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Robotic Inguinal Hernia Repair Outcomes: Operative Time and Cost Analysis

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ABSTRACT

Background: Robotic inguinal hernia repair is the latest iteration of minimally invasive herniorrhaphy. Previous studies have shown expedited learning curves compared to traditional laparoscopy, which may be offset by higher cost and longer operative time. We sought to compare operative time and direct cost across the evolving surgical practice of 10 surgeons in our healthcare system.

Methods: This is a retrospective review of all transabdominal preperitoneal robotic inguinal hernia repairs performed by 10 general surgeons from July 2015 to September 2018. Patients requiring conversion to an open procedure or undergoing simultaneous procedures were excluded. The data was divided to compare each surgeon's initial 20 cases to their subsequent cases. Direct operative cost was calculated based on the sum of supplies used intra-operatively. Multivariate analysis, using a generalized estimating equation, was adjusted for laterality and resident involvement to evaluate outcomes.

Results: Robotic inguinal hernia repairs were divided into two groups: early experience (n = 167) and late experience (n = 262). The late experience had a shorter mean operative time by 17.6 min (confidence interval: 4.06 – 31.13, $p = 0.011$), a lower mean direct operative cost by $538.17 (confidence interval: 307.14 – 769.20, $p < 0.0001$), and fewer postoperative complications ($p = 0.030$) on multivariate analysis. Thirty-day readmission rates were similar between both groups.

Conclusion: Increasing surgeon experience with robotic inguinal hernia repair is associated with a predictable reduction in operative time, complication rates, and direct operative cost per case. Thirty-day readmission rates are not affected by the learning curve.

Key Words: Inguinal hernia, Learning curve, Operative time, Cost, Robotic.

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INTRODUCTION

Robotic inguinal hernia repair (RIHR) is the latest innovation in minimally invasive herniorrhaphy. There is a growing number of inguinal hernia repair (IHR) performed via the robotic approach, and predictors of RIHR seem to include larger non-teaching rural hospitals, and surgeons with lower annual case volume.[1,2] Touted benefits to RIHR include improved visualization and dexterity, evidenced by the decreased minimally-invasive suturing task time learning curve in the robotic compared to laparoscopic approach in a simulated sitting.[3] One benefit of the robotic approach is the ability to repair incidental contralateral hernias, given that as high as 15.8% of patients are reported to have contralateral inguinal hernias identified intra-operatively during RIHR.[4] Other advantages to the robotic technique include its effects on the postoperative experience. Studies have reported improved postoperative pain, shorter use time of prescribed pain medication, lower post-anesthesia-care-unit (PACU) recovery time, and a trend toward sooner return to work compared to laparoscopic inguinal hernia repair (LIHR).[5,6] Such advantages to RIHR are offset by the prolonged intra-operative time and higher cost compared to the laparoscopic approach.[7,8]

Most studies compare RIHR to the laparoscopic and open approaches. A few studies, however, attempt to analyze a surgeon's learning curve in RIHR across time. A recent multi-center study including 335 RIHR cases performed by 18 surgeons showed a learning curve of 11 – 12 cases for one of the involved surgeons, based on consecutive 24 cases performed.[9] Multiple other studies describe the minimum number of cases necessary to reach a learning curve in robotic abdominal surgery in general. In robotic abdomino-perineal resection and anterior resection for rectal cancer, one study of 43 cases used cumulative sum analysis to show a minimum of 21 – 23 cases needed to reach the learning curve.[10] Another study including 62 cases of segmental colectomies, proctectomies, and rectopexies compared the first consecutive 15 cases to the remainder of cases.[11] The study showed a reduced operative time and complication rates in the latter group, which may reflect a learning curve of 15 cases. Another study including 19 cases of robotic radical hysterectomy with lymph node dissection for cervical cancer used cumulative sum analysis to show a minimum of 13 cases required to reach the learning curve.[12] Based on the above studies, it seems that the learning curve of robotic abdomino-pelvic surgery ranges mostly between 15 to 23 cases.[9–12]

Most previous studies compare RIHR to laparoscopic and open IHR, showing increased operative time and cost in the robotic technique.[7,13] However, the previous studies of robotic abdomino-pelvic surgery have smaller sample size and do not seem to examine such outcomes across the learning curve. The aim of this study is to compare intra-operative time, direct operative cost, and postoperative complication rate between an early and a late phase of RIHR learning curve of multiple surgeons.

