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Evaluation of a novel low-cost laparoscopic training model for core laparoscopic skills☆

Damir Ljuhar [a,b,c], Maurizio Pacilli [a,b], Ramesh Mark Nataraja [a,b,c,*]

[a] Department of Paediatric Surgery, Monash Children's Hospital, Clayton, Victoria 3168, Melbourne, Australia
[b] Departments of Paediatrics & Surgery, School of Clinical Sciences, Faculty of Medicine, Nursing and Health Sciences, Monash University, Melbourne, Australia
[c] Department of Surgical Simulation, Monash Children's Hospital, Clayton, Victoria 3168, Melbourne, Australia

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ABSTRACT

The study involves the testing of a novel laparoscopic training model by surgeons of various levels of experience.
Background: There has been an increasing requirement for low-cost simulation. Our aim was to evaluate the construct validity of a low-cost model for teaching core laparoscopic skills.
Methods: The Double-Glove model was made from 2 latex gloves, one placed in the other. The inner glove was filled with water and 3 ovals were drawn on the outer glove. Participants were required to dissect the middle oval out without perforating the inner glove or leaving the line border of the middle oval. The task was assessed using a previously validated scoring system (minimum −120; maximum 80).
Results: Ninety-five participants completed the task: 40 novices, 45 intermediates, and 10 experts. The model revealed statistical significance between the three groups. Experts scored higher than novices (58/80 vs 11.7/80; $p < 0.0001$) and intermediates (58/80 vs 29.1/80; $p = 0.0004$), and intermediates scored higher than novices (29.1/80 vs 11.7/80; $p = 0.014$). Novices took more time to complete the task compared to intermediates (10 min vs 7.87 min; $p < 0.0001$) and experts (10 min vs 6.98 min; $p < 0.0001$). No correlation between time taken and score obtained was seen ($r = -0.06$, $r = 0.01$, $r = -0.2$ for novice, intermediate, and expert groups).
Conclusion: By differentiating between groups of variable experience, the model demonstrated construct validity. It offers an inexpensive model that can be utilized in low-cost laparoscopic simulation.
Type of Study: Study of a diagnostic test.
Level of Evidence: II.

Simulation-based medical education (SBME) is developing an increasing body of evidence supporting both its benefits and validity in medical education, at both an undergraduate [1] and postgraduate surgical training level [2]. The increasing importance and presence of simulation in surgery has been the result of a multitude of reasons including; advances in minimally invasive surgical techniques and technologies, reductions in working time and subsequent decreased training opportunities, and increased awareness of patient safety [3,4].

Laparoscopic surgery in particular has been shown to benefit from using deliberate practice with simulation [5]. Indeed, there has been a growing need for lost-cost laparoscopic simulation in a range of settings. As trainees are faced with increasing requirements and decreased exposure, low-cost simulation offers evaluated and easy to create models for their own self-directed learning.

There has also been an increasing evidence base in the literature for low-cost laparoscopic simulators and models [6]. We recently published an evaluation study of a novel box-trainer model simulating a laparoscopic inguinal hernia and diaphragmatic hernia repair [7]. The Laparoscopic Inguinal and Diaphragmatic Defect (LIDD) model showed construct and content validity in simulating a procedure specific task required for pediatric surgery. In follow-up to this low-cost and easily reproducible model, we aimed to develop a model to address core laparoscopic skills that may be transferrable to all minimally-invasive surgery.

The Double-Glove model is based on a previous pilot study utilizing inexpensive materials to simulate core laparoscopic skills [8]. It involves an inner glove that is filled with water, and an outer glove that is separated from the inner with plastic tubing. The participants are required to carefully dissect a pre-drawn oval on the outer glove without leaving the drawn line and without perforating the inner glove. The model engages core psychomotor domains fundamental to all laparoscopic surgery. These include domains of tissue handling, intracorporal precision cutting and dissection, depth perception, and the realization of a 3D environment onto a 2D screen. The model is unique in that it also

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* Corresponding author at: Department of Surgical Simulation, Monash Children's Hospital, 246 Clayton Road, Clayton, Victoria 3168, Melbourne, Australia. Tel./fax: +61 3 85723838.
E-mail address: ram.nataraja@monashhealth.org (R.M. Nataraja).

