



Laparoscopic appendectomy as an index procedure for surgical trainees: clinical outcomes and learning curve

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Abstract

Surgical training is essential to maintain safety standards in healthcare. The aim of this study is to evaluate learning curves and short-term postoperative outcomes of laparoscopic appendectomy (LA) performed by trainees (TRN) and attendings (ATT). The present study included the medical records of patients with acute appendicitis who underwent a fully LA in our department between January 2013 and December 2018. Cases were divided into trainees (TRN and ATT groups based on the experience of the operating surgeon. The primary outcome measures were 30-day morbidity and mortality. Preoperative patients' clinical characteristics, intraoperative findings, operative times, and postoperative hospitalization were compared. Operative times were used to extrapolate learning curves and evaluate the effects of changes in faculty using CUSUM charts. A propensity score matching analysis was performed to reduce differences between cohorts regarding both preoperative characteristics and intraoperative findings. A total of 1173 patients undergoing LA for acute appendicitis were included, of whom 521 (45%) in the TRN group and 652 (55%) in the ATT group. No significant differences were found between the two groups in terms of complication rates, operative times and length of hospital stay. However, CUSUM chart analysis showed decreased operating times in the TRN group. Operative times improved more quickly for advanced cases. The results of this study indicate that LA can be performed by trainees without detrimental effects on clinical outcomes, procedural safety, and operative times. However, the learning curve is longer than previously acknowledged.

Keywords Laparoscopic appendectomy · Trainees · Surgical Training · Learning curve · Clinical outcomes · CUSUM analysis

Introduction

The adoption of laparoscopy has increased dramatically over the last few decades, and even extended to the emergency setting [1]. This radical shift in surgical practice shows how important is for trainees today to become proficient with currently emerging technologies [2].

However, several factors may limit the possibility to fulfill this need. It is generally accepted that surgical training is associated with increased operative times (OT) [3–5]. In this context, educational needs must not impact the quality of surgeries [6]. Finally, the number of residents might rise to counter the shortage of specialists expected in the next few years [7].

Laparoscopic training can benefit from specific simulators and skill-building programs [8, 9]; however, performing surgery on live patients remains a crucial step for trainees. Experience plays a key role in the outcome of all

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surgical procedures and leads to better allocation of hospital resources [10, 11].

Acute appendicitis (AA) is the most common abdominal emergency, with 100–150 cases per 100,000 person-years [12]. Laparoscopic appendectomy (LA) has been accepted as the gold standard for treating AA [13–15] and is one of the first and most common operations performed by trainees within the emergency setting.

The aim of this study is to evaluate skill acquisition in LA among trainees in our institution by comparing learning curves and short-term postoperative outcomes of LA performed by supervised trainees and mentoring attending surgeons in our center.

Materials and methods

Data collection

Data on patients with confirmed AA who underwent appendectomy at our institution over a six-year period (2013–2018) were prospectively recorded. The exclusion algorithm is shown in Fig. 1.

Exclusion criteria were defined to minimize confounding factors and obtain a set of patients as homogeneously as possible for comparisons. Study size was not defined beforehand, being a result of the chosen collection time.

Patients were divided in two groups based on the experience of the main surgeon, namely ‘Attendings’ (ATT) and ‘Trainees’ (TRN).

Patient characteristics (including sex, age, and comorbidities), general fitness scores (including American Society of Anesthesiologists [ASA] score), presentation characteristics

(including white cell count above $10.5 \times 10^9/L$, neutrophilia $> 82\%$, C-reactive protein (mg/dl), body temperature $> 37.5^\circ C$, location and development of pain, and Alvarado score), histopathological results (edematous, suppurative, or gangrenous appendicitis, presence of perforation or abscess, retrocaecal position of the appendix), OT, complications, length of hospital stay and mortality were compared between the two groups.

The study was approved by our local ethics committee and is reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [16].

Surgical technique

The surgical technique for LA used at our institution is standardized and described in detail elsewhere [17]. The choice of surgical approach was made in advance by the operating surgeon according to their preferences, patient characteristics and current guidelines [12, 15]. All patients received antibiotic prophylaxis before surgery. All cases were initially approached by trainees who were replaced by an attending or a senior trainee only in cases of inability to complete the procedure. When performing surgeries, TRN were always supervised by a skilled surgeon in the operating room.

Endpoints

The primary endpoints were 30-day morbidity and mortality. Secondary endpoints included OT (defined as the time between incision and medication of surgical wounds) and length of hospital stay. Complications were identified from patient records and available follow-up documentation, and stratified according to the Clavien–Dindo classification [18].

