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Robotic-assisted versus laparoscopic unilateral inguinal hernia repair: a comprehensive cost analysis

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Abstract

Background Cost-effectiveness of robotic-assisted surgery is still debatable. Robotic-assisted inguinal hernia repair has no clear clinical benefit over laparoscopic repair. We performed a comprehensive cost-analysis comparison between the two approaches for evaluation of their cost-effectiveness in a large healthcare system in the Western United States.

Methods Health records in 32 hospitals were queried for procedural costs of inguinal hernia repairs between January 2015 and March 2017. Elective robotic-assisted or laparoscopic unilateral inguinal hernia repairs were included. Cost calculations were done using a utilization-based costing model. Total cost included: fixed cost, which comprises medical device and personnel costs, and variable cost, which comprises disposables and reusable instruments costs. Other outcome measures were length of stay (LOS), conversion to open, and operative times. Statistics were done using *t* test for continuous variables and χ^2 test for categorical variables. A *p*-value <0.05 was considered significant.

Results A total of 2405 cases, 734 robotic-assisted (633 Primary: 101 recurrent) and 1671 laparoscopic (1471 Primary: 200 recurrent), were included. The average total cost was significantly higher ($p<0.001$) in the robotic-assisted group ($5517) compared to the laparoscopic group ($3269). However, the average laparoscopic variable cost ($1105) was significantly higher ($p<0.001$) than the robotic-assisted cost ($933). Whereas there was no significant difference between the two groups for LOS and conversion to open, average operative times were significantly higher in the robotic-assisted group ($p<0.001$). Subgroup analysis for primary and recurrent inguinal hernias matched the overall results.

Conclusions Robotic-assisted inguinal hernia repair has a significantly higher cost and significantly longer operative times, compared to the laparoscopic approach. The study has shown that only fixed cost contributes to the cost difference between the two approaches. Medical device cost plus the longer operative times are the main factors driving the cost difference. Laparoscopic unilateral inguinal hernia repair is more cost-effective compared to a robotic-assisted approach.

Keywords Inguinal hernia · Robotic-assisted · Laparoscopic · Cost-effective · Adoption · Cost analysis

In the era of healthcare reform, cost plays a pivotal role in decision-making when deciding whether to adopt new surgical technologies. Until recently, cost was considered a secondary factor for adoption decisions, but with increasing healthcare financial constraints, cost has taken on a role of increasing importance [1]. Obviously, cost should not be the sole determinant, but should be tied to its generated benefits and outcomes, hence the importance of cost-effectiveness analysis, a fundamental research tool, in deciding whether to adopt new technologies. Any additional cost of a new surgical technology needs to be justified by better clinical, social, and/or economic outcomes, compared to the well-established solutions, for the patient and across the healthcare system [2]. When the cost of a technology, that offers no clear benefits, is significantly higher, resources should be reallocated to achieve the maximum benefits regardless of the solution.

A prominent example is robotic-assisted surgery, which has gained popularity since the introduction of the da Vinci Surgical System in the year 2000. Robotic-assisted surgery

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was positioned as a promising solution to the limitations of laparoscopic surgery [3]. Robotic surgical systems have been shown to provide better visualization, increased angulation and range of motion, and more precise suturing when compared to laparoscopic instruments [3, 4]. As a result, one in four United States hospitals has acquired at least one robot, leading to an exponential increase in the number of robotic-assisted procedures performed. Significant benefits of robotic-assisted surgery, over other approaches, have been demonstrated in certain urologic, gynecologic, and colorectal procedures thereby justifying the higher associated cost [5–13]. However, the value proposition of robotic-assisted surgery is still controversial in other surgical procedures [14–17].

