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ORIGINAL ARTICLE

Graded operative autonomy in emergency appendectomy mirrors case-complexity: surgical training insights from the SnapAppy prospective observational study

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Abstract

Introduction Surgical skill, a summation of acquired wisdom, deliberate practice and experience, has been linked to improved patient outcomes. Graded mentored exposure to pathologies and operative techniques is a cornerstone of surgical training. Appendectomy is one of the first procedures surgical trainees perform independently. We hypothesize that, given the embedded training ethos in surgery, coupled with the steep learning curve required to achieve trainer-recognition of independent competency, 'real-world' clinical outcomes following appendectomy for the treatment of acute appendicitis are operator agnostic. The principle of graded autonomy matches trainees with clinical conditions that they can manage independently, and increased complexity drives attending input or assumption of the technical aspects of care, and therefore, one cannot detect an impact of operator experience on outcomes.

Materials and methods This study is a subgroup analysis of the SnapAppy international time-bound prospective observational cohort study (ClinicalTrials.gov Trial #NCT04365491), including all consecutive patients aged ≥ 15 who underwent appendectomy for appendicitis during a three-month period in 2020–2021. Patient- and surgeon-specific variables, as well as 90-day postoperative outcomes, were collected. Patients were grouped based on operating surgeon experience (trainee only, trainee with direct attending supervision, attending only). Poisson and quantile regression models were used to (adjusted for patient-associated confounders) assess the relationship between surgical experience and postoperative complications or hospital length of stay (hLOS), respectively, adjusted for patient-associated confounders. The primary outcome of interest was any complications within 90 days.

Results A total of 4,347 patients from 71 centers in 14 countries were included. Patients operated on by trainees were younger (Median (IQR) 33 [24–46] vs 38 [26–55] years, $p < 0.001$), had lower ASA classifications (ASA $\geq$ 3: 6.6% vs 11.6%, $p < 0.001$) and fewer comorbidities compared to those operated on by attendings. Additionally, trainees operated alone on fewer patients with appendiceal perforation (AAST severity grade $\geq$ 3: 8.7% vs 15.6%, $p < 0.001$). Regression analyses revealed no association between operator experience and complications (IRR 1.03 95%CI 0.83–1.28 for trainee vs attending; IRR 1.13 95%CI 0.89–1.42 for supervised trainee vs attending) or hLOS.

Conclusion The linkage of case complexity with operator experience within the context of graduated autonomy is a central tenet of surgical training. Either subconsciously, or by design, patients operated on by trainees were younger, fitter and with earlier stage disease. At least in part, these explain why clinical outcomes following appendectomy do not differ depending on the experience of the operating surgeon.

Keywords Appendicitis · Surgical training · Outcomes · Snapshot · Prospective · Observational study

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Introduction

Graduated autonomy during surgical training drives increased independence from acquired knowledge coupled with increasing technical skills. This process flows from the apprenticeship model articulated by Halsted, but has been enhanced by planned rotations in complementary disciplines as well as the service-based organization found in teaching centers that house several attendings within a single discipline (e.g. trauma, colorectal, hepatobiliary) [1]. Therefore, the surgical trainee has the benefits of learning from multiple surgeons about the same topic. Further, simulation centers, and specific skills labs—such as the fundamentals of laparoscopic surgery—further accelerate surgical skill development and retention [4, 8–10]. Such an approach may lead to a more rapidly acquired range of skills compared to the apprentice model. Relatedly, volume-based assessments link the frequency of performing a specific procedure (e.g. pancreaticoduodenectomy) to desirable outcomes [2–7]. This observation rests on a foundation of basic, and then increasingly advanced, knowledge and skills that is often complemented by a post-residency fellowship training program for additional refinement. Importantly, training in this fashion also helps develop both experience and judgement.

