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ORIGINAL ARTICLE

Surgeons transitioning from laparoscopic to robotic-assisted inguinal hernia repair: a prospective analysis of efficiency

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Abstract

Background Available reports of surgeon efficiency when transitioning from laparoscopic to robotic-assisted (RA) inguinal hernia repair (IHR) are retrospective or describe single-center experience. The purpose of this study is to provide a prospective, multi-surgeon, multi-center assessment of surgeon efficiency when transitioning from Lap-IHR to RA-IHR.

Methods General surgeons with Lap-IHR experience (≥300 Lap-IHRs prior to the study) but with no robotic experience (no RA cases one year prior to the study) consented to participate in this prospective, observational pilot study of their surgical efficiency as they adopted RA-IHR. Efficiency was measured through procedure durations, including skin-to-skin time and time to establish critical view of the myopectineal orifice (MPO). Rates of conversions, and adverse events (AEs) through 30 days post RA-IHR procedure were also reported. Outcomes with 95% confidence intervals (95% CI) describe surgeons' collective and individual unilateral and bilateral early, middle, and late-phase cases, with each surgeon contributing 25 consecutive cases at each phase.

Results Four surgeons consented to enroll in the study and provided 75 consecutive, prospective RA-IHR cases. Collectively, the surgeons reached relative skin-to-skin time efficiencies for their unilateral repairs in the mid-phase of their prospective cases. For RA-IHR bilateral procedures, skin-to-skin time efficiency was reached in the late-phase cases. Surgeons' skin-to-skin efficiency times varied relative to their retrospective Lap-IHRs. Possible confounders included practice patterns, referrals, proctoring periods, and—for one surgeon—Covid interruptions. One conversion from RA-IHR to open resulted from severe adhesions present after prior prostatectomy. AEs varied broadly from surgeon to surgeon.

Conclusions The four surgeons improved their skin-to-skin efficiencies

Keywords Hernia · Robotic · Inguinal · Learnin Curve

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Introduction

Inguinal hernia repair (IHR) is one of the most frequently performed operations in General Surgery in the United States (US) [1, 2]. On review of 3547 patients in the US, Pokala et al. found that those who had robotic inguinal hernia repair (RIHR) suffered fewer complications (0.67%) than those who underwent laparoscopic (4.44%) or open IHR (3.85%, $P < 0.001$) [3]. An increasing number of publications describe the learning curve for RIHR; however, these studies offer only a retrospective review or single-surgeon experience [4, 5]. Despite these data, some surgeons may hesitate to adopt a robotic approach to IHR due to the perceived duration of the learning curve or potential for compromised patient outcomes.

Most often, the primary endpoint in studies aimed at defining a learning curve for an operation is Operative time with secondary endpoints of conversion, complication, and/or recurrence of disease [6]. Operative time is broadly measured as the time of incision to time of wound closure or from time the patient enters the operating room to time the patient exits the operating room. Unfortunately, these disparate definitions make data analysis and interpretation of learning curves quite difficult. The value of more discrete and granular reporting of surgical (skin-to-skin) time seems apparent and allows for the capture of operation-specific metrics including robotic docking and console time as well as periods defining dissection to the critical view of the myopectineal orifice and mesh placement. Muysoms et al. reported a granular evaluation of operative time composed of seven procedure blocks, but the data were limited to one expert laparoscopic surgeon [5].

The primary objective of the current study is evaluation of intraoperative efficiency progression by experienced laparoscopic general surgeons during their initial RA-IHR experience.

Participants and methods

Participants in this prospective, post-market, observational study were the general surgeon subjects, who were experienced in Lap-IHR and who were transitioning to RA-IHR surgery. Eligible surgeons were certified in General Surgery by the America Board of Surgery, signed informed consent, performed Lap-IHR for at least three consecutive years prior to the study with at least 300 Lap-IHRs overall, and performed at least 60 Lap-IHRs in the two years preceding the study. The enrolled surgeons either had no experience with RA surgery or did not assist in any RA cases prior to the beginning of the study or had no RA surgery cases in the last year. They also completed online and cadaver training related to the robotic surgical system prior to enrollment. Surgeons were excluded if they did not have full access or privileges to use a robotic surgical system, violated study protocol, or failed to complete the study for other reasons. It was recommended that the surgeons only perform RA-IHR procedures during their first five RA cases. Following this period, the surgeon could progress to other types of RA procedures as desired.

The primary outcomes were efficiencies intended to describe progression through the following stages of the RA-IHR procedures: skin-to-skin time (time between first skin incision and last skin closure), time to establish the critical view of the myopectineal orifice (MPO) (time between the identification of the pubic tubercle and start of mesh fixation), and mesh fixation time (time between start and completion of mesh fixation). Granular reporting of time for docking of the robotic surgical system, time spent at the operating console, and total time the patient spent in the operating room served as potential discriminators of efficiency.

The study enrolled surgeon participants prior to their performing RA-IHR cases and following their training periods. Each surgeon was followed up to the completion of 75 RA-IHR cases. The surgeons performed RA-IHR per their standard practice, including peritoneal cavity access, trocar type and location, selected instrumentation, mesh type and fixation strategy, and suture choice.

During each procedure, up to 21 intra-operative time points were prospectively collected on the paper case report form. Post-operative information for procedure-related adverse events, readmissions, and reoperations were also collected through the first standard of care post-operative visit (within 30 days post-discharge) as available. In addition, retrospective data were collected from the medical record of each surgeon's previous 50 laparoscopic IHR cases. All collected data were entered into Medrio Electronic Data Capture System (Medrio Inc., San Francisco, CA).

The study received Institutional Review Board approval from the institutional sites, and all procedures performed in the study involving human participants were in accordance with the ethical standards of each institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

The primary endpoint (skin-to-skin time) as well as time to establish the critical view of the MPO, and duration of mesh fixation were analyzed for each RA-IHR during individual surgeons' early (cases 1–25), middle (cases 26–50), and late (cases 51–75) phase learning curve. The characteristics of the surgeons and 30-day outcomes were described using absolute frequencies (%) for categorical variables and mean and standard deviation with 95% confidence intervals

(95% CI) for continuous variables. Due to the pilot study design and small sample size of four surgeons, a power analysis was not performed.

Results

Four surgeons (A, B, C, D) from four different hospitals in the United States met inclusion criteria and completed the study by submitting their first 75 RA-IHR operations for analysis. All participants practiced General Surgery for 11–20 years, were right-hand dominant, and participated in simulation-based robotic training (range 2 to 20 h) before required hands-on training. Outside the study, one participant (A) conducted 200 robotic operations while three participants (B, C, D) performed 3–23 robotic operations during the study period. Of the 300 RA-IHR operations, one RA-IHR required conversion to an open approach secondary to patient disease and complex surgical history. This procedure was excluded from efficiency analysis, though reported for 30-day outcomes. Table 1 details the demographics and clinical experience of the surgeons. Patient demographics and preoperative characteristics are provided in Table 2. The study surgeons performed most RA-IHRs and Lap-IHRs within four different hospitals; 1.7% of RA-IHRs and 22% of Lap-IHR operations were performed at free-standing surgery centers.