Inguinal hernia repair, a very common general surgery procedure, is one of these debatable procedures. A laparoscopic inguinal hernia repair results in a high rate of symptom relief, high patient satisfaction, and low recurrence rates. The advantage of robotic-assisted inguinal hernia repair, one of the fastest growing robotic-assisted procedures, over the laparoscopic approach is questionable. While most studies have failed to show any significant difference between the robotic-assisted approach and the laparoscopic approach [18–21], there have been a few studies demonstrating an advantage of one approach over the other. Waite et al. showed, in a single-surgeon experience, significantly less post-operative pain after robotic-assisted inguinal hernia repair when compared to laparoscopic repair [22]. Contrarily, Charles et al. demonstrated in a study comparing outcomes of robotic-assisted, laparoscopic, and open inguinal hernia repair that the robotic-assisted group had significantly longer operative times and higher rates of skin and soft-tissue infections [23]. With no clear advantage in outcomes, a comprehensive cost-effectiveness analysis is important in deciding whether to adopt the technology for inguinal hernia repairs. A comprehensive analysis will delineate the factors that drive cost, allowing interventions to reduce cost or suggesting a reallocation of resources for a better return on investment. However, the current literature on the costs of robotic-assisted surgery is lacking and the literature that does exist is inconsistent in cost reporting and difficult to interpret [1]. The aim of this study was to perform a comprehensive cost analysis for robotic-assisted and laparoscopic inguinal hernia repair using a micro-costing model accounting for all of the related cost elements to provide an accurate comparison of the cost-effectiveness of both approaches.

Materials and methods

A single source Electronic Health Record deployed across 32 acute care hospitals in a large healthcare system in the Western United States, (Providence St. Joseph Health), was queried for patients who had undergone unilateral inguinal hernia repair in the period between January 2015 and March 2017. The study cohort was identified by a combination of a Current Procedural Terminology codes and the procedure description. Only elective outpatient laparoscopic and robotic-assisted procedures were included. Open, emergent, concurrent, and bilateral inguinal hernia repairs were excluded.

Procedural total cost was calculated using a micro-costing approach for direct costs only. Indirect cost, the overhead cost that keeps the healthcare system running, was not included. In addition to being difficult to calculate, this cost is incurred regardless of the approach and should be similar for both approaches. Direct cost was defined as the cost of the resources that were directly used for the patient's procedure [1] and comprised two main categories: fixed and variable costs. Fixed costs included personnel and medical devices, and variable costs included reusable instruments and disposables (Fig. 1). The equations used for cost calculations are shown in Table 1.

Medical devices included the unique equipment pertinent for each approach such as laparoscopic towers, with their various components, and robotic consoles. A 6.4-year life expectancy, the average across the health system over an 8-year period, was used for the 29 da Vinci Robotic Surgical Systems used in the study. The multiple components of laparoscopic towers made the calculation of their life expectancy challenging. Therefore, based on discussion with the medical device engineers in our system, we elected to use the same life expectancy of 6.4 years for all of the components of the laparoscopic towers. This was felt to be a very conservative estimate. The cost was calculated to be \$172 per laparoscopic case and \$1272 per robotic-assisted case.

Other outcome measures were length of stay (LOS), conversion to open, and operative times (total in-room time, cut-to-close, and time in the post-anesthesia care unit). Statistical analysis was done using *t* test for continuous variables and χ^2 test for categorical variables. A p-value < 0.05 was considered significant. The study was

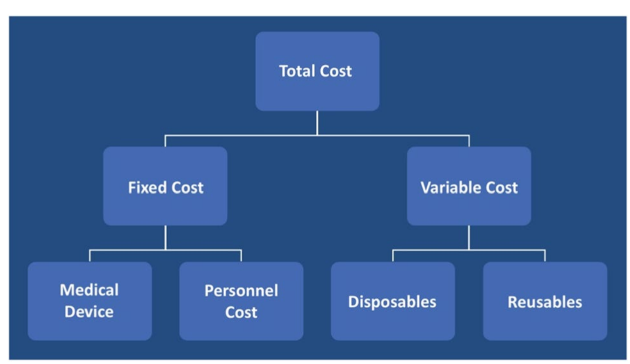

Fig. 1 Cost categories

Table 1 Micro-costing approach for direct cost calculation Adopted from Ismail et al. [1]

Fixed cost		Variable cost	
Personnel	Medical devices	Reusable instruments	Disposables
A per minute personnel cost (PC) of a number p of personnel present during surgical operations is expressed as $PC = \frac{1}{12}\sum_{i=1}^{p}\frac{W_i \times t_i}{L_i \times Ewd_i}$, where W_i, L_i, Ewd_i, and t_i are, respectively, personnel i's annual loaded salary, weekly paid working hours, effective working days per year; as in (working days—paid leave), mean time spent in surgery operations, expressed in minutes	Technology Cost (TC) per operation using the following equation $TC = \sum_{i=1}^{m}\frac{P_i + (M_i \times E_i)}{E_i \times N_i}$, where P_i, M_i, E_i, and N_i are, respectively, medical device i's purchase price, maintenance fee per year, life expectancy expressed in years, mean number of operations per year for which the device has been used	Instrument cost (IC) per operation during which n reusable instruments were needed $IC = \sum_{i=1}^{n}\frac{P_i + (E_i - 1) \times S_i}{E_i}$, where P_i, E_i, and S_i are, respectively, instrument i's purchase price, maximum number of uses allowed, sterilization cost[a]	Disposable cost (DC) per operation using the following equation $DC = \sum_{i=1}^{d}(N_i \times P_i)$, where N_i and P_i are, respectively, disposable i's number of units used, purchase price