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aims to simulate a tissue plane, where participants are required to operate in one plane (outer glove) without disturbing the deeper plane (inner glove). This creates a more complex model compared to other low-cost models seen in other courses and programmes. This not only involves the fine motor skill needed for intracorporeal cutting and tissue handling of fragile tissue, but it also relies on depth perception significantly more. There is also the added pressure of avoiding perforation of the inner water-filled glove, which is simulating stress, a factors known to affect cognitive and psychomotor performance [9]. This is of particular relevance to pediatric surgery, where tissue plans are often thinner, less defined, and straying away from them may lead to more significant consequences.

The aim of the current study was to evaluate the previously published model, and in doing so complement the procedure specific skills addressed by the LIDD model with core laparoscopic skills applicable to a broader range of learners.

1. Material and methods

1.1. Participants

Participants were recruited from all skill levels including; medical students, surgical trainees, and surgical consultants. Students and trainees were recruited from the local institution as part of the regular surgical educational curriculum. Surgical consultants were recruited from the pediatric surgical department of the Monash Childen's Hospital. Participants were to be assigned into either novice (medical student), intermediate (surgical trainee), or expert (surgical consultant) groups for analysis.

All participants completed a standardized pre-course questionnaire assessing basic demographics. The questionnaire also assessed previous laparoscopic experience including number of laparoscopic operations observed, assisted, and performed. No participants had trained on the glove model prior to the study. All data were collected over two identical sessions. Participants consented for their data to be used for the purposes of the following study with approval of the local institution (MCHSIM2019–4).

1.2. The Double-Glove model

The Double-Glove model was created using two non-sterile latex gloves and plastic tubing (Fig. 1). Three pre-determined ovals were drawn on the outer glove, with a red middle oval (Fig. 1A.). The inner and outer gloves were separated by 14 cm of plastic from an IV-giving set (Fig. 1B and C), and the inner glove was filled with 400 ml of

Fig. 1. Construction of the Double-Glove model; **A.** 3 pre-determined circles are drawn on the outer glove; **B** and **C.** The inner and outer glove are separated by 14 cm of plastic tubing; **D.** The inner glove is filled with 400 ml of water and secured with a zip-tie.

Fig. 2. A. Screenshot of a Double-Glove model dissection **B.** Dissected oval showing division into 8 segments.

water and secured with a zip-tie (Fig. 1D.). The total cost of the model was AUD$0.29.

1.3. The simulator

The model was evaluated on an eoSim™ box-trainer simulator (eoSurgical, UK) with a tablet (iPad; Apple Technology, CA, USA) as the video source and a portable battery as a light source. 5 mm eoSurgical branded laparoscopic instruments were used. All participants first completed two previously evaluated warm-up exercises on the simulator over a 10-min period under the supervision of one of the authors. Participants subsequently watched a pre-recorded video demonstrating the exercise and had 20 min to complete the task. The attempts were anonymised for blinded assessment through the use of candidate numbers for each participant's recorded attempt video. All attempts were scored by two of the authors independently utilising the scoring criteria described below.

1.4. Scoring

The exercised involved dissecting out the red oval without a) perforating the inner glove filled with water, and b) leaving the edges of the red line. Points were awarded based on how many of the 8 segments had been dissected out successfully. Fig. 2A. shows a screenshot of the Double-Glove dissection and Fig. 2B. shows the dissected red oval and how it is divided into 8 segments to assign positive point values. Points were subsequently deducted based on the number of times the participants deviated from the red line, and if they crossed into the inner or outer circle black line. The greatest proportion of point deduction was placed on whether there was perforation of the inner glove, as this would was deemed to represent a potential injury to underlying tissues in an actual laparoscopic procedure. The maximum score was 80 points (successful dissection of all 8 segments without leaving the red line and without perforating the inner glove), and the minimum was −120 points. The scoring rubric is summarized in Table 1.

1.5. Timing

The time taken to complete the Double-Glove model was recorded for each attempt. The final time was considered the time from the first cut into the glove until complete excision of the oval. The time was capped at 20 min.

