


Comparative Performance in Single-Port Versus Multiport Minimally Invasive Surgery, and Small Versus Large Operative Working Spaces: A Preclinical Randomized Crossover Trial

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Abstract

Background. Surgical approaches such as transanal endoscopic microsurgery, which utilize small operative working spaces, and are necessarily single-port, are particularly demanding with standard instruments and have not been widely adopted. The aim of this study was to compare simultaneously surgical performance in single-port versus multiport approaches, and small versus large working spaces. **Methods.** Ten novice, 4 intermediate, and 1 expert surgeons were recruited from a university hospital. A preclinical randomized crossover study design was implemented, comparing performance under the following conditions: (1) multiport approach and large working space, (2) multiport approach and intermediate working space, (3) single-port approach and large working space, (4) single-port approach and intermediate working space, and (5) single-port approach and small working space. In each case, participants performed a peg transfer and pattern cutting tasks, and each task repetition was scored. **Results.** Intermediate and expert surgeons performed significantly better than novices in all conditions ($P < .05$). Performance in single-port surgery was significantly worse than multiport surgery ($P < .01$). In multiport surgery, there was a nonsignificant trend toward worsened performance in the intermediate versus large working space. In single-port surgery, there was a converse trend; performances in the intermediate and small working spaces were significantly better than in the large working space. **Conclusions.** Single-port approaches were significantly more technically challenging than multiport approaches, possibly reflecting loss of instrument triangulation. Surprisingly, in single-port approaches, in which triangulation was no longer a factor, performance in large working spaces was worse than in intermediate and small working spaces.

Keywords

minimally invasive surgery, endoscopy, laparoscopy, single-port surgery, single-incision laparoscopy, SILS

Introduction

Minimally invasive surgery (MIS) is arguably the greatest innovation in surgery of the past 30 years.^{1,2} Although most surgeons can perform the majority of multiport adult laparoscopic surgery safely and effectively, the clinical penetration of MIS in other specialties has been variable (Table 1).

Single-port laparoscopic surgery has been suggested as a less invasive alternative to standard multiport laparoscopic surgery, but is more technically challenging, principally due to the difficulty triangulating standard instruments.³⁻⁶ Pediatric laparoscopic surgery may also

be more technically challenging than standard adult laparoscopic surgery because of the difficulty manipulating instruments within small operative working spaces.⁷ Surgical approaches incorporating the smallest operative working spaces, and are necessarily single-port, such as

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Table I. Examples of Multiport Versus Single-Port Surgery in Large, Intermediate, and Small Working Spaces.

	Multiple Ports	Single Port
Large working space, 34 225 cm ³ (Fundamentals of Laparoscopic Surgery box trainer)	Adult laparoscopy	Single incision laparoscopic surgery (SILS)
Intermediate working space, 1620 cm ³ (Pediatric Laparoscopic Surgery box trainer)	Pediatric laparoscopic surgery	Pediatric single incision laparoscopic surgery
Small working space, 81 cm ³		Transanal endoscopic microsurgery Transoral endoscopic microsurgery Transcranial endoscopic microsurgery

