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Original Article

Deciphering the inflection points to achieve proficiency for each procedure step during training in laparoscopic appendicectomy

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Abstract

Background: Laparoscopic appendicectomy is a common procedure early in surgical training. A minimum number is usually required for certification in general surgery. However, data on proficiency are scarce. This study aimed to investigate steps towards proficiency in laparoscopic appendicectomy.

Methods: This was a prospective observational cohort study of laparoscopic appendicectomies performed by junior trainees under supervision scored on a six-point performance scale. Structured assessment was done within a defined programme. Procedures performed for uncomplicated appendicitis in adults were included. The procedures were evaluated with LOWESS graphs generated to investigate inflection points. Factors associated with proficiency rates were reported with odds ratios and 95 per cent confidence intervals.

Results: In total 142 laparoscopic procedures were included for 19 trainees (58 per cent female). The cumulative number of procedures during the study was a median of 20 (i.q.r. 8–33). For overall proficiency, an inflection point occurred at 30 procedures. Proficiency rate increased from 51 per cent for 30 or fewer procedures to 93 per cent for more than 30 procedures (odds ratio 11.9 (95 per cent c.i. 3.4 to 40.9); $P < 0.001$). Inflection points for proficiency for each procedure step varied considerably, with lowest numbers (fewer than 15 procedures) for removing the specimen, and highest for dividing the mesoappendix (more than 55 procedures). Operating time was significantly reduced by a median of 7 minutes after 30 procedures, from median 62 (i.q.r. 25–120) minutes to median 55 (i.q.r. 30–110) minutes for more than 30 procedures.

Conclusion: For junior trainees, variation in proficiency is related to specific procedure steps. Targeted training on specific procedure skills may reduce numbers needed to achieve proficiency in laparoscopic appendicectomy during training.

Introduction

Appendicitis is one of the most common surgical emergency conditions worldwide[1,2]. Accordingly, appendicectomy is one of the most frequently performed emergency general surgery procedures[2,3]. The vast majority of appendicectomies are now done laparoscopically based on favourable outcomes and recommendations by society guidelines[4–7]. There is still, however, notable geographical variation between and within countries in the rate of laparoscopy used for this procedure[3,8]. This may be related to training and level of comfort of the surgeon with the procedure but also to availability of laparoscopic instrumentation, especially in developing countries. Exposure to appendicectomy is gained early on in surgical training with a majority performed by trainees, with safe outcomes reported across studies[9–11]. Notably, both the number of procedures performed and the rate done by laparoscopy compared with open have increased considerably over the years[12].

A minimum number of appendicectomies have been required by many accrediting bodies in order to complete training in general surgery. However, limited data on numbers needed to achieve proficiency exist. Also, there is great variation within programmes in terms of requirements during training[13] as well as exposure to appendicitis and appendicectomy based on demographics of the population and population-catchment area of the hospitals. Learning curves for simulator models have been reported[14–16], and data for single surgeons have been presented[17,18]. However, these are standardized models and may not reflect true proficiency for the procedure. Notably, procedure numbers may not reflect actual proficiency in performance. With increasing pressures from working-time restrictions[19], the request for standardized, structured and simulation-based training has emerged. The request for standardization in education and surgical practice has been received with mixed feelings[20], but the

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need for a competence-based focus in training has become evident[21].

The aim of this study is to investigate the learning curve for laparoscopic appendicectomy performed for uncomplicated appendicitis by junior trainees to evaluate the specific steps towards proficiency.

Methods

A prospective observational cohort study was carried out of junior trainees performing real-life laparoscopic appendicectomy in a structured training programme in a single centre. The STROBE guidelines were consulted and adhered to, where applicable[22].

Ethical approval

The study was approved by the Regional Ethics Committee (REK 2018/811) and Data Protection Officer at Stavanger University Hospital. Consent was obtained from all participating trainees, senior residents and consultant surgeons.

Study setting

The study was undertaken in a university hospital, one of the busiest and largest in Norway. The programme involved all trainees and consultants covering general and gastrointestinal emergency surgery on-call. Staff involved in the study underwent a structured train-the-trainer course prior to commencement. Evaluations were done prospectively over a 12-month period, using a predefined scoring sheet and using set criteria for assessment.