1.6. Analysis

Data were collected on a database (Microsoft Excel 2016, Microsoft Corporation®, Redmond, WA, USA) and analyzed using GraphPad Prism version 8.0.0 (GraphPad Software, Inc., La Jolla, CA, USA). Results are reported as mean (standard deviation, SD) and median (range). Data distribution was confirmed using normality testing on GraphPad Prism (D'Agostino & Pearson normality test) and analyzed with a Mann–Whitney test (p value <0.05 being considered significant). One-way ANOVA and Kruskal-Wallis tests were used to compare multiple samples simultaneously.

2. Results

A total of 95 participants were recruited into the study; 40 medical students (novice group), 45 surgical trainees (intermediate group), and 10 surgical consultants (expert group). Table 2 summarizes the basic demographic data. There was no significance between the three groups in gender, however there was a statistically significant difference in age and self-reported experience.

2.1. Score comparison

All 95 participants were included in the analysis with no participant taking longer than 20 min. The scores are summaries in Table 3.

The scores improved with increasing levels of experience of the participants. There was statistical significance between each of the three groups with experts scoring better than the intermediate ($p = 0.0004$) and novice ($p < 0.0001$) groups, and the intermediate group scoring better than the novice group ($p = 0.014$).

Table 1
Scoring rubric for the Double-Glove model.

Step 1: Dissection of oval segment		Step 2: Crossing the red line		Step 3: Crossing the black line		Step 4: Perforation of inner glove	
No. of segments dissected	Score	No. of times crossed	Score	No. of times crossed	Score	No. of perforations	Score
1	+10	**0**	0	**0**	0	**0**	0
2	+20	**1–3**	−10	**1–2**	−20	**1–2**	−30
3	+30	**4–6**	−20	>**3**	−30	**3–4**	−40
4	+40	**7–9**	−30			>**5**	−50
5	+50	>**10**	−40				
6	+60						
7	+70						
8	+80						

Table 2
Basic demographic data of the participants.

	Novice	Intermediate	Expert	*p*-Value
Gender				
Male	26	24	7	0.44
Female	14	21	3	
Age				<0.001
<25	39	6	0	
25–29	1	31	0	
>29	0	8	10	
No. observed				<0.001
>50	0	8	10	
10–50	20	31	0	
<10	19	6	0	
None	1	0	0	
No. assisted				<0.001
>50	0	3	10	
10–50	9	20	0	
<10	12	21	0	
None	19	1	0	
No. performed				<0.001
>50	0	0	10	
10–50	0	0	0	
<10	0	8	0	
None	40	37	0	
Total	**40**	**45**	**10**	

Furthermore, a Kruskal-Wallis test comparing the score of the three groups showed statistically significant difference ($p < 0.0001$) (Fig. 3A.).

2.2. Task completion time comparison

Time was seen to decrease with increasing levels of experience (Table 2). However, while a Kruskal-Wallis test comparing the time between all three groups shows statistical significance (Fig. 3B; $p < 0.0001$), this was not seen when the groups when individually compared. The novice group took more time than the intermediate ($p < 0.0001$) and expert ($p < 0.0001$) groups, there was no statistically significant difference between the intermediate and expert groups ($p = 0.26$).

Similarly, no correlation between time and score obtained was seen in any of the groups. The score-time correlation for the novice group was -0.06 (Fig. 4A., (95% confidence interval: -0.3 to 0.2; $p = 0.7$), 0.01 for the intermediate group (Fig. 4B., (95% confidence interval: -0.2 to 0.3; $p = 0.9$), and -0.2 for the expert group (Fig. 4C., (95% confidence interval: -0.7 to 0.4; $p = 0.4$).