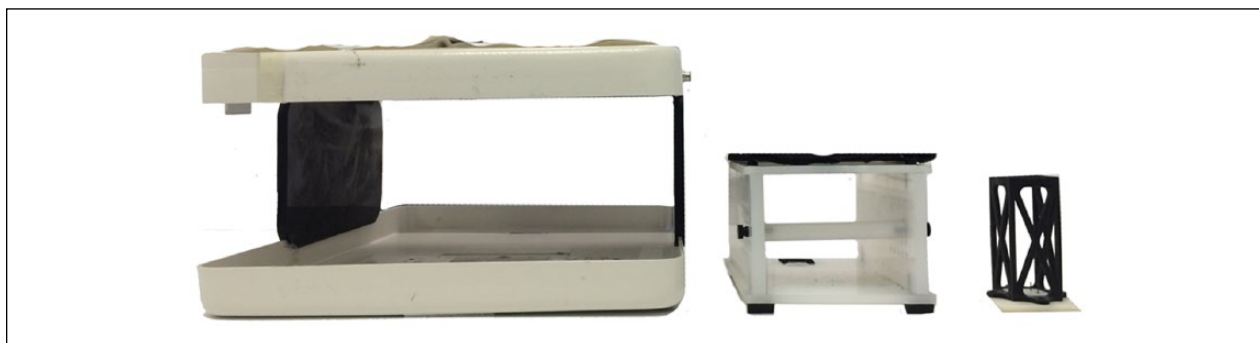


Figure 1. Adult FLS trainer box (left), pediatric PLS trainer box (center), and custom box (right), representing large, intermediate, and small working spaces, respectively.

transoral endoscopic microsurgery, transanal endoscopic microsurgery, and transcranial endoscopic microsurgery, are particularly demanding⁸⁻¹⁰ and have not been widely adopted by their respective surgical communities.

To date, several studies have compared surgical performance in single-port versus multiport approaches,^{4,5,11} but few have compared performance in small versus large working spaces,⁷ and no previous studies have evaluated the influence of both variables simultaneously. The primary aim of this study was therefore to compare simultaneously surgical performance in single-port versus multiport approaches, and small versus large working spaces. The secondary aim was to validate modified tasks and a custom training box to simulate single-port surgical approaches in the smallest operative working spaces.

Materials and Methods

Participants and Study Settings

Ten novice (<10 laparoscopic procedures per year) and 5 intermediate or expert (10-50 and >50 laparoscopic procedures performed per year, respectively) surgeons were recruited from one university hospital. It was decided a priori that intermediate and experts surgeons would be combined for subsequent analysis. Informed consent was obtained from all participants.

All participants underwent a single training session to familiarize themselves with the instruments and tasks. A total of 5 repetitions were performed in each of the trial conditions (see trial design below); previous studies have demonstrated that such a practice is usually sufficient to overcome the initial learning phase.¹²

Trial Design

A preclinical randomized crossover study design was implemented, comparing performance under the following conditions: (1) multiport approach and large working space, (2) multiport approach and intermediate working space, (3) single-port approach and large working space, (4) single-port approach and intermediate working space, and (5) single-port approach and small working space.

An Adult Fundamentals of Laparoscopic Surgery (FLS) trainer box, with internal dimensions 500 × 370 × 185 mm, and a volume of 34 225 cm³, was used for the large working space (Figure 1). A Pediatric Laparoscopic Surgery (PLS) trainer box, with internal dimensions 180 × 100 × 90, and a volume of 1620 cm³ (reduced by a factor of 20), was used for the intermediate working space. A custom cuboid with dimensions 30 × 30 × 90 mm, and a volume of 81 cm³ (reduced by a further factor of 20), was used for the small working space; this is representative of, for example, transanal and transcranial approaches.¹³⁻¹⁵

In multiport approaches, the endoscope port was located at the top center of the adjacent face of the cuboid, with instruments ports on either side. In single-port approaches, a SILS port (Covidien, Mansfield, MA) was located at the top center of the adjacent face of the cuboid. The tasks were placed on a base such that the manipulation angle was 45°, allowing for optimal ergonomics.¹⁶

The peg transfer and pattern cutting drills were selected from the McGill Inanimate System for Training and Evaluation of Laparoscopic Skills (MISTELS)¹⁷ to represent simple and complex tasks, respectively. The drills were modified so as to fit within all the working spaces, including the 30 mm cuboid. The peg transfer drill requires that rings on the left side of the pegboard are grasped with the instrument in the left hand, lifted off the peg, transferred to the instrument in the right hand, and then placed on the right side of the pegboard. After all the pegs are transferred, the process is reversed (see Figure 2). The size of the rings were reduced by approximately a factor of 4 compared to the adult drill (height 4 mm vs 19 mm), and the number of rings transferred reduced to 2. The cutting drill was chosen because it requires considerable dexterity¹⁴ and, unlike suturing, cutting is performed in most MIS procedures.¹⁸ The pattern cutting drill requires participants use scissors to cut a 20-mm diameter circular pattern from a square piece of gauze. The diameter of the circular pattern was also reduced by a factor of 2 compared to the adult drill (20 mm vs 40 mm). The use of smaller peg transfer and pattern cutting tasks with single and multiport approaches have been previously validated in pediatric laparoscopic surgery simulators,⁷ and we recruited novices, intermediates, and experts in the present study for further evidence of construct validity.