Appropriately trained surgeons who serve in teaching programs ideally evaluate learner knowledge and skills to align those elements with patient complexity. Doing so enables the trainee to actively participate in the surgical undertaking, rather than simply serving as an observer. Since appendectomy is a common surgical procedure, and one that may be most suitable for operative autonomy, it should serve as a platform from which to assess the link between operator experience and patient acuity [8]. We, therefore, hypothesize that across cultures, international boundaries and differences in training program structure and duration, the principle of graded autonomy is applied under 'real-world' conditions by surgical trainers. Therefore, within training programs, no impact of operator experience should be identifiable when assessing patient-level outcomes and that case complexity will highly associate with attending surgeon oversight or direct assumption of the technical aspect of surgical care.

Methods

Protocol

A subgroup analysis of the prospective, observational, non-randomized multi-center cohort study, using standardized published methodology [9], was conducted in line with a pre-specified protocol which was registered with ClinicalTrials.gov (Trial # NCT04365491). The study enrolled all consecutive patients admitted with acute appendicitis between a three-month window from November 1, 2020, and May 28, 2021, and followed those patients for 90 days post-admission (up to August 31st 2021). The study complied with both the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines and the Declaration of Helsinki.

Center eligibility

Any unit undertaking adult emergency general surgery was eligible to register to enter patients into the study. No minimum case volume or center-specific limitations were applied. The study protocol was disseminated to registered members of the European Society of Trauma and Emergency Surgery (ESTES), and through national surgical societies.

Patient eligibility

All adult patients (15 years of age and over) admitted for acute appendicitis who underwent appendectomy during index admission were included in the current study. Appendicitis was graded using the American Association for the Surgery of Trauma (AAST) Anatomic Disease Severity grading system for emergency general surgery that provides a uniform method to assess disease severity for a variety of conditions, including acute appendicitis [10–12]. The grading system uses clinical, radiographic, operative, and pathologic criteria to assign an incrementing ordinal severity score of one (mild disease limited to the organ) to five (widespread severe disease). Patients were excluded where the experience level (trainee vs. attending) of the operating surgeon was unknown.

Data capture

Data were recorded contemporaneously and stored on a secure, user-encrypted online platform (SMARTTrial®) without patient-identifiable information. Centers were asked to validate that all eligible patients during the study period had been entered and to attain > 95% completeness of data field entry prior to final submission. The database was closed for analysis on October 1, 2021. Quality assurance guidance to ensure data fidelity was provided by at least one consultant/attending-level surgeon at each site [13].

Outcome measures

The primary outcome of interest was any postoperative complication within 30 days, while severe complications within 30 days and hospital length of stay (hLOS) were secondary outcomes of interest. Severe complications were defined as any complication with a Clavien–Dindo classification grade three to five (reoperation, reintervention, unplanned admission to intensive care unit, organ support requirement, or death) (Fig. 1).

Statistical analysis

Patients were divided into three groups based on the level of the operating surgeon: attending, trainee, or supervised