Surgical efficiency metrics by approach for all surgeons are presented in Table 3 and surgeons served as their own controls. All surgeons achieved skin-to-skin time efficiency for unilateral RIHR during the middle phase of the learning curve (cases 26–50). The average skin-to-skin time during the middle phase of the learning curve was 12 min longer for unilateral RA-IHR than historic Lap-IHR controls. Study surgeons achieved skin-to-skin efficiency for bilateral RA-IHRs during the late phase of the learning curve. Console time for bilateral RA-IHR improved by 7.5 min and operative time by 32 min on average over the course of the learning curve. However, time for docking of the robotic surgical system, time spent at the operating console, and total time the patient spent in the operating room showed no statistical difference across phases of the learning curve. Surgeons achieved efficiency for the secondary endpoint of time to critical view of the MPO during the late phase (cases 51–75). Although the surgeons did not achieve efficiency for duration of mesh fixation, a positive trend was noted between the three phases of the learning curve.

Efficiency metrics are reported by surgeon in Tables 4, 5, 6, 7 and Figs. 1, 2, 3, 4. Surgeon A (Table 4 and Fig. 1), achieved skin-to-skin time efficiency during the middle phase of the learning curve for unilateral RA-IHR evidenced by a 20% reduction in operative time compared to the early phase. Despite the efficiency achieved in unilateral RA-IHR, statistical improvement in skin-to-skin time for bilateral RA-IHR was not achieved during the study period. Time to MPO and mesh fixation times did not differ between phases. Skin-to-skin times of early bilateral RA-IHRs were similar to those of the retrospective bilateral Lap-IHR phase. None of the phased bilateral RA-IHR operating room times decreased over the three prospective phases.

Surgeon B (Table 5 and Fig. 2) showed shorter skin-to-skin time and shorter time to critical view of the MPO during the middle phase of the learning curve for unilateral RIHR—a trend that continued during the late phase. During the late phase of the learning curve, Surgeon B exhibited an average RA-IHR skin-to-skin time that was statistically similar to the average operative time of historic Lap-IHR controls. Secondary endpoints and granular operative characteristics showed a trend toward improvement during all phases of the learning curve for both unilateral and bilateral RA-IHR.

Surgeon C (Table 6 and Fig. 3) showed shorter operative time during the late phase of the learning curve and quicker mesh fixation during the middle phase of the learning curve

Table 1 Surgeon demographics and experience

	Surgeon A (JEJ)	Surgeon B (RRM)	Surgeon C (BHM)	Surgeon D (SSC)
Age group, y	45–49	45–49	60–64	50–54
Sex	Male	Male	Male	Male
Ethnicity	Hispanic or Latino	Not Hispanic or Latino	Hispanic or Latino	Not Hispanic or Latino
Handedness	Right	Right	Right	Right
Surgical specialty type	General	General	General	General
Fellowship type	General	Minimally invasive surgery	General	General
Total years in surgical practice	11–20 years	11–20 years	> 30 years	21–30 years
Number of simulation hours completed prior to in-person training	8	12	2	20
Number of other robotic cases performed during study period	197	3	13	23

Table 2 Patient demographics and preoperative characteristics by surgeon

	Results				
	Surgeon A (JEJ) (N = 125)				
	Retrospective Lap-IHR phase (N = 50)	Early prospective RA-IHR phase (n = 25)	Mid prospective RA-IHR phase (n = 25)	Late prospective RA-IHR phase (n = 25)	All prospective RA-IHR cases (N = 75)
Age, y (mean ± SD)	67.8 ± 11.9	67.8 ± 14.5	65.4 ± 14.2	63.9 ± 13.2	65.7 ± 13.9
Sex, n (%)					
Male	47 (94.0)	21 (84.0)	21 (84.0)	24 (96.0)	66 (88.0)
Female	3 (6.0)	4 (16.0)	4 (16.0)	1 (4.0)	9 (12.0)
BMI, kg/m^2 (mean ± SD)	26.4 ± 4.0	26.7 ± 4.3	26.5 ± 3.9	27.7 ± 5.2	27.0 ± 4.5
ASA Class, n (%)					
I	2 (4.0)	0 (0.0)	5 (20.0)	1 (4.0)	6 (8.0)
II	23 (46.0)	12 (48.0)	11 (44.0)	13 (52.0)	36 (48.0)
III	23 (46.0)	11 (44.0)	7 (28.0)	11 (44.0)	29 (38.7)
IV	2 (4.0)	2 (8.0)	2 (8.0)	0 (0.0)	4 (5.3)
Previous abdomino-pelvic surgery, n (%)	n/a	5 (20.0)	11 (44.0)	5 (20.0)	21 (28.0)
Location of care, n (%)					
Hospital	39 (78.0)	25 (100.0)	25 (100.0)	25 (100.0)	75 (100.0)
Surgery center	11 (22.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
	Surgeon B (RRM)				
	Retrospective Lap-IHR phase (N = 49)	Early prospective RA-IHR phase (n = 24)	Mid prospective RA-IHR phase (n = 25)	Late prospective RA-IHR phase (n = 25)	All prospective RA-IHR cases (N = 74)
Age, y (mean ± SD)	53.9 ± 13.0	63.5 ± 13.4	60.5 ± 18.4	60.1 ± 16.6	61.3 ± 16.15
Sex, n (%)					
Male	44 (89.8)	22 (91.7)	25 (100.0)	24 (96.0)	71 (95.9)
Female	5 (10.2)	2 (8.3)	0 (0.0)	1 (4.0)	3 (4.1)
BMI, kg/m^2 (mean ± SD)	27.2 ± 5.1	27.0 ± 4.9	27.4 ± 4.8	26.1 ± 3.9	26.8 ± 4.5
ASA Class, n (%)					
I	9 (18.4)	1 (4.2)	1 (4.0)	1 (4.0)	3 (4.1)
II	26 (53.1)	13 (54.2)	17 (68.0)	14 (56.0)	44 (59.5)
III	13 (26.5)	10 (41.7)	7 (28.0)	10 (40.0)	27 (36.5)
IV	1 (2.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Previous abdomino-pelvic surgery, n (%)	n/a	11 (45.8)	8 (32.0)	16 (64.0)	35 (47.3)
Location of care, n (%)					
Hospital	25 (51.0)	23 (95.8)	25 (100.0)	25 (100.0)	73 (98.6)
Surgery center	24 (49.0)	1 (4.2)	0 (0.0)	0 (0.0)	1 (1.4)
	Surgeon C (BHM)				
	Retrospective Lap-IHR phase (N = 50)	Early prospective RA-IHR phase (n = 25)	Mid prospective RA-IHR phase (n = 25)	Late prospective RA-IHR phase (n = 25)	All prospective RA-IHR cases (N = 75)
Age, y (mean ± SD)	56.6 ± 10.9	53.6 ± 17.5	57.4 ± 16.0	57.0 ± 14.35	56.0 ± 15.9
Sex, n (%)					
Male	47 (94.0)	17 (68.0)	21 (84.0)	21 (84.0)	59 (78.7)
Female	3 (6.0)	8 (32.0)	4 (16.0)	4 (16.0)	16 (21.3)
BMI, kg/m^2 (mean ± SD)	28.6 ± 3.8	29.3 ± 4.4	27.6 ± 4.2	28.2 ± 4.95	28.4 ± 4.5
ASA Class, n (%)					
I	5 (10.0)	3 (12.0)	4 (16.0)	3 (18.8)	10 (13.3)