Conventional 5-mm rigid laparoscopic graspers and scissors (Ethicon Endo-Surgery, Cincinnati, OH) were used for manipulation. A VisionSense III neuroendoscopy system (Visionsense, Petach Tikva, Israel) was used for visualization. The HD 0° rigid endoscope is 4 mm in diameter, and 18 cm in length, providing a resolution of 1920 × 1200 pixels. Images were displayed using a 24-in. stereoscopic screen.

Participants were randomly allocated using a computer-generated sequence to determine the order of the experimental conditions in which they performed the drills. Each participant was asked to perform the drills once in each condition, with participants given a maximum of 100 seconds to perform the peg transfer task, and 300 seconds to perform the pattern cutting task.

Outcomes

The primary outcome was the total score (nonnormalized MISTELS-based criteria¹⁷). For the peg transfer drill: timing score = 100 seconds minus task completion time

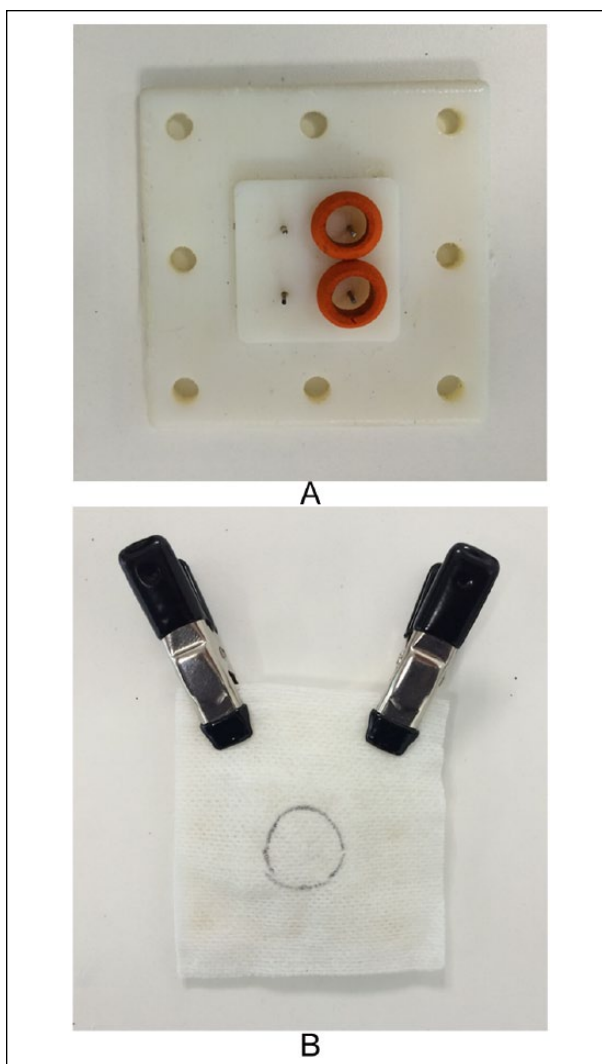


Figure 2. Modified peg transfer (A) and pattern cutting (B) tasks.

(seconds); penalty score = percentage of pegs dropped outside the field of view, or outside of reach; total score = timing score minus penalty score. For the pattern cutting drill: timing score = 300 seconds minus time to complete the exercise (seconds); penalty score = percentage area of deviation from a perfect circle; total score = timing score minus penalty score.

Whereas participants were aware of the instruments they are using, the data analysts were blinded to their allocation.

Statistical Analysis

The sample size was calculated on the basis of recently published work that reported the total score of novices performing the pattern cutting drill using standard instruments was 52 ± 16 ,⁷ and on a pilot study using the

Table 2. Demographics of Participants.