METHODS

This is a retrospective analysis of consecutive, elective robotic transabdominal preperitoneal (R-TAPP) cases performed by 10 surgeons at two institutions in our healthcare system from July 2015 to September 2018. Adults 18 years old or older who underwent unilateral or bilateral RIHR were included in the study. Cases were excluded from the study if they were converted to open hernia repair. With the exception of patients undergoing primary umbilical hernia repair at the site of umbilical trocar insertion, patients undergoing significant concurrent procedure were excluded as well.

The study population was divided into two groups: early experience (defined as the first 20 cases of each surgeon's RIHR experience) and late experience (defined as the remainder of each surgeon's RIHR experience). The 20-case cutoff was assigned based on the above-mentioned literature review showing a robotic-surgery learning curve ranging between 15 and 23 cases. Of note, 3 of the 10 surgeons had performed fewer than 20 cases; with a range of 8 to 11 cases, thus had only their early experience included. Demographics included age, gender, body mass index (BMI), American Society of Anesthesiologists (ASA) classification, and previous ipsilateral IHR. Primary outcomes included intra-operative time and direct operative cost. Secondary outcomes included the rate of post-operative complications, 30-day readmission rate, surgical resident involvement, and change in admission status. Change in admission status was identified as a change from the expected outpatient status of the surgery to an inpatient or overnight 23-hour admission secondary to any cause. Of note, change in admission status did not include patients who were planned to undergo admission secondary to their comorbid conditions.

Given that bilateral RIHR is presumed to have longer operative time compared to unilateral RIHR and that resident involvement may contribute to a longer operative time, a multivariate analysis was performed adjusting for both factors. Variables analyzed in the multivariate model included operative time, direct operative cost adjusted for fiscal year, postoperative complications, and 30-day readmission rate. Operative cost was direct cost; including mesh cost, instrumentation cost (i.e. robotic arm instruments, insufflation tubing), and other supplies (i.e. sutures, gauzes, trocars). Operative cost excluded intra-operative time cost because it is reflected by the intra-operative time comparison analysis. It also excluded the indirect cost of robotic personnel and robot maintenance, given that this measure would be the same throughout the early and late experience of RIHR.

Patient characteristics were summarized using continuous and categorical variables. Continuous variables are presented as mean ± standard deviation (SD). Categorical variables are presented as frequency with a percentage, n (%). The t-test and Chi-squared test were used for comparison. In a multivariate analysis, logistic and linear regression models with generalized estimating equations were used to control for potential confounding. Results are presented as mean difference or odds ratio (OR) with a 95% confidence interval (CI). Data were analyzed using the SAS® Version 9.4 statistics software (SAS Institute, Cary, NC). A p value < 0.05 was considered statistically significant. The study was approved by the Institutional Review Board.

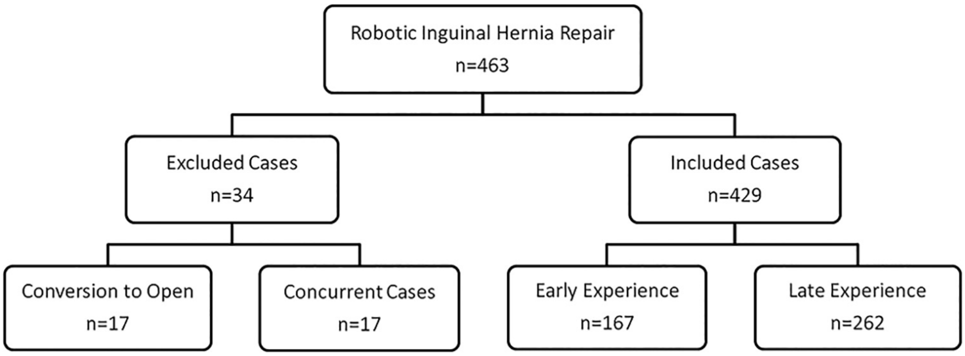

Figure 1. Study Population.