Inclusion and exclusion criteria

The study was set up to investigate junior trainees performing laparoscopic appendicectomy in a structured setting and for a standardized procedure. Every consecutive laparoscopic appendicectomy performed by a junior trainee supervised by a chief resident or consultant surgeon was eligible for inclusion if assessment forms had been completed by both trainer and trainee. Appendicectomies performed overnight (between 23.00 and 7.00 hours) were excluded. Only appendicectomies in adolescents (16 years or over) and adults were included.

Semi-standardization of procedure complexity and evaluation

For the sake of standardization of a real-life situation for evaluation and comparison between procedures, all appendectomies done for complex or perforated appendicitis (even if performed by the junior trainee in its entirety) were excluded. Hence, only uncomplicated appendectomies were included for assessment.

Procedures were scored on a predefined sheet, and for each step of the procedure as well as for the overall assessment of the entire procedure.

Procedure steps

A predefined set-up and structured approach to laparoscopic appendicectomy was agreed and taught through eight steps. All procedures were performed under general anaesthesia by a standard three-port approach. Abdominal cavity entry was done by the open (Hasson's) technique[23], with a 12-mm port in the umbilicus, a 12-mm port in the left iliac fossa and a 5-mm port over the symphysis pubis. A camera with 30° optics was used with 12–14 mmHg capnoperitoneum unless specific conditions required other pressures. Atraumatic graspers were used for manipulation and handling of intestines, the haemostasis of the appendicular artery and of the mesoappendix was sequentially secured by bipolar diathermy and cutting by cold scissors. The appendix was secured using two endo-loop sutures and cut with cold scissors between loops. The specimen was extracted in an endo-bag through the 12-mm left iliac fossa port. Fascia was closed with 1/0 Vicryl® (polyglactin 910) Ethicon Inc., Cincinatti, Ohio, USA) sutures and intracutaneous sutures and strips used for skin closure.

Assessing self-training

In order to gauge trainees' consistency in self-training attitude after completion of a formal introductory and structured training programme of both theory and practical training, the resident recorded whether they had performed further training on a simulation dry-lab tool or rehearsed procedure steps on a web-based

Table 1 Characteristics based on number of procedures

	Procedure groups		Odds ratio†	P (Chi-square)
Characteristics	≤30 procedures	>30 procedures		
Gender				
Female	46 (45)	16 (40)	1.2 (0.6–2.6)	0.582
Male	56 (55)	24 (60)		
Operating time				
Duration (mins)*	62 (25–120)	55 (30–110)		0.038
≥60 minutes	59 (66)	15 (39)	0.7 (0.3–1.5)	0.339
Proficiency				
Yes	52 (51)	37 (93)	11.9 (3.4–40.9)	<0.001
No	50 (49)	3 (7)		
Use of simulation‡				
Yes	23 (29)	3 (10)	0.3 (0.1–0.9)	0.031
No	56 (71)	28 (90)		
Use of web tools‡				
Yes	37 (46)	7 (23)	0.3 (0.1–0.9)	0.022
No	43 (54)	24 (77)		

Values in parentheses are percentages unless indicated otherwise; *values are median (i.q.r.), †values in parentheses are 95 per cent confidence intervals.‡Numbers may not add up due to missing data.