[a]Sterilization cost takes into account the fact that instruments that have used up their last life would not require sterilization

Table 2 Cost comparison between laparoscopic and robotic-assisted approaches for unilateral inguinal hernia repair

	Laparoscopic	Robotic	p-value
Average total cost	$3269	$5517	< 0.001
Average fixed cost	$2164	$4584	< 0.001
Average personnel cost	$1992	$3312	< 0.001
Medical device cost	$172	$1272	< 0.001
Average variable cost	$1105	$933	< 0.001

exempted from Institutional Review Board (IRB) approval due to the de-identified administrative nature of the data.

Results

In the period from January 2015 to March 2017, a total of 2405 unilateral inguinal hernia repair procedures, 734 robotic-assisted and 1671 laparoscopic, met the inclusion criteria. Six hundred and thirty-three (86%) of the robotic-assisted procedures were primary inguinal hernias, and 101 (14%) were recurrent inguinal hernias. In the laparoscopic group, 1471 (88%) procedures were primary and 200 (12%) procedures were recurrent inguinal hernias. The average total cost of the robotic-assisted hernia repair was significantly higher than the laparoscopic repair ($5517 ± $1016 vs $3269 ± $1167; $p < 0.001$). The fixed cost, which comprised personnel and medical device costs, was the main contributor to the significant difference in the total cost of the two procedures. The average fixed cost for the robotic-assisted group was ($4584 ± $769), compared to ($2164 ± $706) for the laparoscopic group ($p < 0.001$). Further analysis of the fixed cost revealed that both the personnel and the medical device costs were significantly higher in the robotic-assisted group. In contrast, the average variable cost was significantly higher in the laparoscopic group compared to the robotic-assisted group ($1105 ± $846 vs $933 ± $484; $p < 0.001$). Table 2 summarizes the average costs in the two groups and the costs are represented graphically in Fig. 2.

There was no significant difference between the two groups for the average length of hospital stay, 0.26 days for the robotic-assisted group versus 0.25 days for laparoscopic group ($p = 0.4$). The rate of conversion to an open procedure was also similar between the groups, 5.4% for robotic-assisted versus 5.3% for laparoscopic ($p = 0.9$). However, average operative times were significantly higher in the robotic-assisted group, an indirect contributor to the higher cost due to the dependence of personnel salaries on operative time. Table 3 and Fig. 3 summarize average operative times for both groups.

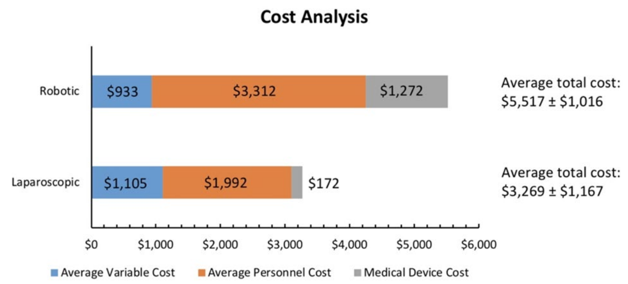

Fig. 2 A cost-analysis comparison between average total cost for laparoscopic inguinal hernia repair and robotic-assisted inguinal hernia repair including average variable cost, average personnel cost, and medical device cost

Table 3 Average operative times for laparoscopic and robotic-assisted unilateral inguinal hernia repair. PACU: post-anesthesia care unit

Operative times (min)	Laparoscopic	Robotic	*p*-value
Average in-room time	90	125	<0.001
Average cut-to-close time	56	87	<0.001
Average PACU time	59	70	<0.001

Subgroup analysis for primary and recurrent inguinal hernias matched the overall results. Table 4 summarizes the subgroup analysis.