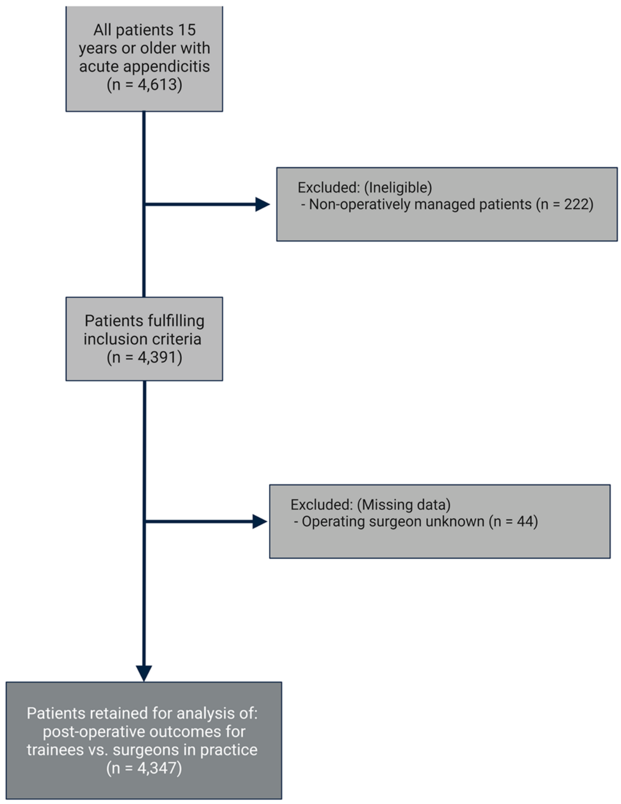

Fig. 1 Study flow diagram, demonstrating patient inclusions, exclusions, and the final number of patients analysed

trainee. Pairwise comparisons were performed between patients operated by an attending and patients operated by a trainee or a supervised trainee. Descriptive results are presented as means and standard deviations (SDs) for continuous, normally distributed variables, medians and interquartile ranges (IQRs) for non-normally distributed continuous variables, as well as counts and percentages for categorical variables. Continuous, normally distributed variables were compared using a Student's *t* test, while non-normally distributed variables were compared using the Mann–Whitney *U* test, for pairwise comparisons. An analysis of variance (ANOVA) or Kruskal–Wallis test was instead used when comparing more than two groups. A Chi-square test or Fisher's exact test was used for categorical variables, as appropriate.

The association between the level of the surgeon and complications was determined using Poisson regression models with robust standard errors. The response variable was either any complication or severe complications, while the predictors were the level of the surgeon as well as the patient's age, sex, American Society of Anaesthesiologists (ASA) classification, a history of previous abdominal surgery, ischaemic heart disease, insulin-dependent diabetes, congestive heart failure, chronic renal disease, current smoking status, immunosuppression, the American Association for the Surgery of Trauma (AAST) appendicitis grade, time to surgery from admission, surgical technique (laparoscopic, open, conversion-to-open), white blood cell count on admission, neutrophil count on admission, CRP on admission, and the country where the surgery was performed. Results are presented as incidence rate ratios (IRRs) and 95% confidence intervals (CIs).

The association between the level of the surgeon and hLOS was determined using a linear quantile regression model. HLOS was the response variable while the explanatory variables were the level of the surgeon as well as the patient's age, sex, ASA classification, a history of previous abdominal surgery, ischaemic heart disease, insulin-dependent diabetes, congestive heart failure, chronic renal disease, current smoking status, immunosuppression, AAST appendicitis grade, time to surgery from admission, surgical technique (laparoscopic, open, conversion-to-open), white blood cell count on admission, neutrophil count on admission, CRP on admission, and the country where the surgery was performed. Results are presented as the median change in hLOS and 95% CI. A two-tailed *p*-value of less than 0.05 was considered statistically significant. Missing data were managed using multiple imputation by chained equations [14]. Analyses were conducted with the statistical software R 4.1.1 (R Foundation for Statistical Computing, Vienna, Austria) using the tidyverse, mice, lubridate, readxl, writexl, robustbase, and quantreg packages [15].

Ethical considerations

All participating centers had Institutional Review Board approval or equivalent. No patient consent was sought since the current study was purely observational and did not impact patient care. All data were de-identified when uploaded to the secure HIPAA- and GDPR-compliant study database.

Results

Compared to patients operated by an attending, patients operated by a trainee were younger (median [IQR]; 33 [24–46] vs 38 [26–55] years, $p < 0.001$), more often male (57.2% vs 53.4%, $p = 0.036$), and more fit for surgery according to their ASA classification (ASA $\geq$ 3: 6.6% vs 11.6%, $p < 0.001$). The patients operated by trainee were also less likely to have a diagnosis of ischaemic heart disease (1.7% vs 3.0%, $p = 0.016$) and insulin-dependent diabetes (1.4% vs 2.8%, $p = 0.016$). Additionally, trainees tended to operate on less complex cases as appendiceal perforation was less common in this cohort (8.7% vs 15.6%, $p < 0.001$).