RESULTS

Figure 1 depicts the study population. Excluded cases were either due to patients undergoing a significant concurrent procedure other than primary umbilical hernia repair at the trocar site insertion (n = 17), or due to conversion to open hernia repair (n = 17). Cases were converted to open hernia repair if the patient could not tolerate pneumoperitoneum secondary to comorbid conditions, if the hernia sac could not be safely dissected secondary to extensive adhesive disease or prior mesh presence, and if the hernia could not be safely reduced secondary to bladder or intestinal

Table 1.
Comparison of Early and Late Experience in Robotic Inguinal Hernia Repair

Variables	Early Experience (n = 167)	Late Experience (n = 262)	*p* Value
Demographics			
Age (year)	56.8 ± 15.0	55.4 ± 14.6	0.340
Male	161 (96.4%)	250 (95.4%)	0.619
BMI (kg/m^2)	27.4 ± 4.5	27.7 ± 5.6	0.572
Prior ipsilateral hernia repair	31 (18.6%)	43 (16.4%)	0.398
ASA Classification			0.606
I	14 (8.9%)	24 (9.8%)	
II	94 (59.5%)	154 (62.6%)	
III	50 (31.7%)	66 (26.8%)	
IV	0 (0%)	2 (0.8%)	
Operative Variables			
Laterality			0.088
Unilateral	115 (68.9%)	200 (76.3%)	
Bilateral	52 (31.1%)	62 (23.7%)	
Resident Involvement	86 (51.5%)	165 (63%)	0.019
Change in Admission Status	14 (8.4%)	5 (1.9%)	0.002
Univariate Analysis			
Operative Time (min)	110.9 ± 41	86.9 ± 28	< 0.0001
Post-operative Complications	25 (15%)	23 (8.8%)	0.047
30-Day Readmission	5 (3%)	4 (1.5%)	0.320

Early: first 20 cases of each surgeon, Late: subsequent cases of each surgeon Continuous variables: means ± standard deviation, Categorical variables: frequency (percentage).
BMI, body mass index; ASA, American Society of Anesthesiologists.

Table 2.
Multivariate Analysis: Association with Late Experience in Robotic Inguinal Hernia Repair

Operative Variables	Mean Difference	95% CI	*p* Value
Intra-operative time reduction (min)	17.60	4.06 – 31.13	0.011
Operative cost reduction ($, adjusted for fiscal year)	538.17	307.14 – 769.20	< 0.0001

Postoperative Variables	Odds Ratio	95% CI	*p* Value
Postoperative complications	0.639	0.427 – 0.957	0.030
30-Day readmission	0.615	0.259 – 1.458	0.270

Early: first 20 cases of each surgeon, Late: subsequent cases of each surgeon, Multivariate analysis: adjusting for laterality and resident involvement.
CI, confidence interval.

involvement. Concurrent procedures that necessitated exclusion from the study included umbilical hernia repair with mesh, hysterectomy, prostatectomy, excision of a previous inguinal mesh, intra- or extra-abdominal cyst or mass removal, cystoscopy with dilation, and hiatal hernia repair.

A total of 429 patients were included in the study analysis. Of those, 167 patients were included in the early experience and 262 patients in the late experience. Both groups had similar average age and BMI, gender distribution, and ASA classification (**Table 1**). In total, 74 patients (17.2%) had at least one previous ipsilateral IHR, which was similar between both groups; p = 0.398. There were 315 (73.4%) unilateral and 114 (26.6%) bilateral RIHR cases, which was similar between both groups as well; p = 0.088.

In univariate analysis, intra-operative time was shorter in the late experience compared to the early experience; 86.9 ± 28 vs. 110.9 ± 41 minutes, p < 0.0001 (**Table 1**). In multivariate analysis, adjusting for resident involvement and laterality, the late experience was associated with a shorter intra-operative time by 17.6 (95% CI: 4.06 – 31.13) minutes per case on average, p = 0.011 (**Table 2**). Prior to the adjustment, bilaterality resulted in a longer intra-operative time by 31.48 (95% CI: 27.04 – 35.92) minutes; p < 0.0001, and there was a trend toward a longer intra-operative time by 7.60 (95% CI: 0.60 – 15.80) minutes, in cases with resident involvement, but the difference was insignificant; p = 0.069. Of note, resident involvement occurred more frequently in the late experience; 63% vs. 51.5%, p = 0.019 (**Table 1**).

In univariate analysis, there was a trend toward less direct operative cost in the late experience compared to the early experience; $1998 ± $637 vs. $2128 ± $730, p = 0.053. In multivariate analysis adjusting for resident involvement, laterality, and fiscal year, the late experience was associated with a reduced operative cost by $538.17 (95% CI: $307.14 – $769.20) per case on average, p < 0.0001 (**Table 2**). Prior to the adjustment, bilaterality resulted in a higher operative cost by $438.38 (95% CI: $338.02 – $538.74), p < 0.0001; however, resident involvement was not associated with a higher operative cost; $38.73 (95% CI: $40.84 – $118.29), p = 0.34. Prior to adjustment for fiscal year, there was an associated increase in operative cost per year; in 2017 by $727.07 (95% CI: $557.98 – $896.15), and in 2018 by $875.41 (95% CI: $662.42 – $1088.39), all p < 0.0001.