Table 2 (continued)

	Results				
II	39 (78.0)	19 (76.0)	13 (52.0)	21 (84.0)	53 (70.7)
III	6 (12.0)	3 (12.0)	8 (32.0)	1 (6.3)	12 (16.0)
IV	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Previous abdomino-pelvic surgery, n (%)	n/a	12 (48.0)	14 (56.0)	14 (56.0)	40 (53.3)
Location of care, n (%)					
Hospital	46 (92.0)	25 (100.0)	25 (100.0)	25 (100.0)	75 (100.0)
Surgery center	4 (8.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
	Surgeon D (SSC) (n = 125)				
	Retrospective Lap-IHR phase (N = 50)	Early prospective RA-IHR phase (n = 25)	Mid prospective RA-IHR phase (n = 25)	Late prospective RA-IHR phase (n = 25)	All prospective RA-IHR cases (N = 75)
Age, y (mean ± SD)	64.9 ± 13.3	61.0 ± 11.9	57.9 ± 14.35	60.1 ± 12.9	59.7 ± 13.0
Sex, n (%)					
Male	47 (94.0)	22 (88.0)	25 (100.0)	24 (96.0)	71 (94.7)
Female	3 (6.0)	3 (12.0)	0 (0.0)	1 (4.0)	4 (5.3)
BMI, kg/m^2 (mean ± SD)	26.6 ± 4.4	25.8 ± 4.0	27.7 ± 3.7	26.6 ± 4.0	26.7 ± 3.95
ASA Class, n (%)					
I	2 (4.0)	1 (4.0)	2 (8.0)	0 (0.0)	3 (4.0)
II	25 (50.0)	20 (80.0)	14 (56.0)	18 (72.0)	52 (69.3)
III	23 (46.0)	4 (16.0)	9 (36.0)	6 (24.0)	19 (25.3)
IV	0 (0.0)	0 (0.0)	0 (0.0)	1 (4.0)	1 (1.3)
Previous abdomino-pelvic surgery, n (%)	n/a	18 (72.0)	15 (60.0)	11 (44.0)	44 (58.7)
Location of care, n (%)					
Hospital	50 (100.0)	23 (92.0)	25 (100.0)	24 (96.0)	72 (96.0)
Surgery center	0 (0.0)	2 (8.0)	0 (0.0)	1 (4.0)	3 (4.0)

Lap-IHR laparoscopic inguinal hernia repair, *RA-IHR* robotic assisted inguinal hernia repair, *SD* standard deviation of the mean, *BMI* body mass index, *ASA* American Society of Anesthesiologists, *n/a* not available

for unilateral RA-IHR. Of note, Surgeon C decreased average late-phase skin-to-skin time by 58 min compared to historic Lap-IHR controls. Bilateral RA-IHR endpoints and granular metrics failed to show a trend or statistical difference during any phase of the learning curve.

Surgeon D (Table 7 and Fig. 4) demonstrated skin-to-skin time efficiency during the middle phase but increased skin-to-skin time during the late phase. Surgeon D showed shorter duration of mesh fixation during the middle phase of the learning curve for unilateral RA-IHR. Secondary endpoints and granular operative characteristics failed to show a trend toward improvement during all phases of the learning curve for unilateral RA-IHR. Although not statistically significant, mean skin-to-skin time decreased by 42 min from early to late phase for bilateral RA-IHR.

Adverse event rates for each surgeon over the course of the study are listed in Table 8. Surgeon A was noteworthy for a low rate of adverse events. Several groin swelling or bruising events were reported but did not require intervention and could be considered sequelae by some of the surgeons. Without the inclusion of bruising and swelling, the rates greatly decreased for all surgeons.

Discussion

More than 20 million patients worldwide undergo groin hernia repair annually with growing adoption of minimally invasive (laparoscopic and RA) approaches [7]. However, as indicated by the vast number of IHR publications, hernia repair techniques vary considerably, and open mesh repair is still the most frequently used approach [7]. The technical difficulty associated with laparoscopic repair may limit its adoption, as the learning curve has been reported to range from 50 to 250 cases [8]. In the current study, we evaluated the efficiencies of four surgeons experienced in Lap-IHR and who transitioned their practices from Lap-IHR to RA-IHR.

Table 3 Intraoperative characteristics and efficiencies for unilateral and bilateral repairs for all surgeons