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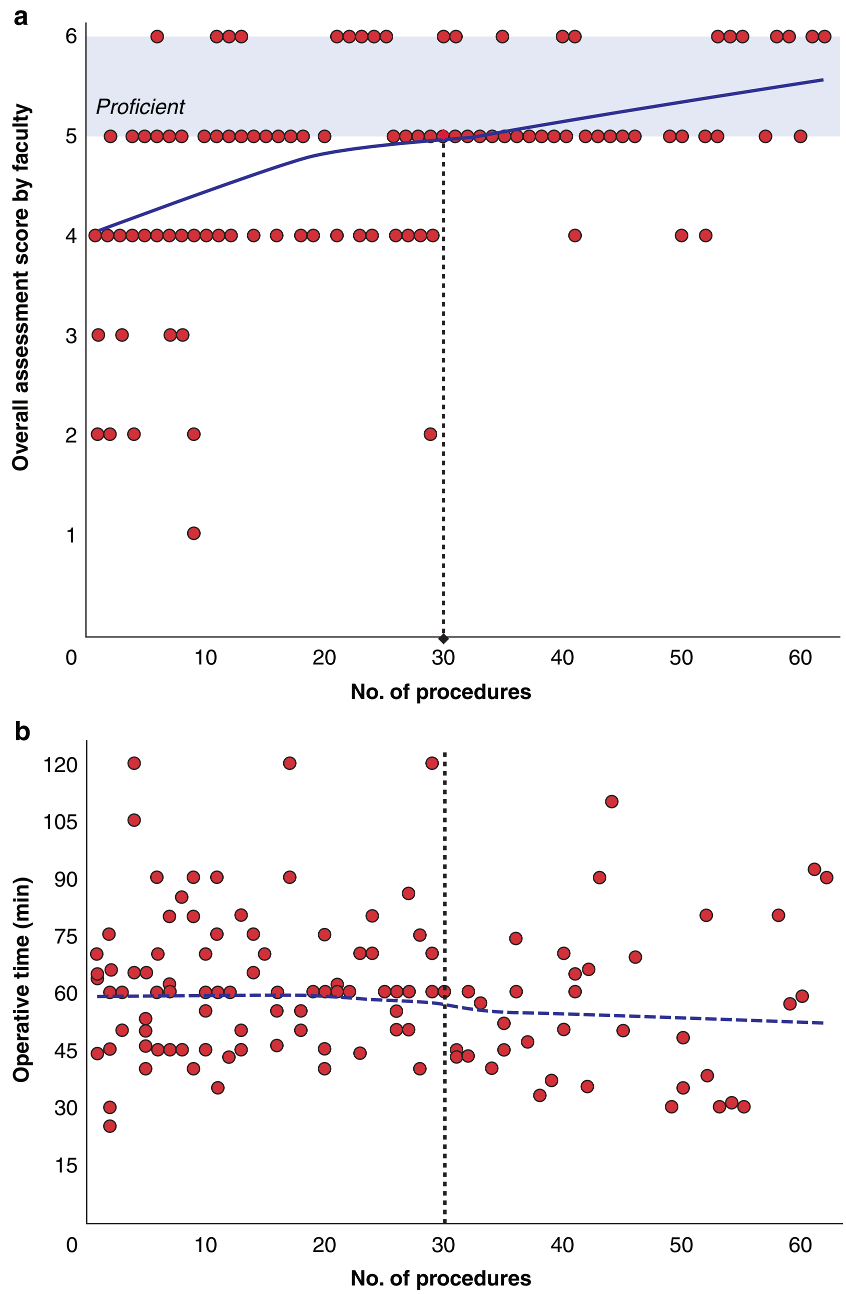

Fig. 1 Effect of procedure numbers on learning curve and operation time

a A LOWESS curve of the increasing number of procedures and proficiency-score on a six-point scale based on the faculty evaluating overall assessment of the completed procedure. The curve shows the suggested inflection point at 30 procedures. **b** The accumulated number of procedures and effect on operating time. Dashed line suggests the inflection point whereby most residents gained proficiency based on overall assessment score.

platform (for example, WebSurg) in the week prior to performing a laparoscopic appendicectomy.

Cumulative sum of procedures

This was a cross-sectional consecutive cohort of appendectomies performed by trainees, so some trainees had previous experience with laparoscopic appendicectomy and hence started the programme and evaluation after a set number of procedures. Other trainees started at time of the study or entered general surgery training by rotating from other surgical services. Hence, rather than reporting the individual trainee data, the cumulative sum of procedures of each surgeon was reported. Accordingly, the deflection curves do not reflect an individual learning curve but rather reflect the cumulative procedure number required to obtain a proficiency score for each step of the procedure.

Definitions

Proficiency was defined as a score of 5 or above on a six-point scale[24], based on the score given by the supervisor to the trainee. Learning curves were achieved by plotting experience (number of procedures performed) on the x-axis, and score by instructor (six-point scale) on the y-axis. Graphically interpreting the learning curves, the inflection point was defined as the number of procedures required to reach a 'proficiency' score, for each step of the procedure and for the overall procedure assessment.