3. Discussion

We have previously evaluated the Laparoscopic Inguinal and Diaphragmatic Defect (LIDD) model, a low-cost model that aimed to engage procedure specific laparoscopic skills essential for pediatric surgery. The current Double-Glove model, however, engages core psychomotor domains fundamental to all laparoscopic surgery. It offers a more complex yet still low-cost model that more deeply engages both psychomotor and cognitive surgical skills. More specifically it creates a model that simulates a tissue plane which is a fundamental aspect of surgery that is often difficult to simulate. Likewise, the 'perforation' of the inner glove introduces a metric error that is easily measurable – it is either perforated, or it is not. Metric errors are performance characteristic that deviate from optimal performance and have been described as some of the most important performance units of SBME [10]. More so, it adds an element of stress not seen in previous models in which perforation of the inner glove has immediate and undesirable consequences. Stressors imposed on the learners during simulation-based training may help support the acquisition of stress management skills that are necessary in the applied clinical setting [9]. These skills may be more applicable to novice participants, as part of establishing foundational skills prior to advancement to procedure specific skills.

Our study reveals that the model is able to differentiate between various levels of laparoscopic competence. Experts scored better than intermediates and novices. Similarly, intermediates were shown to perform better than novices, hence confirming the construct validity of the model. As this model does not aim to simulate one particular procedure or task, content validation was not attempted. Likewise, as the Double-Glove model combines a number of different core tasks, there is no other specific model that tests the same domains in order to show concurrent validity.

For the purposes of this study, medical students were considered novice, surgical trainees intermediate, and surgical consultants were considered experts. In this instance, this is likely to be the most accurate way of classifying the three groups. When an attempt was made to define groups based self-reported experience alone, there was a clear mismatch between medical students and surgical trainees. That is to say, if a novice was to be defined by having no or minimal (<10) laparoscopic assisting experience, irrespective of level, surgical trainees still performed significantly better than medical students. Similarly, if the intermediate group was to be defined by as having more (>10) laparoscopic assisting and no or minimal (<10) laparoscopic performing experience, surgical trainees again performed better than medical students who selected the same experience level. This may represent a recall bias by the participants, or more likely, laparoscopic skill acquisition is more complex than simply the number of procedures observed or assisted. Indeed, open surgical experience may have an impact on laparoscopic skills that may account for the baseline difference. Only surgical consultants had performed more than 50 laparoscopic procedures, as such our definition of 'expert' seems to be accurate in this instance. However, this will likely need to be revisited in future studies where a distinction may need to be made between senior trainees who may have performed more than 50 laparoscopic procedures but still may not be considered experts.

One of the metrics assessed in this study was the time taken to complete the exercise. Time taken is a metric that is often used either in the assessment of skill acquisition [11], in the provision of metric-based feedback [12], or as a means of confirming skill transfer into the operating room (OR) [13]. In this instance, time taken was only able to differentiate the novices and there was no correlation seen between score and time within the groups. As such, while the time appears to be a traditionally used and easy to measure metric, it may not offer much use educational purpose, particularly in the novice trainee.

This model too can be utilized in any box-trainer or laparoscopic trainer and can easily be reproduced in a low-resource setting. In low-middle-income countries (LMICs), due to limited accessibility, acceptability, and often quality of minimally-invasive surgery [14], low-cost simulation such as this offers an effective means to address some of these issues [15]. Likewise, this low-resource setting can also be at home, where trainees of all experience and background may be able to have access to evaluated and easy to create models for their own self-directed learning, or as part of at-home surgical training curriculum. Use of low-cost simulation in both these settings, however, needs careful consideration prior to any implementation. In LMIC, a clear and sustainable model needs to be an overarching driver in the adaptation

Table 3
Summary of task scores and time to complete the procedure.

	Score (from 80)		Time (minutes)	
	Mean (sd)	Median (range)	Mean (sd)	Median (range)
Novice (n = 40)	11.7 (34.2)	20 (−50–70)	10.0 (2.35)	9.91 (5.5–15)
Intermediate (n = 45)	29.1 (24.4)	30 (−20–70)	7.87 (2.18)	7.74 (4.17–12.5)
Expert (n = 10)	58.0 (14.0)	60 (30–70)	6.98 (1.52)	7 (4.33–9)