	Results				
	Unilateral repairs (N = 314)				
	Retrospective Lap-IHR phase (N = 102)	early prospective RA-IHR phase (n = 72)	Mid prospective RA-IHR phase (n = 65)	Late prospective RA-IHR phase (n = 75)	All prospective RA-IHR cases (N = 212)
Skin-to-skin time, min					
Mean ± SD	52.2 ± 30.8	78.5 ± 29.0	64.5 ± 26.8	67.7 ± 31.75	70.4 ± 29.8
95% CI	46.2, 58.3	71.7, 85.3	57.8, 71.1	60.4, 75.0	66.3, 74.4
Time to MPO, min					
Mean ± SD	n/a	19.9 ± 12.1	16.3 ± 11.1	16.0 ± 10.8	17.4 ± 11.4
95% CI	n/a	17.0, 22.7	13.6, 19.0	13.5, 18.5	15.9, 18.9
Mesh fixation time, min					
Mean ± SD	n/a	7.1 ± 5.4	6.1 ± 3.85	5.3 ± 3.65	6.2 ± 4.42
95% CI	n/a	5.8, 8.4	5.2, 7.1	4.5, 6.1	5.6, 6.8
Console time, min					
Mean ± SD	n/a	50.1 ± 23.1	41.0 ± 21.0	42.6 ± 28.4	44.7 ± 24.75
95% CI	n/a	44.6, 55.6	35.8, 46.2	36.0, 49.2	41.3, 48.0
Docking time, min					
Mean ± SD	n/a	5.8 ± 5.8	3.8 ± 3.3	3.9 ± 3.2	4.5 ± 4.4
95% CI	n/a	4.4, 7.2	2.9, 4.6	3.2, 4.7	3.9, 5.1
Operating room time, min					
Mean ± SD	93.1 ± 32.5	123.7 ± 32.6	109.0 ± 29.9	111.4 ± 33.3	114.8 ± 32.5
95% CI	86.7, 99.5	116.0, 131.3	101.5, 116.4	103.8, 119.1	110.4, 119.2
	Bilateral repairs (N = 184)				
	Retrospective lap-IHR phase (N = 97)	Early prospective RA-IHR phase (n = 27)	Mid prospective RA-IHR phase (n = 35)	Late prospective RA-IHR phase (n = 25)	All prospective RA-IHR cases (N = 87)
Skin-to-skin time, min					
Mean ± SD	59.5 ± 30.8	112.4 ± 38.3	92.8 ± 35.5	80.6 ± 28.35	95.4 ± 36.4
95% CI	53.2, 65.7	97.2, 127.5	80.6, 105.0	68.9, 92.3	87.6, 103.1
Time to MPO, min					
Mean ± SD	n/a	50.5 ± 23.6	36.7 ± 12.3	33.0 ± 12.4	39.9 ± 18.0
95% CI	n/a	41.2, 59.9	32.5, 40.9	27.9, 38.1	36.1, 43.8
Mesh fixation time, min					
Mean ± SD	n/a	11.7 ± 11.3	9.2 ± 8.0	8.8 ± 6.6	9.9 ± 8.8
95% CI	n/a	7.2, 16.2	6.4, 11.9	6.1, 11.6	8.0, 11.7
Console time, min					
Mean ± SD		76.6 ± 33.5	64.4 ± 30.7	56.2 ± 20.4	65.8 ± 29.9
95% CI	n/a	63.3, 89.8	53.8, 74.9	47.8, 64.7	59.5, 72.2
Docking time, min					
Mean ± SD	n/a	6.0 ± 4.4	3.9 ± 4.3	3.4 ± 2.6	4.4 ± 4.0
95% CI	n/a	4.2, 7.7	2.5, 5.4	2.3, 4.4	3.5, 5.3
Operating room time, min					
Mean ± SD	103.2 ± 30.9	156.5 ± 40.8	140.1 ± 38.0	125.4 ± 28.3	141.0 ± 38.0
95% CI	97.0, 109.5	140.4, 172.6	127.1, 153.2	113.7, 137.0	132.9, 149.1

Lap-IHR laparoscopic inguinal hernia repair, *RA-IHR* robotic assisted inguinal hernia repair, *SD* standard deviation of the mean, *MPO* myopectineal orifice, *CI* confidence interval, *n/a* not available

Table 4 Intraoperative characteristics and efficiencies: surgeon A

	Results				
	Unilateral repairs (N = 88)				
	Retrospective Lap-IHR phase (N = 31)	Early prospective RA-IHR phase (n = 22)	Mid prospective RA-IHR phase (n = 17)	Late prospective RA-IHR phase (n = 18)	All prospective RA-IHR cases (N = 57)
Skin-to-skin time, min					
Mean ± SD	28.4 ± 10.4	51.2 ± 17.8	41.4 ± 16.1	44.3 ± 12.5	46.1 ± 16.1
95% CI	24.6, 32.2	43.3, 59.1	33.1, 49.6	38.1, 50.5	41.8, 50.4
Time to MPO, min					
Mean ± SD	n/a	19.7 ± 15.0	14.5 ± 11.95	13.8 ± 7.6	16.3 ± 12.25
95% CI	n/a	13.1, 26.4	8.3, 20.6	10.0, 17.6	13.0, 19.5
Mesh fixation time, min					
Mean ± SD	n/a	2.3 ± 1.4	3.8 ± 3.4	2.5 ± 0.9	2.8 ± 2.2
95% CI	n/a	1.7, 2.9	2.0, 5.5	2.0, 3.0	2.2, 3.4
Console time, min					
Mean ± SD	n/a	33.5 ± 14.9	27.3 ± 15.7	26.4 ± 10.4	29.4 ± 14.0
95% CI	n/a	26.9, 40.2	19.2, 35.4	21.3, 31.6	25.7, 33.2
Docking time, min					
Mean ± SD	n/a	2.5 ± 0.6	1.6 ± 0.7	1.4 ± 0.5	1.9 ± 0.8
95% CI	n/a	2.3, 2.8	1.2, 2.0	1.1, 1.6	1.7, 2.1
Operating room time, min					
Mean ± SD	69.1 ± 13.6	94.5 ± 23.3	83.6 ± 21.8	91.8 ± 18.3	90.4 ± 21.5
95% CI	64.1, 74.1	84.2, 104.9	72.4, 94.8	82.7, 100.9	84.7, 96.1
	Bilateral Repairs (N = 37)				
	Retrospective Lap-IHR phase (N = 19)	Early prospective RA-IHR phase (n = 3)	Mid prospective RA-IHR phase (n = 8)	Late prospective RA-IHR phase (n = 7)	All prospective RA-IHR cases (N = 18)
Skin-to-skin time, min					
Mean ± SD	29.7 ± 5.6	56.0 ± 12.3	56.4 ± 12.9	57.6 ± 10.7	56.8 ± 11.3
95% CI	27.1, 32.4	25.5, 86.5	45.6, 67.1	47.7, 67.5	51.2, 62.4
Time to MPO, min					
Mean ± SD	n/a	31.7 ± 3.1	27.8 ± 6.8	34.7 ± 10.6	31.1 ± 8.4
95% CI	n/a	24.1, 39.3	22.1, 33.4	24.9, 44.5	26.9, 35.3
Mesh fixation time, min					
Mean ± SD	n/a	31.7 ± 3.1	27.8 ± 6.8	34.7 ± 10.6	31.1 ± 8.4
95% CI	n/a	24.1, 39.3	22.1, 33.4	24.9, 44.5	26.9, 35.3
Console time, min					
Mean ± SD	n/a	38.7 ± 8.1	37.4 ± 9.2	39.4 ± 9.2	38.4 ± 8.55
95% CI	n/a	18.6, 58.7	29.7, 45.0	30.9, 47.9	34.1, 42.6
Docking time, min					
Mean ± SD	n/a	4.0 ± 2.0	2.1 ± 1.4	1.6 ± 0.5	2.2 ± 1.4
95% CI	n/a	− 1.0, 9.0	1.0, 3.3	1.1, 2.1	1.5, 2.9
Operative room time, min					
Mean ± SD	75.1 ± 11.6	91.3 ± 17.6	100.3 ± 19.8	111.1 ± 12.9	103.0 ± 17.7
95% CI	69.5, 80.7	47.6, 135.1	83.7, 116.8	99.2, 123.1	94.2, 111.8

