors' Contributions Drs. Childers and Maggard-Gibbons had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. All data used for this study are accessible for review.
Study concept and design: Childers.
Acquisition, analysis, or interpretation of data: all authors.
Drafting of the manuscript: Childers.
Critical revision of the manuscript for important intellectual content: all authors.
Statistical analysis: Childers, Cheng.
Obtained funding: Childers.
Administrative, technical, or material support: NA.
Study supervision: Hoffer, Maggard-Gibbons.

Funding Christopher Childers is funded by AHRQ#F32HS025079.

Compliance with Ethical Standards

Ethics The University of California, Los Angeles (UCLA) Institutional Review Board approved this study and a waiver of informed consent was granted for retrospective electronic medical review.

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