	Novice (n = 10)	Intermediate (n = 4)	Expert (n = 1)	Overall (N = 15)
Age (in years), median (range)	27.5 (22-33)	31 (29-33)	34	28 (22-33)
Sex, male:female	7:3	4:0	1:0	12:3
Handedness, right:left	10:0	4:0	1:0	15:0

Table 3. Performance of the Modified Peg Transfer Task^a.

Working Space	Multiple Ports		Single Port	
	N	I-E	N	I-E
Large	57 (42.5-63.8) <i>P</i> = .004	71 (70-76)	-7.5 (-42.5 to 1.5) <i>P</i> = .007	52 (40-55)
Medium	49 (45.8-54.8) <i>P</i> = .022	73 (71-76)	28.5 (2.5-45.5) <i>P</i> = .047	67 (60-70)
Small			38 (16-47.5) <i>P</i> = .019	63 (60-66)

Abbreviations: N, novice; I-E, intermediate-expert.

^aProbabilities represent comparison between novice and intermediate-expert performance.

aforementioned methodology. We estimated that to detect a 50% increase in total score in experts, with a 2-sided 5% significance level and a power of 80%, a sample size of at least 8 novice surgeons and 4 intermediate-expert surgeons, was necessary.

Data was analyzed with SPSS v 20.0 (IBM, Chicago, IL). A value of *P* < .05 was considered statistically significant. The median and interquartile ranges (Q1-Q3) were calculated for the primary outcome measures.

The Mann-Whitney *U* test was used to compare performance between novices and intermediates-experts in each of the study conditions to evaluate construct validity.

Performance was then compared in the different study conditions using the Kruskal-Wallis one-way analysis of variance. If a significant difference was identified, we then directly compared the following groups, with the Bonferroni correction (*n* = 5; *P* < .01): any multiple ports versus any single port; multiple ports with large working space versus medium working space; single port with large working space versus medium working space; single port with large working space versus small working space; and single port with medium working space versus small working space.

Results

Baseline Demographic Data

The demographics of the participants are summarized in Table 2. The expert surgeon had experience with both standard multiport surgery and single-port surgery (including approximately 50 transanal endoscopic

microsurgery procedures). All participants that were enrolled completed the study, and no losses occurred after randomization.

Outcomes

The median and interquartile ranges of performance for the modified peg transfer and pattern cutting tasks are summarized in Tables 3 and 4, respectively. The intermediate-experts performed significantly better than novices in all conditions, confirming construct validity of the modified tasks and custom box trainer (*P* < .05; Tables 3 and 4).

Peg Transfer. The Kruskal-Wallis one-way analysis of variance demonstrated significant variation in the performance of novices in the different study conditions (*P* < .001; Figure 3). Performance in single-port surgery was significantly worse than multiport surgery (*P* < .001). Performance with multiport surgery and a large working space was not significantly different to a medium working space (*P* > .1). Performance with single-port surgery and a large working space was worse than a medium or small working space, approaching significance (*P* = .089 and *P* = .011, respectively).

The Kruskal-Wallis one-way analysis of variance also demonstrated significant variation in the performance of intermediates-experts in the different study conditions (*P* < .001). Performance in single-port surgery was significantly worse than multiport surgery (*P* = .001). Working space did not significantly influence the performance of experts (*P* > .1).

Table 4. Performance of the Modified Pattern Cutting Task^a.

Working Space	Multiple Ports		Single Port	
	N	I-E	N	I-E
Large	152.5 (117.5-174.5) <i>P</i> = .003	215 (202-223)	-35 (-100 to 47.5) <i>P</i> = .014	120 (115-121)
Medium	150 (125.3-168.8) <i>P</i> = .024	188 (176-199)	69.5 (-7 to 140.8) <i>P</i> = .050	155 (154-195)
Small			75.5 (6-97.3) <i>P</i> = .010	167 (135-195)

Abbreviations: N, novice; I-E, intermediate-expert.

^aProbabilities represent comparison between novice and intermediate-expert performance.