Lap-IHR laparoscopic inguinal hernia repair, *RA-IHR* robotic-assisted inguinal hernia repair, *SD* standard deviation of the mean, *MPO* myopectineal orifice, *CI* confidence interval, *n/a* not available

[a]Missing value (n = 1)

Table 5 Intraoperative characteristics and efficiencies: surgeon B

	Results				
	Unilateral repairs (N = 90)				
	Retrospective Lap-IHR phase (N = 35)	early prospective RA-IHR phase (n = 18)	Mid prospective RA-IHR phase (n = 18)	Late prospective RA-IHR phase (n = 19)	All prospective RA-IHR cases (N = 55)
Skin-to-skin time, min					
Mean ± SD	72.9 ± 31.1	103.1 ± 23.4	74.2 ± 18.7	77.3 ± 17.6	84.7 ± 23.55
95% CI	62.2, 83.6	91.4, 114.7	64.9, 83.5	68.8, 85.7	78.3, 91.1
Time to MPO, min					
Mean ± SD	n/a	19.6 ± 10.8	12.4 ± 8.2	10.9 ± 4.9	14.2 ± 9.0
95% CI	n/a	14.2, 24.9	8.3, 16.5	8.5, 13.3	11.8, 16.6
Mesh fixation time, min					
Mean ± SD	n/a	8.9 ± 2.7	8.3 ± 3.3	8.1 ± 4.0	8.4 ± 3.4
95% CI	n/a	7.6, 10.3	6.7, 10.0	6.1, 10.0	7.5, 9.3
Console time, min					
Mean ± SD	n/a	62.8 ± 21.2	44.7 ± 14.5	41.7 ± 13.8	49.7 ± 19.0
95% CI	n/a	52.2, 73.3	37.4, 51.9	34.8, 48.6	44.5, 54.9
Docking time, min					
Mean ± SD	n/a	5.8 ± 5.25	3.8 ± 3.8	4.9 ± 3.4	4.8 ± 4.2
95% CI	n/a	3.2, 8.4	1.9, 5.7	3.2, 6.5	3.7, 6.0
Operating room time, min					
Mean ± SD	109.5 ± 33.85	152.1 ± 26.6	118.5 ± 20.1	118.5 ± 21.5	129.5 ± 27.5
95% CI	97.9, 121.1	138.8, 165.3	108.5, 128.5	108.1, 128.9	122.0, 136.9
	Bilateral repairs (N = 33)				
	Retrospective lap-IHR phase (N = 14)	Early prospective RA-IHR phase (n = 6)	Mid prospective RA-IHR phase (n = 7)	Late prospective RA-IHR phase (n = 6)	All prospective RA-IHR cases (N = 19)
Skin-to-skin time, min					
Mean ± SD	116.0 ± 31.3	142.0 ± 43.3	112.4 ± 23.6	112.5 ± 33.6	121.8 ± 34.9
95% CI	98.0, 134.0	96.6, 187.4	90.6, 134.2	77.2, 147.8	105.0, 138.6
Time to MPO, min					
Mean ± SD	n/a	64.0 ± 13.6	50.3 ± 12.7	40.5 ± 15.5	51.5 ± 16.25
95% CI	n/a	49.8, 78.2	38.6, 62.0	24.2, 56.8	43.7, 59.4
Mesh fixation time, min					
Mean ± SD	n/a	22.8 ± 16.4	18.0 ± 11.7	14.8 ± 7.0	18.5 ± 12.0
95% CI	n/a	5.6, 40.0	7.2, 28.8	7.5, 22.2	12.7, 24.3
Console time, min					
Mean ± SD	n/a	102.8 ± 39.4	77.1 ± 21.0	73.5 ± 20.2	84.1 ± 29.4
95% CI	n/a	61.5, 144.2	57.7, 96.6	52.3, 94.7	69.9, 98.3
Docking time, min					
Mean ± SD	n/a	4.2 ± 3.25	5.9 ± 8.5	2.3 ± 0.8	4.2 ± 5.4
95% CI	n/a	0.8, 7.6	−2.0, 13.7	1.5, 3.2	1.6, 6.8
Operative room time, min					
Mean ± SD	157.7 ± 34.3	183.0 ± 44.5	160.4 ± 25.0	154.5 ± 33.0	165.7 ± 34.8
95% CI	137.9, 177.5	136.3, 229.7	137.3, 183.5	119.9, 189.1	148.9, 182.5

Lap-IHR laparoscopic inguinal hernia repair, *RA-IHR* robotic-assisted inguinal hernia repair, *SD* standard deviation of the mean, *MPO* myopectineal orifice, *CI* confidence interval, *n/a* not available

[a]Missing value (n = 1)

