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ORIGINAL ARTICLE

Design and preliminary evaluation of a low-cost laparoscopic training system for use in low-resource settings

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Abstract

Background: Despite the numerous benefits of laparoscopic surgery over open surgery, the adoption of laparoscopic surgery in low-resource settings has been slow. The lack of effective training models has been identified as the greatest barrier toward implementation of laparoscopy in this setting. We designed a laparoscopic training system which could be built with readily available materials. The aims of this study are to detail the construction of the laparoscopic training system components, to evaluate its ease of build and quality as a laparoscopic training tool, and to evaluate its ability to support completion of targeted tasks, such as salpingostomy and suturing in management of ectopic pregnancy. **Methods:** In April 2021, nine participants consisting of four general surgery attendings, three obstetrics/gynecology attendings, and two general surgery residents (1-PGY1 and 1-PGY3) from Ethiopia, Cameroon, Kenya, and the United States constructed and evaluated the laparoscopic training system. Participants evaluated the system using a web-based survey (Qualtrics, Seattle, WA) that queried construction, quality, ability to support performance of critical tasks, and educational value. **Results:** The laparoscopic training system was easily built with materials readily available locally and was replicable, sturdy, and realistic. Improvements were made in box dimensions, trocar placement, as well as medium of the ectopic pregnancy based on feedback. The system supported the ability to perform targeted tasks including salpingostomy and placement of a suture ligature and was felt to be a training and testing tool relevant to surgical practice. **Conclusions:** Our low-tech, low-cost laparoscopic training system may help to fill the educational gap in the training of laparoscopy in a low-resource setting.

Keywords: *simulation; laparoscopy; low-cost; low-resource; salpingostomy; box trainer*

Introduction

Laparoscopic surgery offers patients numerous benefits including reduced infection rates, decreased blood loss, decreased postoperative pain, and faster return to activity over open surgery.[1] However, its adoption in low-to-middle-income settings has been slow. Barriers to practice adoption include equipment availability, funding, education and training, acceptance from stakeholders, quality, and cost–benefit debate.[1,2] However, the lack of task trainers and effective, accessible training supplies—not cost or lack of equipment—has been identified as the greatest barrier toward the implementation of laparoscopy in low-resource settings.[3]

Box trainers have demonstrated value in supporting learners acquiring laparoscopic skills[4] especially learners who have modest laparoscopic experiences.[5] Structured practice on box trainers has been shown to result in improved resident skills, enhanced confidence, and retention of laparoscopic skills when compared to conventional learning in the operating room alone.[6,7] Additional evidence suggests that

learners who practiced using box trainers demonstrated shortened operating times for performance of a salpingectomy in actual patients.[8]

Numerous laparoscopic training systems are commercially available and range from more basic, minimalistic designs to sophisticated models with high-definition cameras that provide flexible views. Despite the wide range in levels of sophistication, laparoscopic training systems, including those considered 'low-tech' box trainers, showed similar trainee improvement in laparoscopic skills when compared with each other.[9,10] For example, Montanari et al.[4] demonstrated that participants training with a simple box trainer constructed of cardboard were able to achieve shorter task completion times when compared with participants without training. Similarly, Nagendran et al.[11] suggested that low-cost box training systems are effective for the acquisition of basic laparoscopic skills, while Akdemir et al.[12] found similar training efficacy of box trainers when compared to more sophisticated virtual reality simulators. Low-cost box trainers appear to provide equally effective simulation-based training opportunities as the more sophisticated and expensive systems for developing and improving basic psychomotor skills needed to perform laparoscopic surgery.[13,14]

Despite the wide range of features and sophistication, most currently available box trainers share numerous common limitations including single-view camera angles, software and external monitor requirements, small viewing screens, and energy dependence. Perhaps the biggest limitations in the low-resource setting, however, are availability and cost. A listing of commercially available box trainers that could be purchased at the time of the preparation of this article is found in Table 1. Because even low-cost commercial box trainers may be too costly and impractical to purchase in the low-resource setting, we sought to design a box trainer that could be constructed completely from common materials readily available in the home or hospital setting without requiring the purchase of any materials, electronics, or software. Further, we also sought to improve upon design limitations identified in existing low- and high-cost laparoscopic training systems.

Table 1. Commercially available box trainers in 2022

Product	Price	Originating company name
ENDO Simulator Box	$703	ENDO Instruments
Lap Tab Trainer	$440	3D-MED
Laparo Aspire ver. Basic	$451	Laparo Medical Simulators
Laplay Training Box	$369	One Half Design Co. Ltd
LapTrainer	$1250	Simulab
Lap-X Box	$2950	3B Scientific
Pyxus HD, Laparoscopic Simulator	$897	GT Simulators
T5 Large	$2835	3B Scientific

All prices are in US$.