Patients operated by trainees were also less likely to be operated on within 24 h (85.0% vs 86.3%, $p=0.031$); however, there was no statistically significant difference in the length of the surgical procedure. There was no statistically significant difference in the crude rate of complications or in hLOS. However, pelvic abscesses (1.9% vs 4.2%, $p<0.011$), sepsis (0.4% vs 1.1%, $p=0.030$), ileus (1.8% vs 3.4%, $p=0.006$), and severe complications (1.9% vs 3.8%, $p=0.003$) were less common in patients operated by trainees according to the crude univariate analysis (Table 1).

Compared to patients operated by an attending alone, patients operated by a trainee with direct attending supervision were also younger (35 [24–52] vs 38 [26–55] years, $p<0.001$) and more fit for surgery (ASA ≥ 3: 8.3% vs 11.6%, $p<0.001$). Patients operated on by trainees with direct attending supervision were less likely to be perforated (10.9% vs 15.6%, $p=0.027$) and more likely to be operated on within 24 h compared to patients operated by an attending alone (92.0% vs 86.3%, $p<0.001$). There was no statistically significant difference in the length of the surgical procedure between these two cohorts. Furthermore, there was no statistically significant difference in the crude rate of any and severe complications, or hLOS (Table 1).

After adjusting for potential confounders, there was no association between operator experience and rate of complications or hLOS. This remained true for the overall risk of complications both when comparing trainees with attendings [IRR (95% CI) 1.03 (0.83–1.28), $p=0.781$] and trainee with direct attending supervision and attendings [IRR (95% CI) 1.13 (0.89–1.42), $p=0.320$] (Tables 2 and 3).

Discussion

Surgical training differs across the world in a variety of important ways including work hours, specific rotations and their duration, as well as within-residency training specialization [16]. Nonetheless, there remain many commonalities, including perhaps most importantly, graduated autonomy. The methods of assessing a trainees readiness for graduated autonomy have been investigated with increasing vigor [17–19]. Those inquiries suggest that a departure from time-based autonomy to objective multimodal assessment-based autonomy reflects individual skill acquisition wedded to knowledge supported cognitive skill demonstration. Importantly, the latter approach incorporates elements outside of the operating room (OR) as well as intra-operative technical performance [20].

Technical skills may be acquired and reinforced in a variety of structured fashions. Observation provides exposure to a typical sequence of maneuvers, and ideally demonstrates the desired outcome of those interventions. Medical students are often exposed to technical skills in this fashion. Once a surgical training pathway is selected, other complementary approaches become important, including surgical simulation such as the Fundamentals of Laparoscopic Surgery (FLS) that is required during general surgery residency training in the US [21, 22]. Simulation is well embedded in fundamental elements of surgical rescue and include Advanced Cardiac Life Support and Advanced Trauma Life Support courses that are commonly required during surgical training. Animal lab courses that assess skill deployment afford the opportunity to use typical instrumentation to address commonly performed procedures, including injury management, within the context of tissue handling and haemorrhage risk. While providing more fidelity than a simulator, animal models do not precisely replicate human tissue, nor live patient risk. Perfused fresh cadaver models have been developed to fill this void but are less common than desired, are more problematic to schedule, and bear a substantial financial cost. Therefore, commonly performed live patient procedures may be prepared for using a variety of methods to reduce patient risk, enhance operator skill, and improve outcome [23, 24]. Regardless of the method of preparation, there is no substitute for operating on a live patient. Given that laparoscopic—and now robotic—procedures are increasingly common compared to open procedures, straightforward laparoscopic procedures such as laparoscopic appendectomy appear foundational to other more challenging procedures such as splenectomy or colon resection [25].