In univariate analysis, there was no difference in 30-day readmission rates between the early and late experience; 3% vs. 1.5%, p = 0.320 (**Table 1**). In multivariate analysis adjusting for resident involvement and laterality, there was no association between the late experience and 30-day readmission rate, OR = 0.615 (95% CI: 0.259 – 1.458); p = 0.270 (**Table 2**). There were nine patients (2.1%) readmitted within 30 days postoperatively. Reasons for 30-day readmission included the following: contained perforated gastric ulcer, suicidal ideation, urinary retention, dysphagia, dyspnea, chronic obstructive pulmonary disease exacerbation, acute kidney injury, and infectious colitis. The one patient with urinary retention was readmitted on postoperative day 3 and the one patient with kidney injury was readmitted on postoperative day 2; each stayed in the hospital for less than two days.

In univariate analysis, the rate of post-operative complications was lower in the late experience; 8.8% vs. 15%, p = 0.047 (**Table 1**). In multivariate analysis, adjusting for resident involvement and laterality, the late experience was associated with a lower rate of post-operative complications as well; OR = 0.639 (95% CI: 0.427 – 0.957), p = 0.030 (**Table 2**). Post-operative complications occurred in 48 patients (11.2%) during an average follow-up time of 44.8 ± 75.9 days. Twenty-three patients (5.4%) experienced urinary retention requiring catheterization. One of those patients acquired a urinary tract infection requiring treatment, one patient experienced acute kidney injury requiring admission and fluid resuscitation, and one patient experienced atrial fibrillation postoperatively requiring admission. Of those 23 patients, 6 patients were on an alpha-1 receptor blocker, one patient had a history of prostate cancer, one patient was subsequently diagnosed with urothelial carcinoma, and nine patients had documented enlarged prostate; seven of whom were on at least an alpha-1 receptor blocker and/or a 5-alpha reductase inhibitor. Six patients had none of the above history.

Eleven patients (2.6%) experienced chronic pain, defined as ≥ 12 weeks postoperatively; four of whom required medical therapy by interventional pain specialists. No patient required re-operation for chronic pain. Other complications included two patients (0.5%) with postoperative seroma formation requiring aspiration, one patient (0.2%) with wound infection requiring antibiotics, one patient (0.2%) with wound granuloma formation requiring in-office handheld cauterization, three patients (0.7%) with urinary tract infection requiring antibiotic treatment, one patient (0.2%) with stridor requiring re-intubation with admission, one patient (0.2%) with non-ST-elevation myocardial infarction requiring admission, and one patient (0.2%) with a *Clostridium difficile* infection requiring treatment. Given some of the above complications or planned postoperative admission, a few patients were admitted after RIHR. However, change in admission status occurred less frequently in the late experience; 1.9% vs. 8.4%, p = 0.002 (**Table 1**).

Of note, one patient in the early experience acquired a small incisional hernia at the umbilical trocar site and one patient in the late experience acquired an epigastric hernia along with an incisional hernia at the umbilical trocar site requiring mesh repair after 225 days postoperatively. Two patients (0.5%) had late recurrent inguinal hernia requiring intervention. The first patient, who had a history of left IHR, underwent a left RIHR in this study (late experience), and developed recurrent left inguinal hernia requiring open repair with mesh after 320 days of current surgery. The second patient, who had no history of IHR, underwent bilateral RIHR in this study (early experience), and developed recurrent right inguinal hernia requiring open repair with mesh after 301 days of current surgery.