Our collaborative group, the African Laparoscopic Learners for Safe Advancement for Ectopic Pregnancy (ALL-SAFE), comprised of surgeons from Ethiopia, Cameroon, Kenya, and the United States, designed a laparoscopic training system model. The ALL-SAFE laparoscopic system consists of a box trainer that replicates a laparoscopic field of the female pelvis (box trainer) and a task trainer that replicates a uterus and an ectopic pregnancy (task trainer). We anticipate that the box trainer, which also supports 0° and 30° laparoscopic camera views, could be easily built and used in a low-resource environment. We based the box trainer design on the design from van Duren and van Boxel[15] which utilized a cardboard box, cell phone, and a computer. We designed the ectopic pregnancy task trainer to support the practice of a laparoscopic salpingostomy in the box trainer due to its clinical relevance and requirement of higher-level laparoscopic skills, including the placement of a suture ligature, and typical use of an angled scope in the operative setting. Simulation-based education of the surgical treatment of ectopic pregnancy through salpingostomy has been described in mannequin models,[16] while laparoscopic salpingostomy has been described in virtual reality trainers.[17] This work is the first reported use of a low-cost ectopic pregnancy training system that employs a box trainer.

The aims of this study are to detail the construction of the low-cost ALL-SAFE training system components, to evaluate the components' ease of build and quality as a laparoscopic training tool, and to evaluate participants' ability to complete the targeted tasks on the system, such as salpingostomy and suturing in management of ectopic pregnancy.

Materials and methods

The ALL-SAFE laparoscopic training system

The first component of the ALL-SAFE laparoscopic training system, the box trainer, was constructed with office materials that were readily available at hospitals, academic offices, and local office supply stores at all participating low-to-middle-income country sites (Fig. 1 and Supplementary Appendix A). Additional technologies, including a video-capable cell phone, a computer (minimum of single core 1 GHz and 4 GB of RAM), and WiFi or Bluetooth connection, were recommended for assessment purposes. The box trainer was complemented by the second component, the

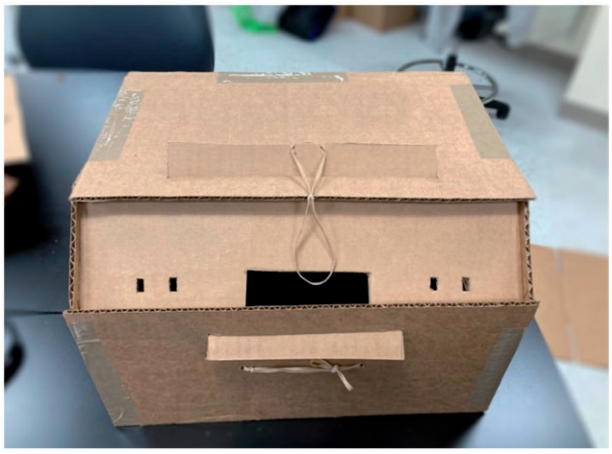

Figure 1. Box trainer.

Figure 2. Ectopic pregnancy task trainer.

ectopic pregnancy task trainer, which was similarly constructed with commonly available materials (Fig. 2 and Supplementary Appendix B). Cost analysis showed that the system could be built for less than US$10 from materials readily available in a hospital or home setting.

Required laparoscopic instruments included a needle driver, blunt grasper, curved tapered (Maryland) grasper, scissors, 10–12 mm trocars, and 2-0 silk suture (18–26 mm) on 1/2-inch taper needle. Supply list is shown in Supplementary Appendix C.

Study

In April 2021, nine participants evaluated the ALL-SAFE laparoscopic training system. The participants consisted of four general surgery attendings, three obstetrics/gynecology attendings, and two general surgery residents (1-PGY1 and 1-PGY3) from Ethiopia ($n=3$), Cameroon ($n=2$), Kenya ($n=1$), and the United States ($n=3$). None of the participants were part of the ALL-SAFE collaborative, and all participants were naïve to the testing platform and participated on a voluntary basis. The group self-reported their previous experience: they had managed between 0 and 50 laparoscopic ectopic pregnancies [mean (M) = 9.4, SD = 17.8], and between 20 and 1000 other laparoscopic cases (M = 415, SD = 387.8).