Laparoscopic appendectomy is foundational, building on established tenets of patient care including interpreting history and physical examination findings, evaluating radiology data, establishing a diagnosis, performing risk assessment, and securing informed consent all prior to operation. Training programs must meet certain requirements to train developing surgeons including knowledge and skill assessments. Laparoscopic appendectomy is an ideal procedure to build those skills (or specific elements) including discourse with the Anesthesia team and the OR team, positioning, prepping, draping, port site selection, as well as the technical aspects of performing the laparoscopic appendectomy. Management of potential critical decision points also falls under the OR space but is more uncommon than in other kinds of procedures. Post-operative care is usually straightforward in a similar fashion. All these elements render laparoscopic appendectomy a procedure in which more junior trainees participate from patient presentation to discharge. Therefore, it may also provide a lens into how graduated autonomy occurs [25–27].

Work hours restrictions drive efforts at maximizing the value of time spent teaching trainees. Therefore, aligning case complexity with trainee skills appears to be one viable approach to maximizing education that marries cognitive

Table 1 Demographics, clinical characteristics, and crude outcomes, comparing operating surgeon (trainee, supervised trainee or attending)

	Attending (*N* = 1443)	Supervised trainee (*N* = 1131)	Trainee (*N* = 1773)	*p* value
Age, median [IQR]	38 [26–55]	35 [24–52]	33 [24–46]	< 0.001
Sex, *n* (%)				0.092
Female	670 (46.4)	511 (45.2)	757 (42.7)	
Male	771 (53.4)	617 (54.6)	1,014 (57.2)	
Missing	2 (0.1)	3 (0.3)	2 (0.1)	
Body mass index, mean (SD)	26.9 (± 8.3)	25.7 (± 7.7)	26.5 (± 16.7)	0.097
Missing	233 (16.1)	377 (33.3)	423 (23.9)	
ASA classification, *n* (%)				< 0.001
1	794 (55.0)	720 (63.7)	1,123 (63.3)	
2	479 (33.2)	315 (27.9)	514 (29.0)	
3	157 (10.9)	82 (7.3)	114 (6.4)	
4	10 (0.7)	11 (1.0)	4 (0.2)	
Missing	3 (0.2)	3 (0.3)	18 (1.0)	
Comorbidities, *n* (%)				
Ischaemic heart disease	44 (3.0)	23 (2.0)	30 (1.7)	0.032
Congestive heart failure	20 (1.4)	12 (1.1)	17 (1.0)	0.511
Insulin-dependent diabetes	40 (2.8)	22 (1.9)	24 (1.4)	0.016
Chronic kidney disease	18 (1.2)	7 (0.6)	13 (0.7)	0.166
Missing	9 (0.6)	4 (0.4)	10 (0.6)	
Smoking history, *n* (%)				0.004
Active smoker	145 (10.0)	103 (9.1)	229 (12.9)	
Non-smoker	938 (65.0)	773 (68.3)	1,109 (62.5)	
Ex-smoker	100 (6.9)	71 (6.3)	104 (5.9)	
Missing	260 (18.0)	184 (16.3)	331 (18.7)	
Immunosuppression, *n* (%)	33 (2.3)	21 (1.9)	31 (1.7)	0.528
Missing	9 (0.6)	3 (0.3)	14 (0.8)	
AAST severity, *n* (%)				< 0.001
Grade 1: acutely inflamed appendix; intact	798 (55.3)	617 (54.6)	912 (51.4)	
Grade 2: gangrenous appendix; intact	71 (4.9)	62 (5.5)	58 (3.3)	
Grade 3: perforated appendix with local contamination	108 (7.5)	58 (5.1)	99 (5.6)	
Grade 4: perforated appendix with phlegmon/abscess	101 (7.0)	51 (4.5)	50 (2.8)	
Grade 5: perforated appendix with generalized peritonitis	16 (1.1)	15 (1.3)	5 (0.3)	
Missing	349 (24.2)	328 (29.0)	649 (36.6)	
Time to OR in hours from admission to operation, *n* (%)				< 0.001
< 6 h	249 (17.3)	274 (24.2)	262 (14.8)	
6–12 h	519 (36.0)	422 (37.3)	590 (33.3)	
12–24 h	476 (33.0)	345 (30.5)	654 (36.9)	
> 24 h	191 (13.2)	84 (7.4)	254 (14.3)	
Missing	8 (0.6)	6 (0.5)	13 (0.7)	
Length of procedure in minutes, mean (SD)	62.3 (± 35.0)	60.5 (± 28.0)	61.2 (± 35.0)	0.376
Missing	27 (1.9)	32 (2.8)	77 (4.3)	
Laparoscopic or open				< 0.001
Laparoscopic	1,280 (88.7)	966 (85.4)	1,514 (85.4)	
Laparoscopic converted to open	66 (4.6)	34 (3.0)	27 (1.5)	
Open	86 (6.0)	126 (11.1)	221 (12.5)	
Missing	11 (0.8)	5 (0.4)	11 (0.6)	
Years of surgical experience, median [IQR]	10 [7.0–15]	3.0 [2.0–4.0]	4.0 [3.0–7.0]	< 0.001
Missing	359 (24.9)	95 (8.4)	459 (25.9)	
Length of stay, median [IQR]	1.9 [1.1–3.5]	1.9 [1.3–3.2]	1.9 [1.3–3.0]	0.663