DISCUSSION

Multiple studies have analyzed operative time and cost, as well as postoperative recovery time and pain, between the robotic and laparoscopic approach to IHR. A single-surgeon experience of 24 LIHRs and 39 RIHRs showed significantly reduced recovery-room time (109.1 vs. 133.5 min) and pain score (2.5 vs. 3.8) in the robotic group compared to the laparoscopic group.[5] In a propensity-matched analysis, patients without a prior IHR reported a significantly reduced postoperative inguinal pain score at one week in RIHR compared to LIHR and open IHR (3.8 vs. 4.9 vs. 5.5, respectively).[6] In the same study, a subgroup of patients who underwent RIHR reported significantly shorter time to stopping the use of prescribed pain medication postoperatively compared to LIHR and open IHR (9 vs. 12.6 vs. 11.2 days, respectively). A non-statistically-significant trend was also reported toward a faster return-to-work in the RIHR group compared to the LIHR and open IHR groups (18.2 vs. 21.1 vs. 23.6 days, respectively), in a subgroup of patients.[6] As discussed earlier, previous studies have shown prolonged operative time and higher cost, while also having an improved recovery time and postoperative pain in robotic compared to laparoscopic IHR.[5–8,13,14] No study, with a significant population size, analyzed whether such outcomes change with a surgeon's growing RIHR experience across the learning curve. To our knowledge, this is the largest RIHR experience in literature to address this topic.

We show that increasing surgeons' experience with RIHR correlates with a shorter intra-operative time; especially after 20 cases, reaching a 17.6-min reduction in the late compared to the early experience. A previous multi-institutional study showed a longer intra-operative (125 vs. 90 min), operative (87 vs. 56 min), and PACU (70 vs. 59 min) time in the RIHR group.[7] However, length of stay seemed to be similar between RIHR and LIHR in primary and recurrent repairs; ranging from 0.24 to 0.26 days. Another study, in a dedicated minimally-invasive surgery center, showed an increased mean operative time in RIHR compared to LIHR (116 vs. 95 min, p < 0.01); with a significantly longer operative time in unilateral IHR (110 vs. 88 min, p < 0.01) and a trend toward longer operative time in bilateral IHR (143 vs. 114 min, p = 0.06) in the robotic group.[8] However, a study of one surgeon's experience showed a reduction in the operative time of R-TAPP IHR during the learning curve, to reach a similar operative time of laparoscopic TAPP.[15] A similar study showed a reduction in operative time of robotic inguinal and ventral hernia repairs as surgeons' experience increased; reaching a similar time as the laparoscopic repairs.[16] A recent study analyzed the first 24 unilateral RIHR cases of one surgeon and recognized a change in operative time after the first 11 cases; marking the learning curve at this point;[9] however, it was a single surgeon's experience of only the first 24 cases. A larger sample size would be required to recognize a defined learning-curve case-number. Based on our results, intra-operative time of RIHR is shorter as experience increases over time.

In this study, we show that with an increasing surgeons' experience with RIHR, there is a reduction in average direct operative cost per case; especially after 20 cases, reaching a $538.17 reduction in the late compared to the early experience. Based on a previous large study, RIHR has a much higher average total hospital cost ($5517 vs. $3269) and fixed cost (medical device; $1272 vs. $172, and personnel; $3312 vs. $1992), but less variable cost (reusables and disposables; $933 vs. $1105), compared to LIHR.[7] Another study comparing 69 RIHRs to 241 LIHRs showed physician charges to be the same between both groups ($2663 vs. $2239), but RIHR had a higher hospital cost ($7162 vs. $4527) and total hospital charge ($27,017 vs. $16,016) compared to LIHR.[13] Similarly, a study in a dedicated minimally-invasive surgery center, comparing 45 RIHRs to 138 LIHRs, showed an increased total hospital cost ($9994 vs. $5995), mesh cost ($468 vs. $330), and other supplies cost ($679 vs. $454); but a lower access instruments cost ($190 vs. $269) in RIHR compared to LIHR, with a similar total cost of disposable supplies ($1588 vs. $1380).[8] All the above studies compare summative robotic and laparoscopic IHR cost; however, none compare either the early or late robotic experience to the laparoscopic approach. One small study of a single surgeon's experience with 39 R-TAPP and 24 laparoscopic TAPP cases showed equivalent average direct costs of $3479 in RIHR compared to $3216 in LIHR.[5] Our operative cost analysis included direct cost: mesh cost, variable cost (reusables and disposables), and access instruments cost. Based on our results, direct operative cost of RIHR is reduced as experience increases over time. This is likely due to the consistency and stability of instrumentation use that surgeons develop across their learning curve with experience over time.