The study included laparoscopic inguinal hernia repairs performed by 115 surgeons and robotic-assisted repairs performed by 49 surgeons. We compared the top five surgeons with the highest volumes in both groups in an attempt to avoid the bias from surgeons who are still early on their learning curve. The top five surgeons with the highest volumes in the laparoscopic group performed from 67 to 188 procedures for a total of 505 inguinal hernia repairs during the study. In the robotic-assisted group, the top five surgeons with the highest volumes performed 42–118 repairs for a total of 339 procedures. As shown in Fig. 4, the mean operative times for the laparoscopic group were 41 min (cut-to-close), 77 min (in-room), and 55 min (PACU time). Whereas in the robotic-assisted group, these times were 73 min (cut-to-close), 107 min (in-room), and 66 min (PACU time). There was a significant difference between the two groups in all operative times ($p < 0.001$).

Discussion

The cost of surgical technologies is an increasingly important metric in surgical care, as it consumes a large proportion of the "limited" healthcare budget. Therefore, any newly introduced surgical technology needs to be demonstrably "cost-effective" before being adopted by healthcare systems. Unfortunately, in today's complex hospital economic environment, it is extremely difficult to perform the necessary analysis for cost-effectiveness evaluation [1].

The cost-effectiveness of robotic-assisted surgery has been a subject of significant debate since its introduction. This debate has intensified with the increasing adoption of robotic surgery. Surgeons on one side of the debate argue that robotic surgery provides improved ergonomics for the surgeon, minimizing fatigue and injuries; the three-dimensional cameras offer a better view of the surgical field; and robotic surgery provides an advantage when operating in space-limited fields, such as the pelvis, due to enhanced manual dexterity [24–28]. Surgeons on the other side of the debate argue that these advantages cannot be easily quantified and there is no evidence that they improve performance

Fig. 3 Robotic-assisted versus laparoscopic average operative times. *PACU* post-anesthesia care unit

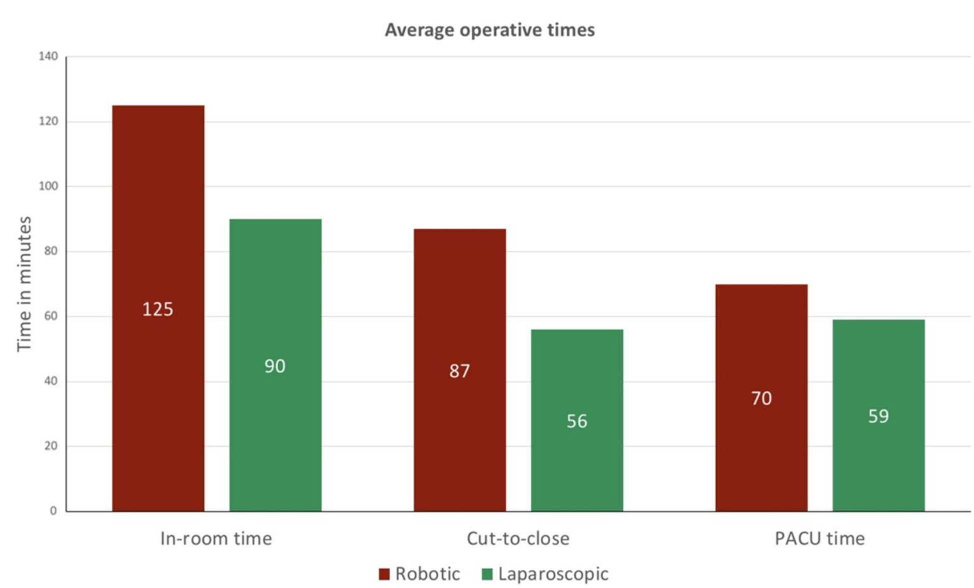

Table 4 Summary of subgroup analysis

Primary hernia repair	Laparoscopic ($n=1471$)	Robotic ($n=633$)	p-value
Average total cost	$3235	$5484	< 0.001
Average fixed cost	$2150	$4562	< 0.001
Average personnel cost	$1978	$3290	< 0.001
Medical device cost	$172	$1272	< 0.001
Average variable cost	$1086	$922	< 0.001
Average In-out time (min)	89	122	< 0.001
Average Cut-to-close time (min)	54	85	< 0.001
Average recovery room time (min)	59	69	< 0.001
Average hospital LOS (days)	0.25	0.26	0.37
Rate of conversion to open, *n*	73 (5.0%)	32 (5.1%)	0.93
Recurrent hernia repair	**Laparoscopic ($n=200$)**	**Robotic ($n=101$)**	**p-value**
Average total cost	$3519	$5726	< 0.001
Average fixed cost	$2270	$4722	< 0.001
Average personnel cost	$2,098	$3450	< 0.001
Medical device cost	$172	$1272	< 0.001
Average variable cost	$1249	$1004	0.008
Average In-out time (min)	99	137	< 0.001
Average cut-to-lose time (min)	66	96	< 0.001
Average PACU (min)	59	72	0.006
Average hospital LOS (days)	0.24	0.24	0.96
Rate of conversion to open, *n*	16 (8.0%)	8 (7.9%)	0.98