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Table 2 Proficiency rates for each step and overall assessment based on procedure volume

Step number and explanation	≤30 procedures	>30 procedures	Odds ratio*	P (Chi-square)
1. Abdominal entry				
Proficient	57 (58)	35 (92)	8.6 (2.5–29.8)	<0.001
Non-proficient	42 (42)	3 (8)		
2. Placing the trocars				
Proficient	68 (67)	37 (95)	9.0 (2.0–39.5)	0.001
Non-proficient	33 (33)	2 (5)		
3. Identifying the appendix				
Proficient	70 (69)	38 (95)	8.4 (1.9–37.1)	0.001
Non-proficient	31 (31)	2 (5)		
4. Handling bowel				
Proficient	57 (58)	34 (87)	4.9 (1.8–13.6)	0.001
Non-proficient	41 (42)	5 (13)		
5. Dividing mesoappendix				
Proficient	36 (36)	25 (63)	3.0 (1.4–6.3)	0.004
Non-proficient	64 (64)	15 (37)		
6. Dividing appendix				
Proficient	58 (59)	33 (83)	3.3 (1.3–8.3)	0.007
Non-proficient	41 (41)	7 (17)		
7. Removal of specimen				
Proficient	68 (69)	35 (88)	3.2 (1.1–8.9)	0.022
Non-proficient	31 (31)	5 (12)		
8. Closure of fascia				
Proficient	69 (69)	33 (85)	2.5 (0.9–6.5)	0.061
Non-proficient	31 (31)	6 (15)		
Overall assessment				
Proficient	52 (51)	37 (93)	11.9 (3.4–40.9)	<0.001
Non-proficient	50 (49)	3 (7)		

Values in parentheses are percentages unless indicated otherwise; *values in parentheses are 95 per cent confidence intervals.

Compliance was defined as the rate of trainees who documented completion of simulation exercises or rehearsal of web-based educational tools prior to performing live surgery for laparoscopic appendicectomy.

The operative time for each procedure was defined as 'knife in' to 'knife out' and recorded in minutes.

Statistical analyses

Statistical analyses were done by Social Package for Social Sciences for Mac version 26 (IBM® SPSS® Statistics; Armonk, NY, USA). Data are described by medians and ranges or interquartile ranges. Categorial variables were analysed by χ^2 or Fisher's exact test. Continuous data were analysed using non-parametric tests. To identify inflection points for a learning curve effect, non-parametric locally weighted smoothing (LOWESS; LOcally WEighted Scatter-plot Smoother) was used to fit a continuous curve across the continued sum of procedures recorded. The LOWESS smoother was estimated by starting with the first procedure, using 80 per cent of the data closest to each point (span = 0.8). All tests were two-tailed and statistical significance set at $P < 0.050$.

Results

During the study period 409 laparoscopic appendicectomies were performed. There were 142 laparoscopic appendicectomies done for uncomplicated acute appendicitis by junior trainees and for which formal assessment was available. A total of 19 trainees in general surgery participated, of which 11 (58 per cent) were female. The numbers of evaluated procedures were 62 (44 per cent) for female and 80 (56 per cent) for male trainees. The cumulative number of procedures registered per trainee during the study was a median of 20 (i.q.r. 8–33). There were no differences in the number or rate of cumulative procedures done by male and female trainees (*Table 1*).

The overall learning curve towards proficiency is depicted in *Fig. 1*. With an increasing number of cumulative procedures (*Fig. 1a*), there was a higher number of procedures for which the trainee was scored 5 points or more for overall performance. An inflection point at 30 procedures was noted (*Fig. 1a*), above which most trainees gained a 'proficient' score on the overall assessment evaluation. The proficiency for each step of the procedure is represented in *Table 2*, and for the overall assessment, proficiency increased from 51 per cent among those who had performed 30 or fewer procedures to 93 per cent among the more experienced trainees (more than 30 procedures). With an increasing number of cumulative procedures, a decrease in operating time was noted (*Fig. 1b*). Operating time was significantly reduced by a median of 7 minutes after 30 appendicectomies (*Table 1*). Overall, the proportion of operations lasting 60 minutes or more dropped non-significantly, from 66 to 39 per cent, after 30 procedures (*Table 1*).

The inflection point for each of the procedure steps is presented in *Fig. 2*. The steps of placing trocars, identifying the appendix, removing the appendix and closure seem to have the steepest learning curve, and the inflection point is noted at around 15 procedures. After 20 procedures, proficiency is achieved for safe entry of the abdomen and division of the appendix. Another five procedures (giving a total of 25) are necessary to reach proficiency for handling of bowel, and the inflection point for overall assessment reaches proficiency at around 30 procedures. Even so, it is noted that it takes around 50 to 60 procedures before proficiency is reached for dividing the mesoappendix.

Use of and compliance with training and simulation opportunities are presented in *Fig. 3*. The figures depict the use of simulation tools and web tools, respectively, related to duration of operation (in minutes) and the number of procedures performed.