Subsequently, we stratified outcomes by the overall resident’s experience, defined by year of training or number of LA ever performed.

Statistical analysis

Summary statistics were expressed as numbers (percentages) or means (standard deviation [SD]) as appropriate. We used independent *t* tests for continuous variables and Pearson’s Chi-squared test for categorical variables. Variance analysis (ANOVA test) was used to compare continuous variables grouped in more than 2 sets.

To increase the homogeneity of the two groups, we extracted a subgroup of patient using propensity score matching to account for the following independent confounders: age, sex, ASA score, histopathological severity of AA, retrocaecal position of the appendix, presence of paraperidicular abscess, perforation of the appendix. We performed

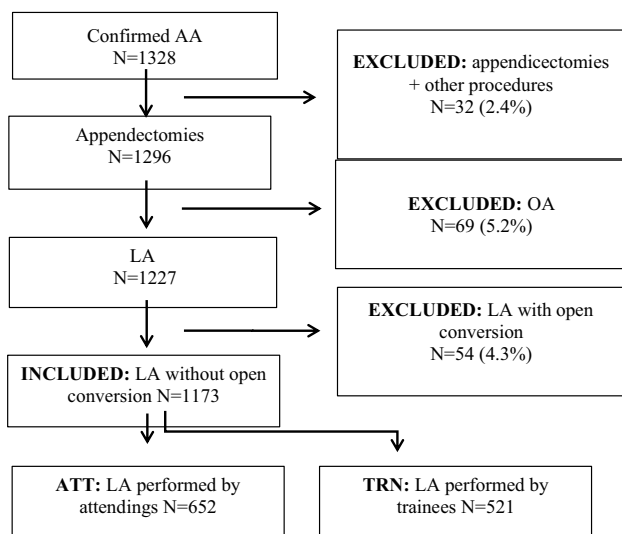


Fig. 1 Flowchart of patient selection

a one-to-one matching without replacement with nearest neighbor using the logit of the propensity score. Conditional logistic regression was performed to determine the adjusted odds ratios (OR) and 95% confidence intervals (CI) for the association between cases performed by residents and attending surgeons and other comorbid diseases.

Analysis of the relationship between OT and year of training as well as between OT and number of LA performed was performed using OLS (ordinary least squares) regression.

Statistical analysis was carried out using Stata 16 SE (Stata Corp. College Station, TX, USA). A p value < 0.05 was considered statistically significant.

Results

During the study period, 1173 patients with a diagnosis of AA underwent LA at our institution (TRN 521 [44.4%]; ATT 652 [55.6%]). Surgeries were performed by a total of 64 TRN (with a mean of 8.1 ± 8.6 procedures performed per trainee) and 9 ATT throughout the study period. Overall, 39% of TRN completed at least 10 cases and 14% of trainees performed at least 20 cases within the timeframe of the study.

Preoperative patients' characteristics, intraoperative findings and postoperative outcomes are detailed in Table 1.

All patients were over 14 years old. Compared to the ATT group, patients in the TRN group were younger (33.6 ± 16.6 vs 37.6 ± 18.3 ; $p < 0.001$) and had a slightly lower body mass index (BMI) (23.6 ± 4.2 vs 24.1 ± 4.5 ; $p = 0.050$). Comorbidities were globally slightly lower in the TRN group but similarly distributed between groups. No substantial differences were found on ASA, Alvarado score, WCC, and neutrophilia; C-reactive protein levels were significantly lower in the TRN group (6.2 ± 7.8 vs 4.4 ± 5.6 ; $p < 0.001$). Patients in the TRN group were less likely to have undergone preoperative imaging. However, imaging findings were comparable between the two groups.

Overall, cases in the TRN group were less complex than those in the ATT group. Notably, patients in the TRN group had fewer retrocecal appendices (17% vs 22%; $p < 0.05$), gangrenous appendices (22% vs 34%; $p < 0.001$) and peri-appendicular abscesses (15% vs 22%; $p < 0.001$). The use of endo-staplers for stump closure was also significantly lower in the TRN group (11% vs 23%; $p < 0.001$). Interestingly, OT were similar in the two groups (69.0 ± 24.0 ATT; 68.3 ± 19.3 TRN; $p = 0.581$).

There were no deaths within 30 days from surgery. Global complication rates and Clavien–Dindo grade were similar. The average length of hospital stay was significantly shorter in the TRN group (2.6 ± 2.2 vs 3.1 ± 2.2 ; $p = 0.001$).