Participants evaluated the ALL-SAFE box trainer and the ectopic pregnancy task trainer using a web-based survey (Qualtrics, Seattle, WA). They first evaluated the box trainer across two domains: (a) ease of build using six items rated on Likert scales that ranged from 1 (strongly disagree) to 5 (strongly agree), with 3 representing the inflection point between disagree and agree throughout, and a seventh item to capture time to build the box trainer, and (b) the quality of the box trainer using another six items rated on Likert scales, a seventh 'overall quality' item and an eighth fill-in-the-blank item to capture suggestions for improvements. All participants also evaluated the ectopic pregnancy task trainer across the same two domains: (a) ease of build measured via two items, and (b) quality measured using another 11 items rated using Likert scales, and a 14th item used to capture time required to build the ectopic pregnancy task trainer. Rating means were reported and organized in tables.

Participants evaluated the overall quality of the ALL-SAFE box trainer in two ways: (a) by using four-point rating scales, ranging from 1 (the ALL-SAFE box trainer requires *extensive* adjustments before it can be considered for use in salpingostomy training) to 4 (the ALL-SAFE box trainer can be used in salpingostomy training with no improvements made), and (b) rating the value of the simulation using a four-point rating scale, scored as 1 (no value/relevance), 2 (little value/relevance), 3 (some value/relevance, and 4 (high value/relevance) with a 'don't know' option provided.

Table 2. Mean ratings associated with the ALL-SAFE box trainer's ease of build, $n = 4$

No.	Item	Mean (SD)	Meet criteria? (⩾3.0)
1.	Build instructions for the box trainer were easy to understand	4.50 (0.58)	Yes
2.	Materials required to build box trainer were easy to acquire	4.50 (0.58)	Yes
3.	Reproduced box trainer matched the intended design	4.50 (0.58)	Yes
4.	Box trainer is of adequately stable construction, overall	4.33 (0.58)	Yes
5.	Estimated time to build (mins)	90 (42.40)	–

Table 3. Mean ratings associated with the ALL-SAFE box trainer's quality, $n = 9$

No.	Item	Mean (SD)	Meet criteria? (⩾3.0)
1.	The amount of light from window/cutouts allows for adequate visualization	3.25 (0.50)	Yes
2.	Box trainer dimensions provide a working space which adequately represents an average pelvic cavity	2.50 (0.58)	No
3.	Front camera placement provides a view adequately comparative to that of a 30° laparoscope	2.75 (0.50)	No
4.	Top camera placement provides a view adequately comparative to that of a 0° laparoscope	2.75 (0.50)	No
5.	The trocar site placement was flexible enough to allow comfortable instrument management	2.00 (0.50)	No
6.	Box trainer of adequately stable construction, overall	3.00 (0.00)	Yes
7.	During testing, were you required to take action to stabilize the box trainer on the table? (scored yes = 1, no = 0)	0.50 (0.58)	–

Finally, participants also rated their personal ability to perform the critical tasks associated with the laparoscopic management of ectopic pregnancy on the ALL-SAFE training system using five items rated on five-point rating scales, scored from 1 (too difficult to perform) to 5 (too easy to perform), with a 'don't know' option provided. The study was granted exemption status by the University of Michigan Institutional Review Board #HUM00199557.

Results

Box trainer

The box trainer 'ease of build' mean ratings were well over 3.0 (agree) criteria, and there were no suggestions for improvement on the build instructions, so no actions were needed. As the value of 3.0 represents the inflection point between the 'disagree' and the 'agree' responses, this value was used as the benchmark for meeting criteria. Means are reported in Table 2 for each item. The ALL-SAFE box trainer's 'quality' mean ratings ranged from 2.00 (trocar site placement) to 3.25 (amount of light). Means are reported in Table 3 for each item.

Suggestions for improvement included 'need to readjust the port sites,' which targeted making the port sites bigger in size to allow instruments to slide through the sites with improved ease as well as adjusting their placement. Most participants (six, 66.7%), selected a rating of 3.0 or higher, suggesting participants believed 'the ALL-SAFE box trainer can be used in training salpingostomy as is, but could be improved slightly.'

Ectopic pregnancy task trainer

The ALL-SAFE task trainer's quality mean ratings ranged from 3.17 (proportions of simulated pelvic organs: trainer box) to 4.63 (identifiability of uterus, fallopian tubes, and ectopic pregnancy). Means are reported in Table 4 for each item.