Table 1 (continued)

	Attending ($N = 1443$)	Supervised trainee ($N = 1131$)	Trainee ($N = 1773$)	p value
Missing	36 (2.5)	48 (4.2)	49 (2.8)	
Complications within 30 days, n (%)	212 (14.7)	171 (15.1)	237 (13.4)	0.365
None	1,231 (85.3)	955 (84.4)	1,534 (86.5)	0.346
Wound infection	31 (2.1)	25 (2.2)	29 (1.6)	0.444
Wound dehiscence	10 (0.7)	12 (1.1)	8 (0.5)	0.151
Pelvic abscess	60 (4.2)	44 (3.9)	33 (1.9)	< 0.001
Subphrenic abscess	5 (0.3)	0 (0.0)	2 (0.1)	0.076
Haemorrhage	6 (0.4)	2 (0.2)	7 (0.4)	0.612
Sepsis	16 (1.1)	7 (0.6)	7 (0.4)	0.050
Ileus	49 (3.4)	36 (3.2)	32 (1.8)	0.011
Other complication	90 (6.2)	77 (6.8)	150 (8.5)	0.042
Missing	0 (0.0)	5 (0.4)	2 (0.1)	
Severe complications within 30 days, n (%)	55 (3.8)	31 (2.7)	34 (1.9)	0.007
Missing	37 (2.6)	44 (3.9)	91 (5.1)	
Complication severity according to Clavien–Dindo classification, n (%)				0.021
None	1231 (85.3)	960 (84.9)	1,534 (86.5)	
1	56 (3.9)	49 (4.3)	53 (3.0)	
2	64 (4.4)	47 (4.2)	61 (3.4)	
3a	32 (2.2)	13 (1.1)	19 (1.1)	
3b	20 (1.4)	14 (1.2)	12 (0.7)	
4a	1 (0.1)	1 (0.1)	0 (0.0)	
4b	1 (0.1)	0 (0.0)	0 (0.0)	
5	1 (0.1)	3 (0.3)	3 (0.2)	
Missing	37 (2.6)	44 (3.9)	91 (5.1)	
Reoperation, n (%)	26 (1.8)	15 (1.3)	25 (1.4)	0.561
Missing	10 (0.7)	13 (1.1)	19 (1.1)	

Temperature is measured in degrees Celsius. Length of stay is measured in days. A severe complication is defined as a Clavien–Dindo classification ≥ 3a

ASA American Society of Anaesthesiologists, *WBC* white blood cell count, *CRP* C-reactive protein, *OR* operating room, *SIRS* systemic inflammatory response syndrome, *CT* computed tomography, *AAST* American Association for the Surgery of Trauma

skills with technical skills by ensuring that active participation occurs throughout the operation. Our data demonstrate this alignment across a vast array of cases and metrics including AAST severity grading, number of comorbidities, or ASA classification. Trainee autonomy inversely varied with case complexity across a gradient from independence to supervised operating to participating in a case performed by the attending. While this observation appears to be intuitively satisfying, it bears additional implications for data and outcome analysis.