Using propensity score matching, we extracted a subset of patients with more balanced characteristics thus

obtaining two groups, a trainee group (pTRN) and an attending group (pATT), each including 409 patients.

Preoperative characteristics, intraoperative findings, and postoperative outcomes of the two patients' subsets are summarized in Table 2.

Compared to our original groups, clinical and pathological features were much more similar between the new subsets. All 3 grades of pathologic severity, as well as accessory findings that could complicate AA and worsen outcomes (e.g. abscesses, perforation and retrocecal position of the appendix) were similarly represented. Similar OT were confirmed between the two groups. TRN were still more likely to use endoloops for stump closure (80% vs. 89%; $p < 0.001$).

There was no significant difference in complication rates, both overall and stratified by severity. Differences in length of hospital stay between the two groups were less pronounced than before but still statistically different (pTRN: 2.6 ± 2.1 vs. pATT 3.0 ± 2.0 days; $p < 0.007$).

To continue our analysis, we evaluated OT, length of hospital stay and surgical outcomes in patients in the TRN group by taking into account the year of training and number of LA performed by the trainee. Furthermore, cases were stratified according to severity of inflammation on pathology (Table 3). Overall, year of training did not seem to affect OT. For lower grades (i.e., edematous and suppurative) AA, we found a statistically significant decrease in OT as the number of years of training increased. This was not confirmed during LA performed for gangrenous AA. Clinical outcomes (complication rates and length of stay) were similar in all series.

In Fig. 2, we showed the minimum number of cases that were necessary to be considered proficient in LA, including the “plateau effect” or rather the number of LA cases performed by a trainee after which improvement slows down or stops.

If limiting our analysis to edematous cases, we noticed a quadratic relationship between OT and number of cases performed, with improvements in OT decreasing after about 20 cases. On the other hand, there was a steady improvement in OT without any apparent plateau for suppurative cases. Finally, OT in gangrenous cases did not show any improvement as the number of procedures performed increased.

To better evaluate the overall trends, we used Cumulative Sum chart analysis, using OT as main quality number. We analyzed cases in the TRN and ATT groups. Results are presented in Fig. 3a.

Both graphs show a turning point around mid-2016, while variations before and after that point are much less pronounced. In particular, the turning point in the TRN group is about 3 months after the one in the ATT group.

Table 1 Summary of preoperative characteristics of patients, intraoperative findings and postoperative outcomes for surgeries performed by attendings (ATT) versus trainees (TRN)

	<i>n</i>	Attendings (ATT) (<i>N</i> =652)	Trainees (TRN) (<i>N</i> =521)	<i>P</i> value
Patient characteristics				
Age (years)	1173	37.6 ± 18.3	33.6 ± 16.6	<0.001
Male sex	1173	347 (53%)	294 (56%)	0.273
BMI (kg/m ²)	1012	24.1 ± 4.5	23.6 ± 4.2	0.050
ASA class	1096			
I–II		540 (92%)	477 (94%)	0.272
III–IV		47 (8%)	32 (6%)	
Comorbidities	1089	183 (31%)	129 (25%)	0.033
Cardiovascular		80 (14%)	54 (11%)	0.111
Diabetes		16 (3%)	12 (12%)	0.677
COPD		18 (3%)	10 (2%)	0.236
CKD		9 (2%)	7 (2%)	0.809
Alvarado score	1173			
0–4		178 (27%)	136 (26%)	0.600
5–6		265 (41%)	227 (44%)	
7–10		209 (32%)	158 (30%)	
Laboratory tests				
WCC (× 10 ⁹ /L)	1173	13.4 ± 4.4	13.3 ± 4.3	0.642
Neutrophils	592	11.0 ± 4.5	11.4 ± 8.0	0.409
CRP	1112	6.2 ± 7.8	4.4 ± 5.6	<0.001
Preoperative imaging				
Effusion	974	394 (78%)	331 (71%)	0.006
Thickening		200 (51%)	145 (44%)	0.062
Thickening		264 (67%)	228 (69%)	0.582
Appendicolith		77 (20%)	57 (17%)	0.414
Intraoperative findings				
Pathologic severity				<0.001
Edematous		168 (26%)	114 (22%)	
Suppurative		259 (40%)	290 (56%)	
Gangrenous		224 (34%)	116 (22%)	
Appendicular abscess		141 (22%)	80 (15%)	0.006
Perforated appendix		137 (21%)	56 (11%)	<0.001
Retrocecal appendix		146 (22%)	87 (17%)	0.015
Use of endoloop		502 (77%)	465 (89%)	<0.001
Operative time (min)		69.0 ± 24.0	68.3 ± 19.3	0.581
Postoperative outcomes				
Complications (CD)		51 (8%)	33 (6%)	0.603
Grade I		13 (2%)	6 (1%)	
Grade II		16 (2%)	14(3%)	
Grade III-a		9 (1%)	4(1%)	
Grade III-b		13 (1%)	8(2%)	
Grade IV-a		0	0	
30-day mortality		0	0	1.000
Length of stay (days)		3.1 ± 2.2	2.6 ± 2.2	<0.001