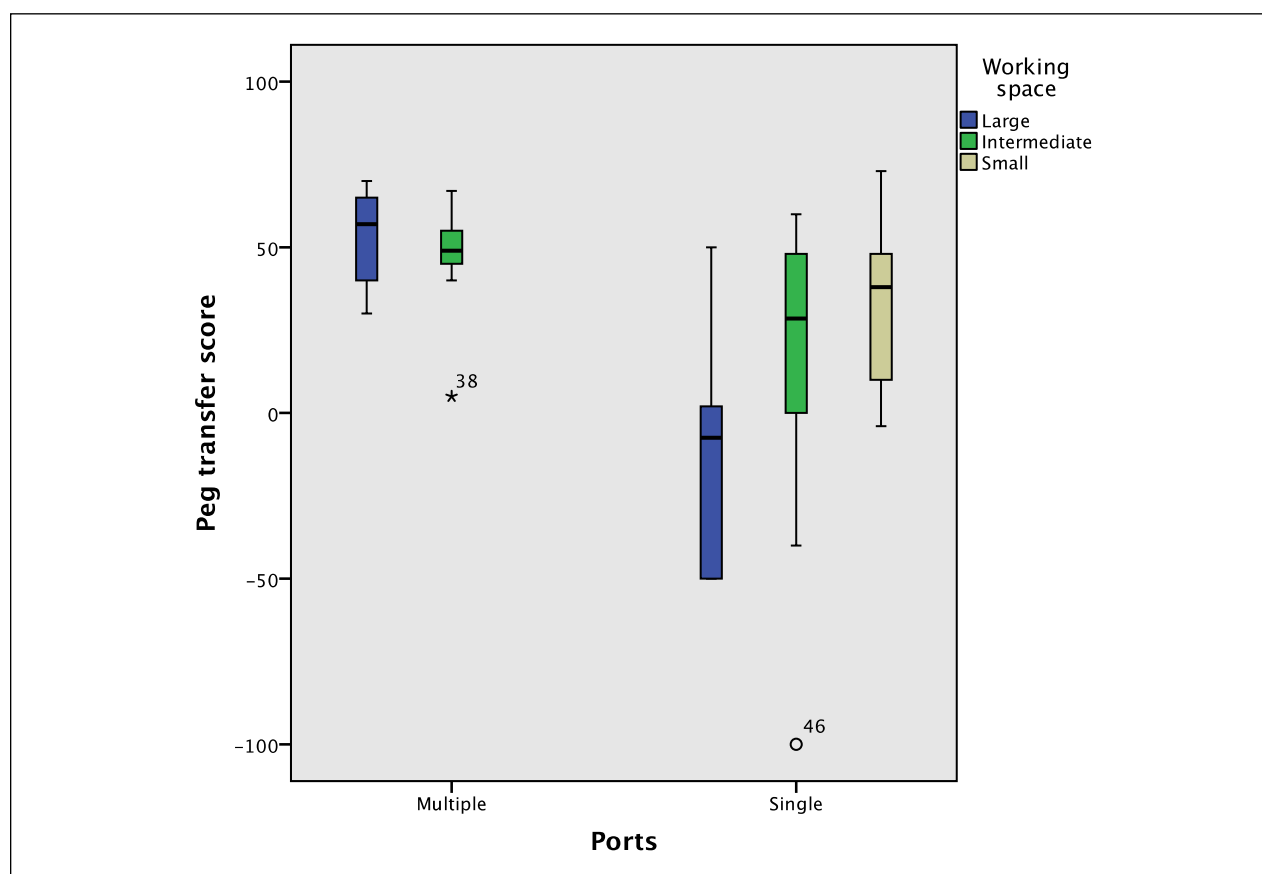


Figure 3. Performance of the modified peg transfer tasks by novices in different experimental arrangements (circle greater than 1.5 times the interquartile range; star greater than 3 times the interquartile range).

Pattern Cutting. The findings for the pattern cutting task were comparable to the peg transfer task. The Kruskal-Wallis one-way analysis of variance demonstrated significant variation in the performance of novices in the different study conditions ($P < .001$; Figure 4). Performance in single-port surgery was significantly worse than multiport surgery ($P < .001$). Performance with multiport surgery and a large working space was not significantly different to

a medium working space ($P > .1$). Performance with single-port surgery and a large working space was worse than a medium or small working space, approaching significance ($P = .075$ and $P = .026$, respectively).