Given that, at least in our snapshot audit data, complexity and trainee autonomy appear linked, one would not anticipate identifying meaningful differences in patient outcomes. Indeed, the most complex patients were operated upon by the attending surgeon. Unsurprisingly, our data demonstrate no significant outcome differences based on operator experience across 14 different countries and 71 unique care facilities. Complications, as well as severe complications assessed by Clavien–Dindo classification, were similar across all levels of operator experience; approximately 85% of patients demonstrated no complication. Accordingly, the breadth and homogeneity of this data render appendectomy in training facilities a less ideal operation to use to query the impact of surgical training on outcomes. Furthermore, hLOS is sufficiently short that evaluating prolonged hLOS as a quality indicator—outside of those who present with septic shock—is an inadequate surrogate for virtually any aspect of usual care.

The results of the current study demonstrate that trainees, on average, operate on younger and healthier patients and face lower case complexity compared to their attendings. This observed trend may explain why the duration of the procedure was on average longer for attendings compared to trainees and why there was no significant different in duration between attendings and trainees operating under attending supervision. While difference in mean operating

Table 2 Incidence Rate Ratios (IRR) for postoperative complications after an appendectomy, based on the surgeon's experience

Outcome	IRR (95% CI)	*p* value
Any complication		
Attending	Ref	
Trainee	1.03 (0.83–1.28)	0.781
Supervised trainee	1.13 (0.89–1.42)	0.320
Severe complication		
Attending	Ref	
Trainee	0.82 (0.51–1.33)	0.436
Supervised trainee	0.90 (0.55–1.47)	0.689

Poisson regression models with robust standard errors. Multiple imputation with chained equations was used to manage missing values. The models are adjusted for age, sex, American Society of Anaesthesiologists classification, previous abdominal surgery, ischaemic heart disease, insulin dependent diabetes, congestive heart failure, chronic renal disease, smoking history, immunosuppression, American Association for the Surgery of Trauma disease severity, time to OR in hours from admission till operation, laparoscopic surgery, conversion to open surgery, open surgery, white blood cell count, neutrophil count, C-reactive protein level, and operating country

Table 3 Change in median length of stay after an appendectomy, based on the surgeon's experience

	Change in median length of stay (95% CI)	*p* value
Attending	Ref	
Trainee	−0.07 (−0.14 to 0.01)	0.105
Supervised trainee	0.02 (−0.08 to 0.12)	0.690

Quantile regression model. Multiple imputation with chained equations was used to manage missing values. The model was adjusted for age, sex, American Society of Anaesthesiologists classification, previous abdominal surgery, ischaemic heart disease, insulin dependent diabetes, congestive heart failure, chronic renal disease, smoking history, immunosuppression, American Association for the Surgery of Trauma severity, time to OR in hours from admission till operation, laparoscopic surgery, conversion to open surgery, open surgery, white blood cell count, neutrophil count, C-reactive protein level, and operating country. Length of stay is measured in days