Table 6 Intraoperative characteristics and efficiencies: surgeon C

	Results				
	Unilateral repairs (N = 42)				
	Retrospective lap-IHR phase (N = 3)	Early prospective RA-IHR phase (n = 11)	Mid prospective RA-IHR phase (n = 11)	Late prospective RA-IHR phase (n = 17)	All prospective RA-IHR cases (N = 39)
Skin-to-skin time, min					
Mean ± SD	106.7 ± 59.2	66.0 ± 17.2	52.2 ± 23.5	48.5 ± 11.6	54.5 ± 18.3
95% CI	−40.4, 253.8	54.5, 77.5	36.4, 68.0	42.5, 54.4	48.5, 60.4
Time to MPO, min					
Mean ± SD	n/a	13.3 ± 11.5	12.7 ± 11.4	8.9 ± 3.8	11.2 ± 8.9
95% CI	n/a	5.6, 21.0	5.1, 20.4	7.0, 10.8	8.3, 14.1
Mesh fixation time, min					
Mean ± SD	n/a	3.7 ± 1.85	2.3 ± 1.4	2.5 ± 1.3	2.8 ± 1.6
95% CI	n/a	2.5, 5.0	1.3, 3.2	1.8, 3.1	2.3, 3.3
Console time, min					
Mean ± SD	n/a	30.1 ± 7.2 [a]	29.5 ± 17.0	27.8 ± 9.7	28.9 ± 11.5 [a]
95% CI	n/a	24.9, 35.3 [a]	18.0, 40.9	22.9, 32.8	25.1, 32.7 [a]
Docking time, min					
Mean ± SD	n/a	8.6 ± 11.6 [a]	2.7 ± 1.95	2.9 ± 2.9	4.3 ± 6.6 [a]
95% CI	n/a	0.3, 16.9 [a]	1.4, 4.0	1.4, 4.4	2.2, 6.5 [a]
Operating room time, min					
Mean ± SD	159.7 ± 60.5	110.0 ± 20.6	99.4 ± 27.0	91.1 ± 19.4	98.7 ± 22.95
95% CI	9.4, 309.9	96.1, 123.9	81.2, 117.5	81.1, 101.1	91.3, 106.2
	Bilateral repairs (N = 83)				
	Retrospective Lap-IHR phase (N = 47)	Early prospective RA-IHR phase (n = 14)	Mid prospective RA-IHR phase (n = 14)	Late prospective RA-IHR phase (n = 8)	All prospective RA-IHR cases (N = 36)
Skin-to-skin time, min					
Mean ± SD	52.8 ± 14.8	104.8 ± 22.6	91.5 ± 25.9	69.9 ± 13.45	91.9 ± 25.55
95% CI	48.5, 57.2	91.7, 117.8	76.5, 106.5	58.6, 81.1	83.2, 100.5
Time to MPO, min					
Mean ± SD	n/a	47.6 ± 25.9	35.9 ± 9.9	27.4 ± 11.9	38.6 ± 19.5
95% CI	n/a	32.7, 62.6	30.2, 41.7	17.4, 37.3	32.0, 45.2
Mesh fixation time, min					
Mean ± SD	n/a	6.4 ± 4.2	5.1 ± 1.6	7.1 ± 6.3	6.0 ± 4.0
95% CI	n/a	4.0, 8.8	4.1, 6.0	1.8, 12.4	4.7, 7.4
Console time, min					
Mean ± SD	n/a	63.1 ± 9.4	55.5 ± 19.5	48.4 ± 15.2	56.9 ± 15.9
95% CI	n/a	57.7, 68.5	44.3, 66.7	35.7, 61.1	51.5, 62.2
Docking time, min					
Mean ± SD	n/a	7.1 ± 5.4	3.3 ± 1.8	3.5 ± 2.7	4.8 ± 4.1
95% CI	n/a	4.0, 10.3	2.3, 4.3	1.3, 5.7	3.4, 6.2
Operative room time, min					
Mean ± SD	97.3 ± 15.2	152.6 ± 26.4	138.4 ± 31.9	107.3 ± 16.2	137.0 ± 31.4
95% CI	92.8, 101.7	137.4, 167.8	120.0, 156.8	93.7, 120.8	126.4, 147.6

Lap-IHR laparoscopic inguinal hernia repair, *RA-IHR* robotic-assisted inguinal hernia repair, *SD* standard deviation of the mean, *MPO* myopectineal orifice, *CI* confidence interval, *n/a* not available

[a]Missing value (n = 1)

Table 7 Intraoperative characteristics and efficiencies: surgeon D

	Results				
	Unilateral repairs (N = 94)				
	Retrospective lap-IHR phase (N = 33)	Early prospective RA-IHR phase (n = 21)	Mid prospective RA-IHR phase (n = 19)	Late prospective RA-IHR phase (n = 21)	All prospective RA-IHR cases (N = 61)
Skin-to-skin time, min					
Mean ± SD	47.7 ± 18.3	92.6 ± 19.6	83.0 ± 25.2	94.7 ± 39.3	90.3 ± 29.3
95% CI	41.2, 54.2	83.7, 101.5	70.9, 95.1	76.8, 112.6	82.8, 97.8
Time to MPO, min					
Mean ± SD	n/a	23.8 ± 8.8	23.7 ± 9.3	28.2 ± 10.85	25.3 ± 9.8
95% CI	n/a	19.8, 27.8	19.2, 28.2	23.3, 33.2	22.8, 27.8
Mesh fixation time, min					
Mean ± SD	n/a	12.3 ± 5.6	8.3 ± 2.5	7.5 ± 2.5	9.4 ± 4.35
95% CI	n/a	9.7, 14.8	7.1, 9.5	6.4, 8.7	8.3, 10.5
Console time, min					
Mean ± SD	n/a	66.2 ± 17.85	56.4 ± 21.7	69.2 ± 38.1	64.2 ± 27.6
95% CI	n/a	58.1, 74.3	46.0, 66.9	51.9, 86.6	57.1, 71.3
Docking time, min					
Mean ± SD	n/a	8.0 ± 3.6	6.3 ± 3.3	6.1 ± 2.9	6.8 ± 3.3
95% CI	n/a	6.3, 9.6	4.7, 7.9	4.8, 7.4	6.0, 7.7
Operating room time, min					
Mean ± SD	92.2 ± 21.1	137.0 ± 20.9	128.2 ± 28.7	138.4 ± 39.8	134.7 ± 30.7
95% CI	84.7, 99.6	127.5, 146.5	114.3, 142.0	120.3, 156.5	126.8, 142.6
	Bilateral repairs (N = 31)				
	Retrospective lap-IHR phase (N = 17)	Early prospective RA-IHR phase (n = 4)	Mid prospective RA-IHR phase (n = 6)	Late prospective RA-IHR phase (n = 4)	All prospective RA-IHR cases (N = 14)
Skin-to-skin time, min					
Mean ± SD	64.5 ± 15.5	136.8 ± 36.0	121.3 ± 48.0	94.8 ± 6.8	118.1 ± 38.4
95% CI	56.6, 72.5	79.5, 194.0	71.0, 171.7	83.9, 105.6	96.0, 140.3
Time to MPO, min					
Mean ± SD	n/a	54.5 ± 28.9	34.5 ± 10.9	30.0 ± 8.3	38.9 ± 19.0
95% CI	n/a	8.6, 100.4	23.1, 45.9	16.8, 43.2	27.9, 49.9
Mesh fixation time, min					
Mean ± SD	n/a	19.0 ± 9.35	15.0 ± 5.1	12.5 ± 2.4	15.4 ± 6.2
95% CI	n/a	4.1, 33.9	9.7, 20.3	8.7, 16.3	11.9, 19.0
Console time, min					
Mean ± SD	n/a	112.8 ± 36.0	106.2 ± 32.65	75.5 ± 5.7	99.3 ± 31.1
95% CI	n/a	55.4, 170.1	71.9, 140.4	66.4, 84.6	81.3, 117.3
Docking time, min					
Mean ± SD	n/a	6.0 ± 2.2	5.7 ± 3.4	7.8 ± 1.0	6.4 ± 2.6
95% CI	n/a	2.6, 9.4	2.1, 9.3	6.2, 9.3	4.9, 7.9
Operative room time, min					
Mean ± SD	106.4 ± 17.5	179.5 ± 38.1	173.7 ± 37.6	142.8 ± 13.5	166.5 ± 34.2
95% CI	97.3, 115.4	118.8, 240.2	134.2, 213.1	121.2, 164.3	146.8, 186.2

Lap-IHR laparoscopic inguinal hernia repair, *RA-IHR* robotic-assisted inguinal hernia repair, *SD* standard deviation of the mean, *MPO* myopectineal orifice, *CI* confidence interval, *n/a* not available

[a]Missing value (n = 1)