The Kruskal-Wallis one-way analysis of variance also demonstrated significant variation in the performance of intermediates-experts in the different study conditions ($P < .001$). Performance in single-port

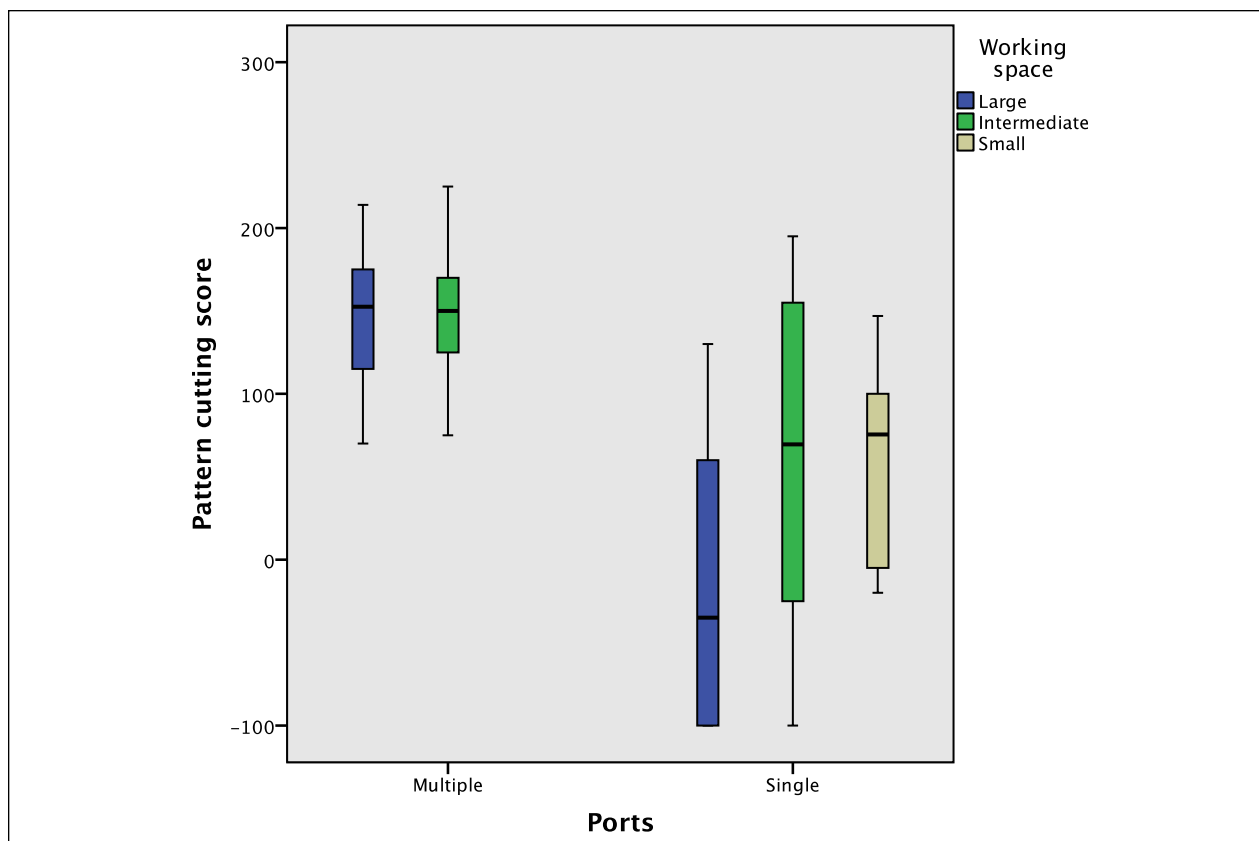


Figure 4. Performance of the modified pattern cutting tasks by novices in different experimental arrangements.

surgery was significantly worse than multiport surgery ($P = .004$). Working space did not significantly influence performance in experts ($P > .1$).