time between trainees and attendings (68 min vs 50 min, $p < 0.0001$) has been observed in laparoscopic appendectomy [8], other studies investigating accumulated surgical experience or surgical learning curve show that operating duration seems to decrease with increased procedural volume, before reaching a plateau [28–32]. However, there are factors in addition to surgical experience which also affect operating duration which this study outlines. Furthermore, there were no differences in the average hLOS between trainees and attendings. This is in line with the findings of other studies [8, 33–38] and may be explained by the fact that other patient factors such as whether the appendix is perforated or not are more important than the level of the surgeon performing the operation. In addition, there was no significant difference in the observed overall 30-day morbidity between trainees and attendings or between attendings and trainees under attending supervision. When adjusting for potential confounders there were still no significant differences the level of the operating surgeon and surgical outcomes in terms of postoperative complications and hLOS. However, an unadjusted subgroup analysis of the incidence of pelvic abscesses, ileus and sepsis showed that attendings had a statistically higher prevalence compared to trainees. A valid explanation to this finding could be the increased case complexity (higher AAST grading) and increased comorbidity burden of the surgical cases carried out by the attending group. In addition, we believe these findings support our hypothesis that the traditional apprenticeship model which offers gradually granted autonomy counteracts any possible links between surgical inexperience and postoperative adverse events.

The current study is strengthened by its prospective nature, homogenous patient population and its large patient cohort collected across multiple participating. There are, however, some limitations that require highlighting. Fundamental differences in patient characteristics and disease severity grading exist between groups arbitrarily defined by level of trainee operative involvement. While this would severely confound propensity-matched analysis of outcomes between these groups, we believe this analysis, at such a granular level, requires a prospective randomized control trial design. Instead, our analysis intended to assess graded operative autonomy as it intersects with case complexity. Our data may not represent outcomes in those with clinically severe obesity as the mean BMI was < 30. However, the laparoscopic approach (once the ports are placed) is often easier than the open approach. We cannot detail the precise level of Attending surgeon supervision that may range from verbal cueing while not scrubbed into the operation to specific intervention while scrubbed. Similarly, it is unknown which technical parts of the procedure were carried out by the trainee and the attending. It is also likely that there are some cultural differences in the teaching process between the participating countries. In some training systems, a trainee is considered independent even though a more experienced surgeon is present in the operating room to provide mentorship unscrubbed. This may lead a shorter operating time and lower 30-day morbidity, given that the unscrubbed attending can verbally intervene without partaking physically. In contrast, in others it is more common that a trainee be left alone in the operating room when considered independent but trusting that the trainee calls for help when needed. While it might be interesting to evaluate for differences between a 1 year compared to a

20 year Attending and a last year of residency trainee, we were unable to collect granular data on the number of years of experience of either the Attendings or the trainees, as the alignment of skill sets, and a short LOS would require a vast study to accomplish. The omission of the training level of trainee was in part a conscious decision anchored in a desire not to overcomplicate the data collection instrument with definitions that may not be universal. However, in hindsight, not collecting data on the level of trainee experience/seniority was an opportunity missed. Instead, we focused on supervision as an indicator of autonomy. Furthermore, the level of the operating surgeon was decided based on the surgeon's title stated on the data collection sheet, i.e., trainee or attending. Therefore, the split between the attending versus trainee groups was not based on the total number of years of surgical experience. The length of surgical training differs between countries which is why it is possible that a surgeon considered a junior attending in some countries would be considered a senior trainee in other countries. This represents another example of cultural differences and a limitation of the current study. Moreover, the length of time to complete surgical training may differ between countries adding complexity to the evaluation of Attending experience. Therefore, a binary designation of Attending versus trainee was much more readily deployable.

Conclusion

Evaluating appendectomy outcomes is unlikely to yield useful data regarding the impact of developing surgeon experience on patient level or facility outcomes because of case alignment with skill sets. Case complexity may drive how trainees are engaged in cases, especially in the era of work hours restrictions—all learning should be of high value, ensuring active participation is maximized. This prospective multicenter snapshot study demonstrates that clinical outcomes following appendectomy do not differ depending on the level of the operating surgeon. We believe this may be explained by an association between case complexity and a well-functioning apprenticeship model where trainee autonomy gradually increases. The current study demonstrates that graduated autonomy is successfully deployed across the continuum of case complexity.

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