Discussions

As the health system continues to change, it needs to offer opportunities for TRN to develop their surgical skills. At the same time, it is important to ensure that high standards of care are maintained in training programs to preserve patient safety [19, 20]. Our study examined the impact of resident training on patient outcomes in our program using matching techniques to control for patient factors.

Due to national regulations (DL368/99) [21], Italian TRN are always supervised when performing surgeries, with or without direct assistance. This makes our study generalizable to other similar settings. It has been shown that surgeon's experience may deeply impact on OT and outcomes [5].

TRN are increasingly performing laparoscopic and complex cases [22]. A retrospective analysis [23] showed that an increasing fraction of the total cases performed by general

Table 2 Summary of patient characteristics for surgeries performed by attendings (pATT) versus trainees (pTRN) in the subgroups obtained using propensity score matching analysis

	<i>n</i>	Attendings (pATT) (<i>N</i> =409)	Trainees (pTRN) (<i>N</i> =409)	<i>P</i> -value
Patient characteristics				
Age (years)	818	36.2 ± 17.4	33.8 ± 16.8	0.047
Male sex	818	222 (54%)	232 (57%)	0.482
BMI (kg/m ²)	818	23.8 ± 4.1	23.6 ± 4.2	0.453
ASA class	818			
I–II		385 (94%)	386 (94%)	0.881
III–IV		24 (6%)	23 (6%)	
Comorbidities	818	116 (28%)	115 (27%)	0.755
Cardiovascular		47 (11%)	44 (11%)	0.739
Diabetes		11 (3%)	11 (3%)	0.999
COPD		14 (3%)	10 (2%)	0.407
CKD		3 (1%)	5 (1%)	0.477
Alvarado score	818			
0–4		127 (31%)	112 (27%)	0.412
5–6		171 (42%)	172 (42%)	
7–10		111 (27%)	125 (31%)	
Laboratory tests				
WCC (× 10 ⁹ /l)	818	13.4 ± 4.4	13.2 ± 4.4	0.513
Neutrophils	411	11.1 ± 4.7	11.5 ± 8.8	0.507
CRP	787	5.4 ± 6.9	4.6 ± 5.8	0.069
Preoperative imaging				
Effusion	779	291 (76%)	283 (71%)	0.121
Thickening		138 (48%)	126 (45%)	0.462
Thickening		193 (67%)	197 (70%)	0.617
Appendicolith		45 (16%)	47 (17%)	0.736
Intraoperative findings				
Pathologic severity	818			
Edematous		101 (25%)	95 (23%)	0.274
Suppurative		195 (48%)	217 (53%)	0.623
Gangrenous		112 (27%)	96 (24%)	0.124
Appendicular abscess	818	68 (17%)	63 (15%)	0.199
Perforated appendix	818	62 (15%)	49 (12%)	0.634
Retrocecal appendix	818	84 (21%)	64 (16%)	0.184
Use of endoloop	818	327 (80%)	363 (89%)	0.070
Operative time (min)	818	70.5 ± 25.1	68.3 ± 18.8	<0.001
0.173				
Postoperative outcomes				
Complications (Clavien–Dindo)		34 (8%)	27 (7%)	0.579
Grade I		11 (3%)	5 (1%)	
Grade II		9 (2%)	11 (3%)	
Grade III-a		5 (1%)	4 (1%)	
Grade III-b		9 (2%)	7 (2%)	
Grade IV-a		0	0	
30-day mortality		0	0	1.000
Length of stay (days)		3.0 ± 2.0	2.6 ± 2.1	0.007

surgery trainees in the United States are minimally invasive procedures. These results not only reflect general changes in surgical practice, but also illustrate the crucial adaptation of residency programs to provide proper skills in minimally invasive approaches.