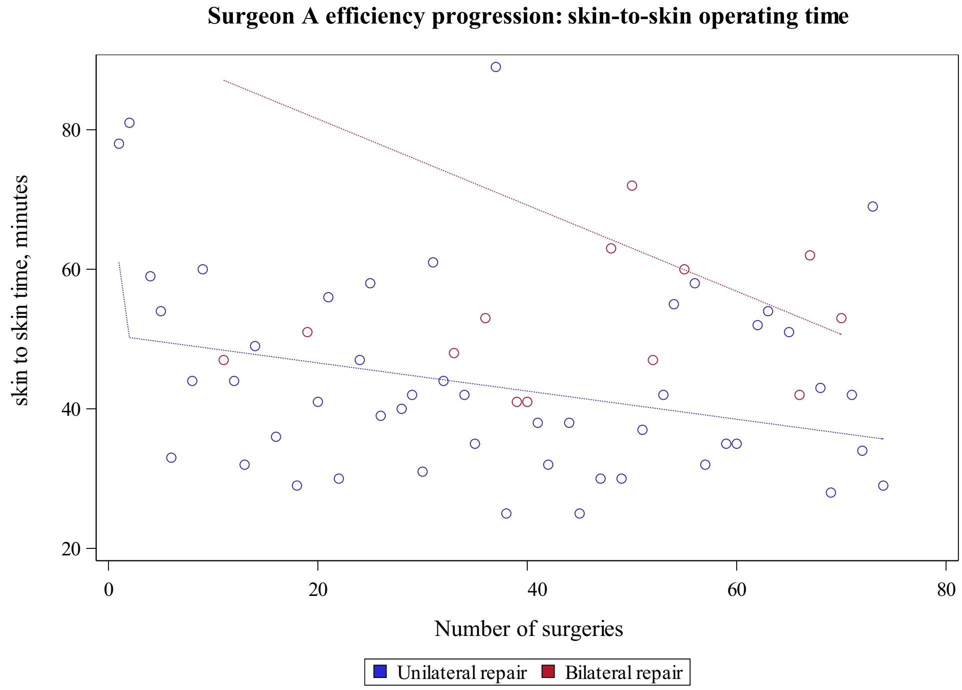

Fig. 1 Surgeon A efficiency progression: skin-to-skin operating time

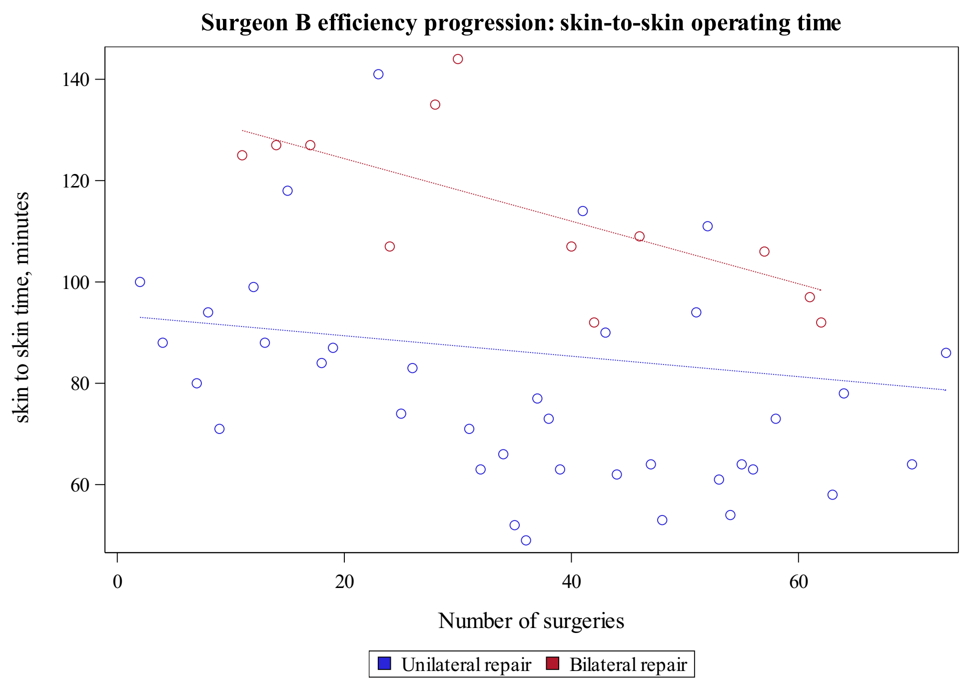

Fig. 2 Surgeon B efficiency progression: skin-to-skin operating time

The current multi-surgeon, multicenter analysis is first study of its kind to be presented.

Kudsi and colleagues performed retrospective analyses of RA-IHR learning curves. In one single-center, single-surgeon report, they evaluated operative times when transitioning from laparoscopic totally extraperitoneal (LapTEP) IHR (N = 157) to robotic-assisted transabdominal preperitoneal (rTAPP) IHR (N = 118) [4]. Mean surgical times for each group were nearly identical as were the intraoperative and postoperative complication rates, despite the significantly higher number of complex cases in the rTAPP group. In another retrospective analysis of rTAPP in 371 consecutive patients over 5 years, Kudsi et al. evaluated surgical times and outcomes and, despite the complexity of the study cases, rTAPP operative times and surgical site events gradually decreased after 138 cases [9]. Muysoms et al. also evaluated