This current study also found that postoperative complications decreased with increasing RIHR experience; from 25/167 patients (15%) in the early experience to 23/262 patients (8.8%) in the late experience. The most prevalent complication was urinary retention requiring catheterization in 23 patients (5.4%). Prior studies have reported urinary retention rates after RIHR within the range of 3.3% to 10.2% with some reportable similarity to LIHR.[8,9,15,17,18] The second most prevalent complication was chronic pain in 11 patients (2.6%). Prior studies have reported 2.4 to 14.1% rates of inguinodynia after RIHR with some reportable similarity to LIHR.[9,17] However, a recent study showed higher postoperative complications in RIHR compared to LIHR; with Clavien-Dindo Grade I-II in 10/45 patients (22.2%) and Clavien-Dindo Grade III-IV in 3/45 patients (6.7%) in the robotic approach compared to Clavien-Dindo Grade I-II in 25/138 patients (18.1%) and Clavien-Dindo Grade III-IV in 0/138 patients in the laparoscopic approach.[8] In that study, it is important to note that patients in the RIHR group had a higher rate of chronic kidney disease and obstructive sleep apnea pre-operatively. In addition, one of four surgeons performed all robotic cases while all four surgeons performed the laparoscopic cases. The same study also reported a higher 30-day readmission rate in the RIHR compared to LIHR group; 3/45 patients (6.7%) vs. 1/138 patients (0.7%), respectively.[8] In our current study, only 9 of 429 patients (2.1%) who underwent RIHR required readmission within 30 days post-operatively; with no difference between the early and late experience of RIHR. Another study, comparing 1100 open IHRs to 128 LIHRs and 71 RIHRs, reported higher postoperative complications in the minimally invasive approaches compared to the open approach, with recurrence in 4/71 patients (5.6%) who underwent RIHR.[17] In this current study, we report a recurrence in 2 of 429 patients (0.5%) who underwent RIHR. In total, our study shows reduced postoperative complications with increasing RIHR experience, with low recurrence rates, and similar and low 30-day readmission rates in the early and late RIHR experience. This further reflects improved surgeons comfort level and outcomes with the robotic approach over time.

Overall, this current study supports the notion that intra-operative time, direct operative cost, and postoperative complication rates decrease with increasing surgeon's RIHR experience across the learning curve. Such findings question whether it is necessary to incorporate RIHR as part of the curriculum of general surgery residency. A large study showed an increase in the number of robotic inguinal and ventral hernia repairs, with a correlated increase in resident involvement and noted differences in participation of post-graduate year (PGY) level.[19] Previous studies showed no difference between operative time and postoperative complication rates between RIHR cases with and without resident involvement.[9,20] However, a recent R-TAPP study of 27 residents at PGY levels 2 – 4 and two attending surgeons reported a longer average operative time for residents (53.0 min vs. 30.8 min; p = 0.01) compared to attending surgeons.[18] The same study showed that residents who selfreportedly completed ≤ 10 cases had lower mean robotic-skill assessment scores, while those who completed ≥ 30 cases had higher mean scores. This shows improved autonomy to residents as their extent of involvement increases overtime, which can be reflective of the increased attending surgeon's comfort level with RIHR as they reach their own learning curve. Our current study shows an increased resident involvement in the late compared to early RIHR experience; despite having lower intra-operative time, direct operative cost, and postoperative complications in the late experience. We believe this reflects advances in surgeons' efficiency as their RIHR experience develops.

Although this is the largest scale RIHR experience in a single healthcare system to date, there are limitations to the study including its retrospective nature. There is also operative heterogeneity given the involvement of 10 surgeons in two centers utilizing both Xi and Si DaVinci robot. Furthermore, surgeons were variable based on their years in practice and previous laparoscopic hernia repair experience. Of note, the extent of resident involvement (bedside or console participation) could not be accurately and consistently measured for the purpose of this study. However, the teaching opportunity is more evident in the late experience based on the increased number of involved residents in the cases.

CONCLUSION

Surgeons show higher efficiency and improved postoperative outcomes after gaining experience in RIHR. After a 20-case learning experience, surgeons can decrease their average operative time by 17.6 min and their average direct case cost by $538.17. Although previous studies show increased operative cost and time in the robotic compared to the laparoscopic approach to IHR, based on the above findings, this likely changes over time as surgeons gain more experience with the robotic approach and reach their learning curve. Future studies should focus on assessment of the RIHR learning curve with operative time, cost, and outcomes. Larger scale studies are needed to analyze such outcomes, comparing early and late experience of RIHR to LIHR. It is also not known whether surgeons' previous laparoscopic training affects their RIHR learning curve.

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