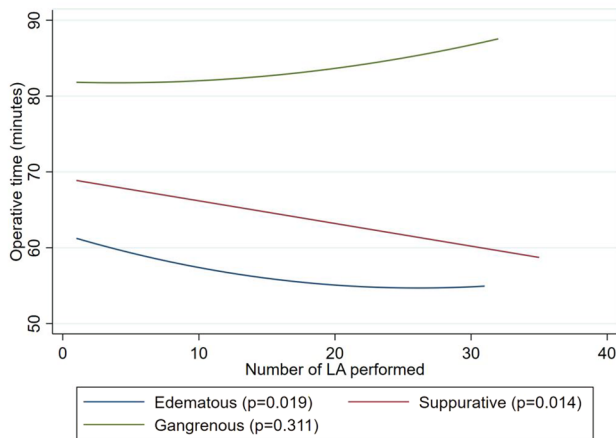
Appendectomy is one of the first operations performed by TRN. In current clinical practice, ATT tend to tackle more challenging cases than TRN; this was clearly evident

by looking at the preoperative and intraoperative data we collected initially (Table 2). In particular, ASA scores were higher, there was a higher rate of complicated appendicitis and pathology was less favorable in the ATT group compared to the TRN group. The association between patient fitness and surgical outcomes is well established [24–27].

These differences were similar to other works reported in the literature [3, 28]. By selecting a subset of patients with

Table 3 Operative times and postoperative clinical outcomes divided by year of training (YoT) of the trainee performing the surgery

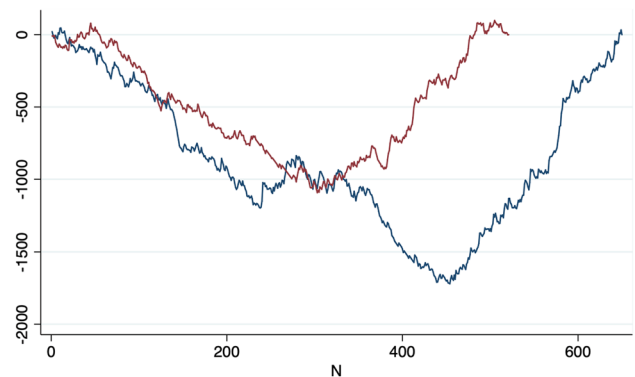
	YoT 2 66	YoT 3 72	YoT 4 125	YoT 5 155	YoT 6 101	P-value
Overall results						
Operative time (min)	73.0	71.8	66.6	66.8	67.2	0.072
Length of stay (days)	2.7	2.9	2.6	2.6	2.45	0.826
Complications (total)	9.2%	6.9%	4.8%	5.2%	6.9%	0.756
Complications \geq IIIa	3%	4.2%	3.2%	0.6%	2%	0.460
Mortality	0	0	0	0	0	1
Non-gangrenous AA						
Operative time (min)	71.4	67.0	62.7	63.0	61.4	0.006
Length of stay (days)	2.2	2.2	2.3	2.3	2.3	0.98
Complications (total)	5.4%	1.8%	3.3%	4.0%	5.4%	0.83
Complications \geq IIIa	0%	1.8%	2.2%	0%	1.3%	0.47
Mortality	0	0	0	0	0	1
Gangrenous AA						
Operative time (min)	85.0	87.6	78.6	81.0	82.8	0.683
Length of stay (days)	5.3	5.1	3.3	3.9	3.0	0.248
Complications (total)	33.3%	23.5%	9.4%	9.7%	11.1%	0.257
Complications \geq IIIa	22%	12%	6.3%	3.2%	3.7%	0.292
Mortality	0	0	0	0	0	1

**Fig. 2** Relationship between number of laparoscopic appendectomies (LA) performed and average operative time, divided by severity of inflammation

similar characteristics using propensity score matching, we were able to minimize differences between groups at the cost of a slight reduction in the overall number of cases. The two new cohorts of patients were much more similar to each other.

Imaging studies were performed less frequently than the US average reported in the literature [29]. As we excluded negative appendectomies from the study, we cannot comment on the diagnostic accuracy of our workup.

The use of endo-staplers for stump closure was lower in patients in the pTRN group than in the pATT group.

**Fig. 3** CUSUM chart analysis for operative times. Red Line = cases performed by attendings. Blue Line = cases performed by trainees

Endo-staplers are usually preferred in case of inflammation of the base of the appendix [30]. In any case, it is worth noting that the two techniques are equivalent both in regard to OT and infectious complication rates [31, 32].