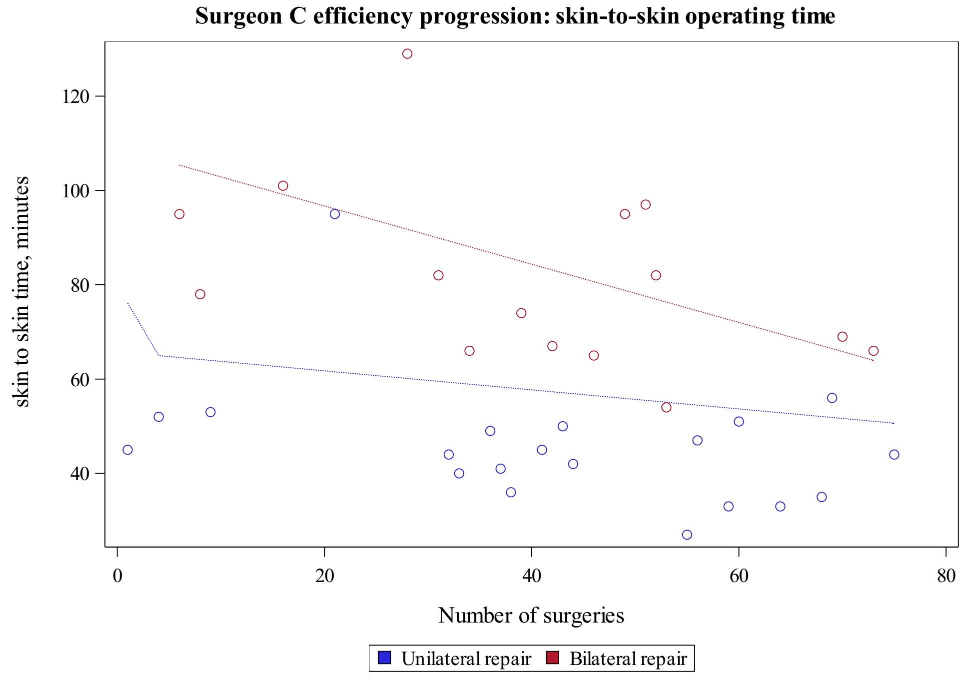

Fig. 3 Surgeon C efficiency progression: skin-to-skin operating time

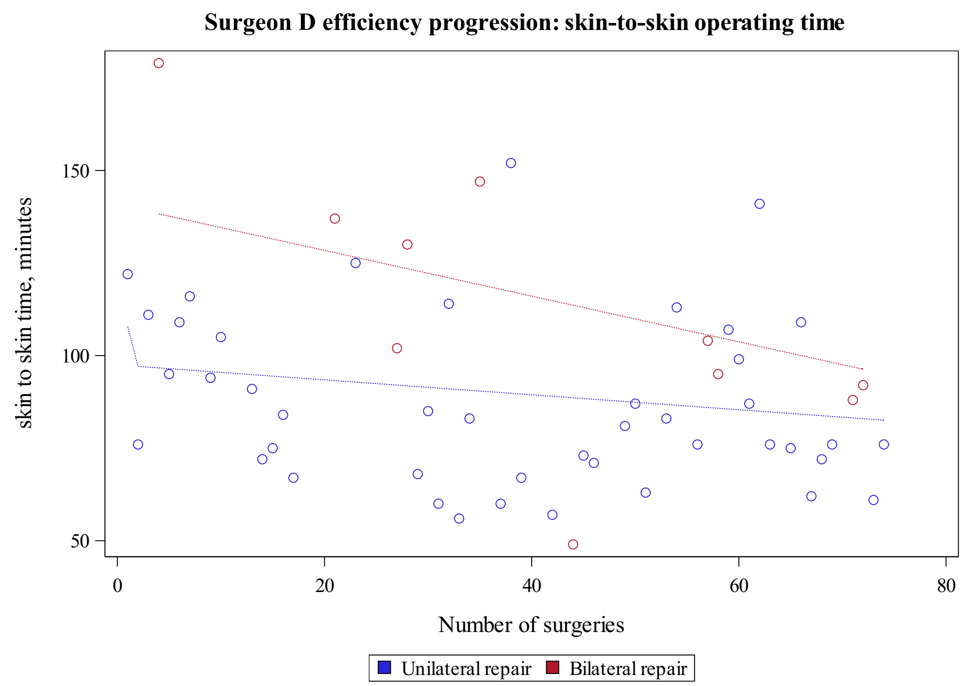

Fig. 4 Surgeon D efficiency progression: skin-to-skin operating time

operative times for rTAPP for a single surgeon during the initial experience of 50 cases and reported improved operative times that were comparable to those of the laparoscopic procedures [5].

The current study differs from existing published learning curve analyses of rTAPP in its prospective design, inclusion of multiple surgeons at different institutions, and inclusion of real-world consecutive cases without exclusion criteria based on case complexity during the learning curve. As might be expected, the learning curves and efficiencies of these surgeons varied, but important to note, all achieved improved efficiency in their overall skin-to-skin times during the study period of 75 prospective cases. There was no obvious indicator (such as time to MPO, mesh fixation time, docking) that influenced the timing of efficiency from the early-to-mid-to-late phase. Three of the four surgeons reached acceptable skin-to-skin times with either or both unilateral and/or bilateral laparoscopic cases. One surgeon's

Table 8 Adverse events per subject by surgeon

Surgeon	Phase	Subjects with one or more adverse event including swelling or bruising, n (%)	Subjects with one or more adverse event other than swelling or bruising, n (%)
A (JEJ)	Retrospective	1 (2.0)	0 (0.0)
	Prospective	2 (2.7)	1 (1.3)
B (RRM)	Retrospective	27 (51.1)	13 (26.0)
	Prospective	27 (36.5)	13 (17.3)
C (BHM)	Retrospective	7 (14.0)	7 (14.0)
	Prospective	14 (18.7)	12 (16.0)
D (SSC)	Retrospective	8 (16.0)	8 (16.0)
	Prospective	20 (26.7)	18 (24.0)

times were slower. This study represents the first part of this learning curve study. All surgeons had their cases video recorded and are being analyzed by blinded surgeons using a standardized video grading form. The results of this video grading will be forthcoming but all surgeons had acceptable performance of their cases without any blinded graders concern for below standard hernia repairs.

The study was limited in its design as a small pilot study as the number of surgeons and cases based on power calculations was not obtainable as it was very hard to recruit surgeons into this study. Given the variability in efficiency during the surgeons' transitions to RA-IHR, especially when defined according to unilateral and bilateral cases performed by only four surgeons, analysis of a larger number of surgeons may be warranted and likely would be better studied in a registry type study. Although many variables related to transitioning and learning curve were collected, variables such as practice patterns and referrals, proctoring period, and number of non-hernia robotic cases performed during the trial are not accounted for, may have affected efficiency. In addition, the length of the prospective period in which the 75 cases were performed varied from surgeon to surgeon, ranging from 8 months for Surgeon A to 20 months for Surgeon C and some surgeons performed other robotic surgeries during the trial period. The varied length of the study window may have been another confounder with Covid interrupting the surgical schedule for at least one surgeon. The current study did not assess surgical proficiency; however, a proficiency study involving the same surgeons is underway. Also, the targeted study population were surgeons that have surgical skill just naïve to the robot. Future studies hope to incorporate novice learners, such as residents. Last, adverse event rates were surprisingly high for three of the surgeons—regardless of the group (retrospective or prospective). On a granular basis, many of the surgeon-reported AEs (such as bruising or swelling) might have been considered sequelae and not AEs. Despite these limitations this study is unique and strengthened by including multiple surgeons, a prospective design, comparisons to previous laparoscopic cases, and inclusion of consecutive inguinal hernia cases. It also represents a real-world experience of surgeons with variable training and case volumes and the learning curves associated.

We report on the learning curve of four experienced laparoscopic surgeons' transition from Lap-IHRs to RA-IHRs. Although experience and efficiency differed among the four surgeons, all improved their efficiencies during the study period. A study of a larger number of surgeons with in-depth review of efficiency metrics and video review might elucidate true learning curves for transitioning from laparoscopic to robotic inguinal hernia repair and is warranted.

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