Discussion

In this study, we have validated modified tasks and a custom box trainer to simulate single-port surgical approaches in the smallest operative working spaces. Moreover, we have compared simultaneously performance in single-port versus multiport approaches, and small versus large working spaces. In keeping with previous studies, we identified that single-port approaches are significantly more technically challenging than multiport approaches, irrespective of the level of experience of the surgeon, or the nature of the surgical task performed, reflecting loss of instrument triangulation.^{4,5} Interestingly, the influence of working space on surgical performance was variable. In multiport approaches, there was a nonsignificant trend toward worsened performance in smaller working spaces, perhaps resulting from reduced triangulation, as the instrument ports were necessarily placed closer together. In singleport approaches, in which triangulation was no longer a factor, performance in large working spaces was,

surprisingly, worse than in intermediate and small working spaces.

Several studies have previously compared the performance of surgeons when performing laparoscopic tasks through single-port versus multiport access. Cox et al randomized 40 medical students into 2 groups, using single-port and multiport access.⁵ Both groups were trained in 4 basic laparoscopic drills (including peg transfer and pattern cutting), before being crossed over to the alternate approach. Participants in the single-port group took more time to reach proficiency (178.0 ± 93.4 vs 119.1 ± 69.7 minutes; $P = .058$), with significantly greater repetitions (118.8 ± 54.3 vs 77.6 ± 42.6 ; $P = .027$). Santos et al⁶ and Lewis et al⁴ performed similar randomized crossover studies, confirming these findings in novice surgeons, and also suggesting that experience can mitigate, at least to some extent, the technical barriers associated with loss of triangulation in single-port surgery.^{4,6}

Few studies have looked at the effect of working space on performance of laparoscopic surgery, though many surgeons have argued that operating within smaller working spaces such as the pediatric abdomen is inherently more technically challenging than standard laparoscopy.⁷ Azzie et al developed and validated the PLS box trainer

simulator used in the present study, and they found that the revised total PLS scores in their simulator were considerably worse than in the adult FLS trainer box.⁷ Our study also trended toward worsened performance in multiport approaches in the PLS trainer box, compared to the adult FLS trainer box. However, in contrast to the aforementioned multiport approaches, we found a trend toward *improved* performance in single-port approaches in smaller working spaces. We speculate this may be the result of instruments being more frequently lost outside the operative field when performing tasks through single-port approaches and large working spaces, particularly in the hands of novices. Nonetheless, no previous studies have previously assessed the impact of smaller working spaces in single-port approaches, and further investigation is merited to confirm and extend these findings.

Limitations

It should be noted that this study has limitations. Intermediate and expert surgeons were combined for analysis due to lack of experts familiar with uncommon and difficult single-port approaches in the smallest operative working spaces. Nonetheless, the significant difference in performance between novices and intermediates-expert surgeons supports use of modified tasks and a custom box trainer.

The sizes of the tasks themselves, while appropriate in the small custom box and intermediate pediatric training box, may have been mismatched in the large adult FLS training box. While this does not in itself invalidate the findings of this study, it suggests that it is not the physical constraints of the operating working space per se but rather the size of the tasks themselves that may be particularly important in determining operative performance. This may, at least to some extent, explain the reason that performance in smaller working spaces was not significantly worse and, in single-port approaches, actually better than in larger working spaces, despite an abundance of anecdotal evidence to the contrary.

Generalizability

The generalizability of this study is likely to depend on several other factors including the experience of the surgeon with a particular approach, the instruments and endoscopes used, and the size and complexity of the surgical task performed. Nonetheless, the finding that instrument triangulation is perhaps the most critical determinant of surgical performance is likely to hold true, and has been corroborated by other groups comparing multiport and single-port approaches.³⁻⁶ This insight supports the efforts of several groups to improve the performance of surgeons in single-port approaches through improved training and technology. In the near future, advances in

surgical simulation and laparoscopic instruments may shorten the learning curve for these technically challenging procedures.

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Acquisition of data: Hani J. Marcus, Carlo A. Seneci, Archie Hughes-Hallett, Thomas P. Cundy

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Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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