Generally, prolonged OT for laparoscopic surgeries are associated with increased complication rates [33, 34]. Our data did not show a significant increase in OT, compared to other series [35–37].

We found no increase in complications among patients operated by TRN. This finding is in accordance with a number of previous studies on the subject [3, 38, 39], even if the topic is still controversial [40, 41]. Some authors report that a higher year of training can be associated with

increased morbidity because of reduced supervision and longer OT, but this is difficult to assess properly [4, 42].

Globally, there is no significant improvement in OT as trainee experience increases in our study, as shown in Table 3. This is probably because the difficulty of cases that the trainee is allowed to tackle increases concurrently. If we stratify surgeries according to the severity of inflammation, we see an improvement in OT for edematous and suppurative cases. The relative simplicity and higher standardization of these procedures might account for this.

Our data show a significant improvement that correlates with experience, meaning both years of training and number of procedures. Regarding the existence of a plateau related to the year of training, our data only show a non-significant trend as shown in Fig. 2. This conclusion is not shared by all authors in the literature [5].

It is also worth noting that a reduction in OT can be a good indicator for skill increase, but it is by no means the only one. Different indicators, for the most part subjective in nature, are found in the literature. This might help explain why some studies suggest that 20 LA might be too high [42, 43]. Moreover, general surgical experience has a strong influence on proficiency. That is the reason why OT improve with the increase in year of training, independent of the number of LA performed.

CUSUM chart analysis is a sequential analysis technique that is typically used for monitoring change detection, especially in the industrial sector, as well as to estimate the point in the learning curve where a surgeon stops improving according to a given quality index.

We found that overall OT had lengthened around the same time, first for ATT and then for TRN shortly thereafter. Looking back at our organizational charts, we found that several trainees completed their training and were hired as attendings around that time. This might explain the lengthening of OT in both groups, as new attendings might be less able to complete their procedures and help trainees in a timely manner compared to more experienced attendings. The delayed increase in the residents' group might further be attributed to the initial reluctance of newly hired attendings to let trainees perform cases under their supervision. We interpreted this finding as an indication that the new attendings had yet to complete their learning curve.

One of the main strengths of this study compared to similar works found in the literature is that every medical record included was thoroughly reviewed by one of the authors. All surgeries were performed by a faculty group following the same standardized method; TRN were required to spectate several cases to familiarize themselves with the technique before even assisting on their first operation. The data we collected should provide a robust base for the stratification of surgical complexity of each case in all groups.

However, this study has some limitations, including its retrospective nature and the inherent limitations associated with an observational study. Nevertheless, it must be noted that a blinded randomized trial is unlikely feasible due to ethical concerns [44]. Data were collected from electronic medical records of our institution: it is possible that some complications that emerged after discharge were lost at follow-up. In particular, reported superficial surgical site infection rates were low, though still close to those reported in literature [29].

Due to the design of the study, we were unable to account for the increased time in cases where procedures were started by a trainee but completed by an attending; these cases have been attributed to the attending and might have affected OT, which are slightly longer than what has been reported in the literature [29].

Conclusions

Outcomes of LA do not substantially differ between supervised trainees and attending surgeons. Trainees performance does not threaten patients' safety nor substantially increase overall OT and postoperative hospital stay.

At the same time, OT shorten with experience, both during and after residency, with more substantial improvements in less complex cases. While being a resident should not preclude performing this operation, it is crucial to provide support and supervision during the entire training curve, especially for challenging cases.

Author contributions AU: substantial contributions to the conception and design of the work; acquisition, analysis, and interpretation of data for the work. Drafting the work. Final approval of the version to be published. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy and integrity of any part of the work are appropriately investigated and resolved. SV, RU and PB contributed equally to this work: substantial contributions to the conception and design of the work; acquisition, analysis, and interpretation of data for the work. Final approval of the version to be published. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy and integrity of any part of the work are appropriately investigated and resolved. GG, UG, SS contributed equally to this work: substantial contributions to the conception and design of the work. Drafting the work and revising it critically for important intellectual content. Final approval of the version to be published. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy and integrity of any part of the work are appropriately investigated and resolved. All authors contributed to the conception and design of the work and to the final approval of the version to be published.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The study protocol was approved by the Ethical Committee of the Sant'Orsola University Hospital of Bologna. Internal Code CE: 156/2018/Oss/AOUBo. Protocol No. 953, 14/01/2019.

Research involving human participants and/or animals All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

Availability of data and material (data transparency) The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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