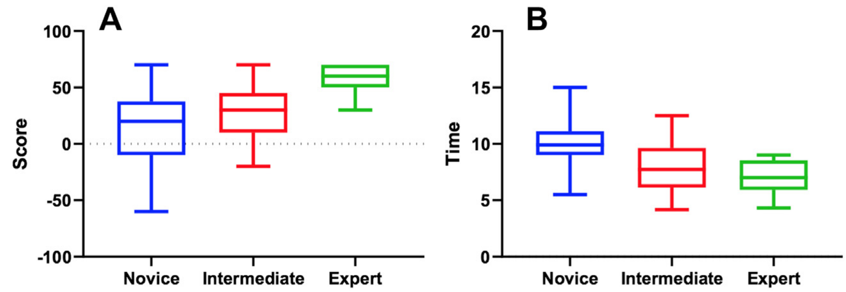

Fig. 3. Kruskal-Wallis one-way analysis **A.** Score ($p < 0.0001$) **B.** Time ($p < 0.0001$).

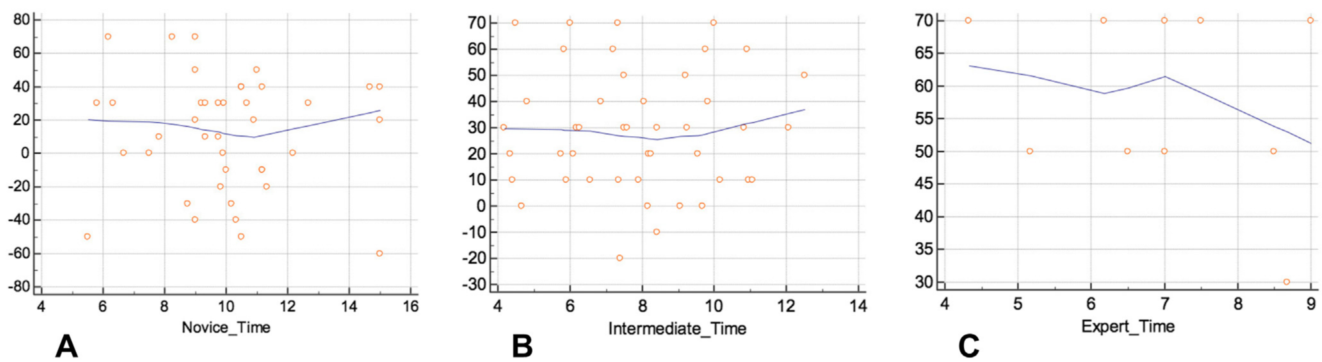

Fig. 4. Score-time correlation graphs **A.** Novice group (score-time correlation = −0.06; p = 0.7) **B.** Intermediate group (score-time correlation = 0.01, p = 0.9) **C.** Expert group (score-time correlation = −0.2; p = 0.4). No statistically significant correlation between score and time is seen within any group.

of laparoscopic surgery, with low-cost simulation simply being one of the tools in its delivery. Similarly, for any at-home laparoscopic training curriculum, the focus needs to be around the provision of effective feedback. Feedback has been shown to be one of the most important factors in the acquisition of skills [16] and effective learning [17], and this model should be considered as an avenue from which feedback can occur. In this instance, combining low-cost simulation with effective feedback may be a way to address the number of issues seen in the changing nature of modern surgical education. A future direction for research utilizing this model may be in the use of simulator-generated feedback (SGF) in which pre-determined and validated metrics can be used to provide trainees with simulator-generated real-time feedback. SGF allows for feedback that resembles that which an expert would provide in order to optimize independent learning and help overcome some of the barriers in SBME.

Slowly, it is becoming more evident how skills learnt in simulation are translating to the OR [18,19]. However, this has been difficult to quantify, and the literature remains sparse. The assumption from this model is that expert performance will translate to OR by way of improved psychomotor and cognitive surgical skills. While it is out of the scope of this study to measure this translatability, this model offers a quantifiable way of addressing this issue in the future. Similarly, with the newer standards for a unitary concept of construct validity, this model may not be suitable for high stakes validation such as certification, rather it may be reserved mainly for educational purposes as it was always intended.

4. Conclusion

This inexpensive and easy to reproduce model was able to successfully differentiate between various levels of laparoscopic experience, demonstrating construct validity for core laparoscopic skills. When combined with the previously evaluated procedure specific model, it offers to provide a more comprehensive low-cost simulation program that can be utilized with a range of laparoscopic simulators as well as in a range of settings.

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