PACU post-anesthesia care unit

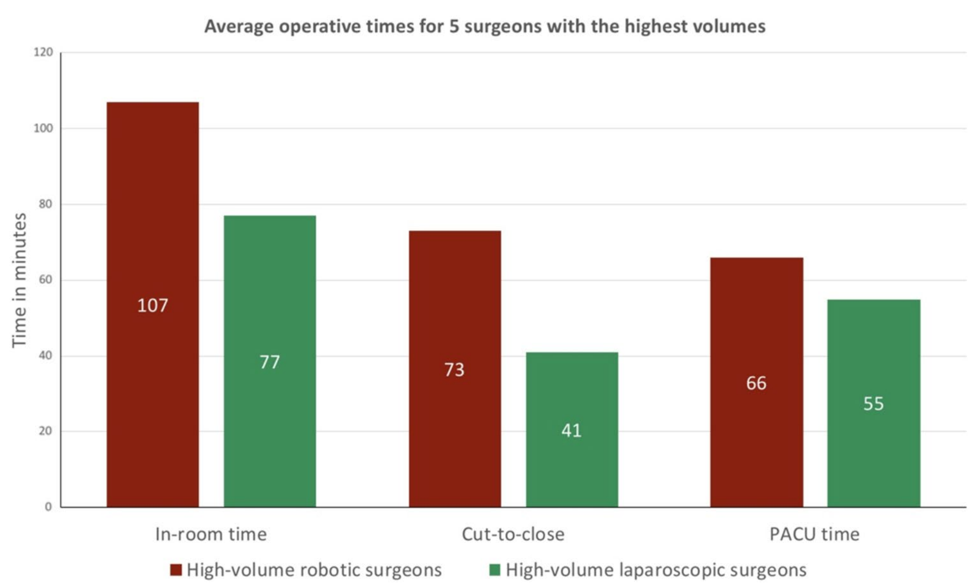

Fig. 4 Comparison of operative times between the five surgeons in each group with the highest volumes

[27–29]. A thorough evaluation of the cost-effectiveness, analyzing both the cost and the clinical outcomes, is necessary to better inform both sides of the debate.

A comprehensive cost analysis becomes even more important when the clinical advantage of a new surgical technology is not obvious, as in the case of robotic-assisted inguinal hernia repair when compared to laparoscopic. Currently, the literature on the cost of robotic-assisted surgery is limited and where it exists it is inconsistent and unreliable. In a systemic review and economic analysis by Bailey et al., they found that the cost associated with surgical robots was rarely addressed and when addressed it was incomplete or biased. Inaccuracy was also an issue, with cost models based on assumptions that were not validated or generalizable [30]. The European Association of Endoscopic Surgeons (EAES), in a consensus statement on the use of robotics in general surgery, described the level of evidence for the reported cost or cost-effectiveness analysis in general surgery procedures as poor. The investigated studies were either small and underpowered or biased due to case selection and learning curve. They noted a lack of consistency in cost reporting, with different authors using different approaches to report the cost [29]. Higgins et al. analyzed the cost for three general surgery procedures: cholecystectomy, inguinal hernia, and fundoplication, comparing only the consumable costs of robotic-assisted versus laparoscopic procedures [17]. They found that the total cost of consumables was significantly higher in the robotic-assisted procedures. In contrast, Waite et al. in their study to compare robotic versus laparoscopic transabdominal preperitoneal inguinal hernia repair reported nearly equivalent direct cost and contribution margin for both procedures. Their cost report included the direct costs, facility net revenue, and contribution margin for each case. However, their definition of direct cost only included variable cost without the fixed cost of the medical device and the personnel costs [22]. Without data on the initial acquisition price of both the robotic and laparoscopic systems, maintenance costs, and amortization of both systems, the usefulness of these studies to evaluate cost-effectiveness is severely limited.