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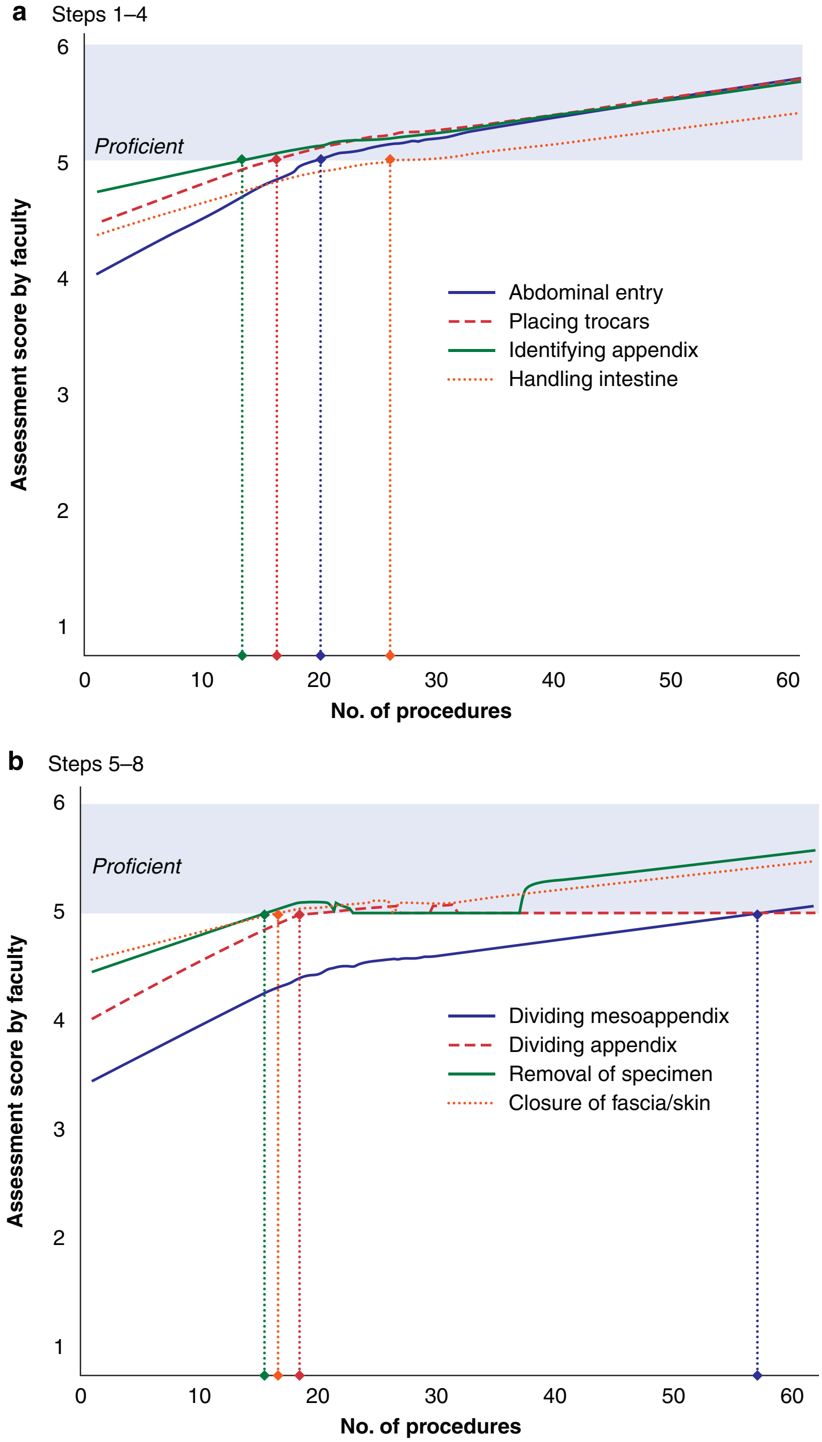

Fig. 2 The inflection points for proficiency for each of the procedural steps

Assessments given by the faculty to the residents for **a** steps 1–4: safe entry, placing, trocars, identifying appendix and handling bowel; and **b** steps 5–8: dividing appendix, dividing mesoappendix, removing appendix and closure. The dotted lines represent the cut-offs for the inflection points for proficiency (score of 5 or 6) for each step.

Discussion

The present study demonstrates an overall inflection point for procedure proficiency for laparoscopic appendicectomy at about 30 procedures. Notably, each step has considerable variation, with greater than 50 procedures required for certain steps to demonstrate proficiency in the task when performed by junior trainees. The findings have implications for training and for how specific tasks can be subject to simulation and practice outside the operating room. Identifying the challenging steps clearly can be valuable to surgical educators when planning curricula for more efficient surgical training to reach proficiency.

The certification of surgeons has been based historically on a fixed number of procedures as a proxy for proficiency. The European Association for Endoscopic Surgeons consensus guidelines suggested that residents should perform a minimum of 20

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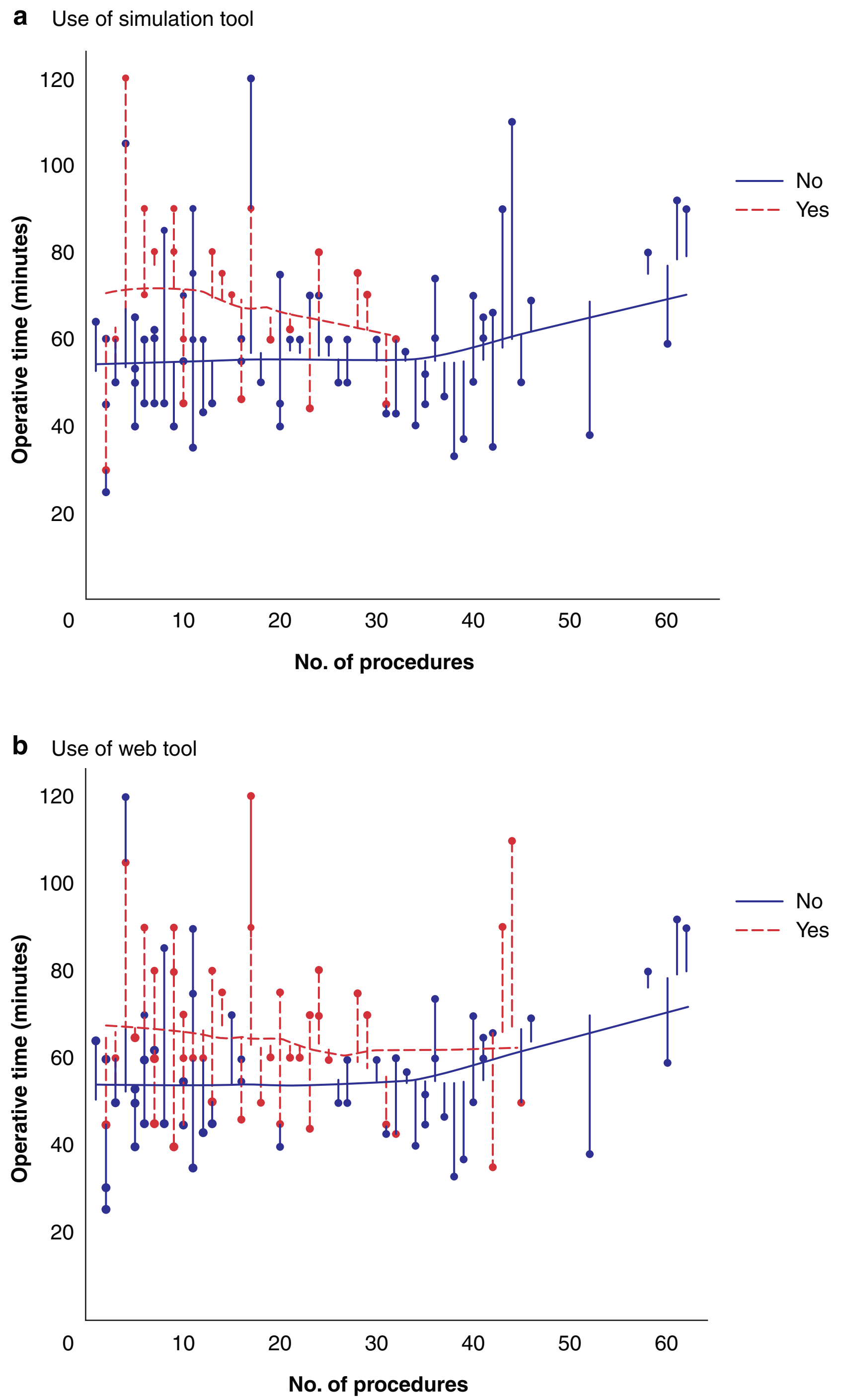