The goal of our study was to perform a comprehensive analysis covering all components of cost related to inguinal hernia repair, using the equations proposed by Ismail et al. [1]. As they noted, the equations do not take indirect cost into consideration due of the complex nature of the data and the difficulty in obtaining accurate values. However, the indirect cost for both approaches will be the same, as it is incurred irrelative of the approach used. Direct cost was defined to include all the fixed and variable costs that are related to the surgical approach for every patient.

Our study demonstrates that robotic-assisted inguinal hernia repair is associated with a significantly higher total cost compared to the laparoscopic approach. The difference in the total cost between the two approaches is $2200 per case on average. This significant difference in cost is dominated by two main cost categories, the cost of the medical devices and the personnel costs. These results are supported by Barbash et al. who showed that, on average, across a full range of 20 different surgical procedures the amortization cost of the surgical robot, when included, adds an extra $1600 per procedure to the total cost. Their study also demonstrated that using the robot added an additional variable cost of about $1600 per procedure, similar to what Higgins et al. showed [17, 31]. Both of these studies are in contrast to what was shown in our study, where the variable cost was significantly higher in the laparoscopic group. The higher variable cost in the laparoscopic cohort of our study may be attributable to the use of mesh fixation devices, balloon dissectors, and/or disposable trocars, which are all modifiable factors [32].

Medical device amortization cost was calculated using the purchase price, maintenance fee per year, life expectancy, and the mean number of operations per year for which the device has been used. We choose to amortize the purchasing price over 6.4 years, the average useful life of the surgical robots in our system, which represents a realistic appraisal of the life expectancy. In other published studies, the robot amortization ranged from 5 to 7 years as a preset value for simplicity of calculations [15, 16, 33]. However, a unified system for cost calculation can adjust for these differences when comparing between different hospitals. We used the same 6.4-year useful life for amortization of the laparoscopic systems due to the complexity of calculating the life expectancy of a laparoscopic tower. However, this is considered a conservative approach based on discussion with the medical device engineers in our system. The study reveals an average $1100 per procedure difference in medical device costs between the two approaches. This significant cost difference invalidates any conclusions about the cost-effectiveness of robotic-assisted surgery if it is not included.

The other significant factor contributing to the increased cost of robotic-assisted inguinal hernia repairs is the personnel cost. The personnel cost represents the salaries of all the personnel involved in the patient's care during the encounter, including anesthesia and nursing staff, but not the surgeon. The increased cost stems, indirectly, from the longer operative times of the robotic-assisted approach. It can be argued that the operative times for the robotic-assisted approach will improve as the experience of the surgeons increases. However, in our cohort the operative times of the most experienced robotic surgeons were still significantly longer than the operative times of the most experienced laparoscopic surgeons. This suggests that the difference in operative time was not a product of the learning curve of the surgeons. However, the learning curve for robotic-assisted inguinal hernia repair is not well known and if these surgeons were still on their learning curve, operative times could decrease, resulting in a smaller difference in cost between the two approaches.

Until the higher cost of using robots in inguinal hernia repair is justified by a validated improvement in outcomes or the cost of the robotic surgical system decreases, using robots for inguinal hernia repair is a waste of valuable resources. The opportunity cost of using the same invested amount of money on surgeons' training or improving quality of service for the inguinal hernia patient is obvious. The time used to perform, for example, two successive robotic-assisted procedures could be used to perform a higher number of laparoscopic procedures, generating more revenues without affecting the clinical outcomes for the patients.

In summary, on average, robotic-assisted inguinal hernia repair costs $2200 more than laparoscopic repair. Over the 26 months represented in this study, 734 robotic-assisted unilateral inguinal hernia repairs were performed resulting in an increased cost of approximately $1.6 million to the healthcare system. Until the cost of robotic surgical system decreases, it is difficult to justify their use for unilateral inguinal hernia repairs. As demonstrated in this study, a unified cost calculation methodology is key for comparisons across different systems. However, the equations used in our study need validation with further studies across additional healthcare systems.

Compliance with ethical standards

Disclosures Lee Swanstrom is on the Scientific Advisory board of Olympus and Boston Scientific. Chet Hammill is a Medtronic consultant and Intuitive Surgical proctor. Walaa Abdelmoaty, Christy Dunst, and Chris Neighorn have no conflicts of interest or financial ties to disclose.

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