Fig. 3 Use of simulation and web tools related to procedure time

Self-reported use of either **a** simulation training in a dry lab the week prior to performing a procedure, or **b** web-based learning tools the week prior to surgery. Both learning modalities are also explored for effect on procedure time in relation the number of procedures. Note residents may have used learning tools more frequently than displayed, as this relates to the specific reported use in the week before having done a laparoscopic appendicectomy.

laparoscopic appendicectomies before accreditation[25]. This would be in line with most, but not all, steps based on the present study. There is no clear evidence for the minimum number of procedures needed to achieve proficiency and safety[26]. Other studies have found the learning curve for laparoscopic appendicectomy to range between 11 and 35 procedures[17,18]. However, none of the previous studies have considered the tasks of each step, nor do they suggest specific training to enhance or amplify the training process. Also, previous studies have been based mostly on single or a few surgeons only, while the present study investigates a cohort of junior trainees.

In the present study, the cumulative number of procedures needed for overall proficiency was about 30 laparoscopic appendicectomies. However, the variation in number of procedures required to master any step varied: up to 60 procedures were necessary to safely divide the mesoappendix, while proficiency

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was reached after as few as 15 procedures for placing the trocars. The study emphasizes the need for specific and targeted training on the different steps. For example, placing trocars is about understanding triangulation, relation in trocar positions and avoiding landmarks (for example, not perforating the epigastric vessels), all of which are done with hand–eye coordination on the abdominal surface with aided visualization by the laparoscopic camera. The mesoappendix division may be interpreted as a particular step that requires the trainee to master the two-hand technique (left- and right-hand coordination in a three-dimensional space) with two-dimensional camera vision while making sure to use bipolar diathermy safely, and secure the appendicular artery efficiently and safely while using scissors to expose the appendiceal base.

The operating time was significantly reduced after performing 30 procedures and this is consistent with other studies[26]. The operating time also seemed to be related to compliance, in that the trainees using webtools and simulation tools had a longer operating time initially but this decreased after reaching proficiency. However, time is a surrogate for proficiency and many confounders may explain small variations in operating time.

The use of simulation training and web-based tools reduced with increasing number of procedures done. Several reasons may explain this. One is the lack of specific appendicectomy models for simulation training. The basic laparoscopy skills programme is generic and meant to foster training in using laparoscopy per se. Fatigue in the tasks available for training may result. Use of models that lack fidelity with the real procedure and repetition of simple tasks may be viewed as mundane. Also, available time may be an issue, as designated time to use dry labs and simulation rooms are not incorporated into the trainee rotation at this time. Thus, after completing the compulsory courses of simulation training, the trainees may defer further training over doing real-life surgery. Structured assessment and implementation should be done to explore any structured effect of compulsory, continued training and effect on real-life performance. This would be in line with current thinking and models for training[27,28], moving away from counting procedures and rather working towards competency and autonomy[21].

This study has some limitations. The study was performed in a single institution in a Nordic training environment and may not apply to other countries. However, there is no evidence to suggest that surgical trainees in Nordic countries fare any better or worse than in other regions and laparoscopic appendicectomy is a common procedure which trainees are exposed to at an early stage in most systems. The results therefore are likely to have a wide applicability and can be generalized beyond the study site. Also, the standardized description of the procedure steps is in line with previous reports[29]. Further, any other previous experience in surgery, the trainee age and even gender may have affected the study results. The possible variation in previous exposure has not been controlled for but the entry level (less than 4 years) of training and sample size of 19 residents with a balance of male and female trainees ensures a reasonable spread in demographics while maintaining a focus on junior trainee training level. This study focused on uncomplicated appendicitis to reduce the likely variation in difficulty that would come with more overt disease severity and perforated appendicitis. Further studies need to investigate how trainees' proficiency in uncomplicated appendicectomy can be transferred to management of more complex disease states. In further studies, other procedures performed by the trainees should also be taken into account as additional experience might lead to an underestimation of the learning curve. Of note, several methods exist to gauge learning curves and score competencies, with no universal agreement of one method being superior to others[30–32]. However, most of these are aligned in a tiered evaluation towards proficiency scored by the supervisor or trainer, which has inherent subjectivity. This also applies to the six-point Likert scale used in this study as this has not been formally validated for laparoscopic appendicectomies.

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