For the ectopic pregnancy task trainer, comments targeted two primary areas: the ectopic pregnancy contents and the fallopian tubes. Suggested improvements for the ectopic pregnancy contents included 'need to have something a bit more solid for the ectopic' and 'would suggest thicker substance such as Play-Doh to mimic clot/tissue of ectopic.' The comment associated with the fallopian tube was 'typically fallopian tube has more resistance than Penrose, so Penrose was easier to cut.' Favorable feedback included: 'the feel of the trainer felt very conducive to educational simulation.'

In response to ratings and suggestions, the team modified the ectopic pregnancy contents from toothpaste to a

Table 4. ALL-SAFE ectopic pregnancy task trainer ease of build and quality mean ratings, $n = 9$

No.	Item	All ($n = 9$) Mean (SD)	Obs/gyn[a] ($n = 2$) (SD)	Meet criteria? ($\geqslant 3.0$)
Ease of build				
1.	Build instructions for the ectopic task-trainer were easy to understand	4.50 (0.58)	4.00 (0.00)	Yes
2.	Materials required to build ectopic task-trainer were easy to acquire	4.50 (0.58)	4.00 (0.00)	Yes
Quality				
3.	The proportions of the simulated pelvic organs were appropriate to each other	4.14 (0.69)	3.5 (0.71)	Yes
4.	The proportions of the simulated pelvic organs were appropriate to the size of the box trainer	3.17 (0.76)	4.0 (0.00)	Yes
5.	The uterus, fallopian tubes, and ectopic pregnancy were uniquely identifiable	4.63 (0.52)	5.0 0 (0.00)	Yes
6.	The uterus, fallopian tubes, and ectopic pregnancy were located realistically in relation to one another	4.00 (1.10)	3.5 (2.12)	Yes
7.	The fallopian tube could be retracted with similar force to reality	4.20 (0.45)	4.0 (0.00)	Yes
9.	The tactility of the fallopian tube was realistic	3.33 (.82)	3.0 (1.41)	No
10.	The tactility of the ectopic pregnancy was realistic	3.40 (1.52)	2.5 (2.12)	No
11.	Amount of force required to evacuate the ectopic contents was realistic	3.80 (1.10)	3.0 (1.41)	No
12.	The feeling of the fallopian tube (Penrose drain) during cutting of salpingostomy was realistic	3.60 (1.14)	3.0 (1.41)	No
13.	Reproduced ectopic model matched the intended design	4.29 (0.49)	4.5 (0.71)	Yes
14.	Estimated time to build (mins)	45 (21.21)	–	–

[a]Obstetrics/gynecology participants.

Table 5. Summary of formative participant comments

Category	Comment	Resultant action
Box trainer	'Need to readjust port sites'	Placement of ports adjusted, and port sites enlarged. Box elongated to create more realistic working space
Ectopic pregnancy task trainer	'Need to have something a bit more solid for the ectopic'	Modified substance from toothpaste to homemade play dough
Ectopic pregnancy task trainer	'Would suggest thicker substance such as Play-Doh to mimic clot/tissue of ectopic.'	As above
Ectopic pregnancy task trainer	'Typically fallopian tube has more resistance than Penrose, so Penrose was easier to cut.'	No change, as no viable low-cost alternative to a Penrose was identified

homemade dough although no changes were made to the 'fallopian tubes,' given there were no viable low-cost alternatives available. A summary of the comments is shown in Table 5.

Ability to perform tasks

The mean ratings for ability to perform tasks ranged from 2.67 (complete salpingostomy without injury to ovary) to 3.86 (evaluate both fallopian tubes), falling within a reasonable range of difficulty with 3.0 aligning with 'reasonably difficult to perform.' Means are reported in Table 6 for each item.

Value/relevance

Value of the ALL-SAFE laparoscopic training system was rated by eight participants using a 4-point rating scale, scored as 1 (no value/relevance), 2 (little value/relevance), 3 (some value/relevance), and 4 (high value/relevance) with a 'don't know' option provided. Obstetrics/gynecology participants were separated for transparency. Means for these groups are reported in Table 7 for each item.

Discussion

Laparoscopy is being used with increasing frequency for the treatment of general surgical and gynecologic pathologies in low-to-middle-income countries. One of the biggest challenges associated with the adoption of laparoscopy is the lack of readily available, low-cost simulation-based, laparoscopic training resources for the training of surgeons. Our research aimed at documenting the creation of the low-cost

Table 6. Ability to perform tasks mean ratings, $n = 6$

No.	Item (task)	All ($n = 6$) Mean (SD)	Ob/gyn[a] ($n = 2$) Mean (SD)	Meet criteria? ($\geqslant 2.5$)
1.	Evaluate both fallopian tubes	3.86 (0.38)	3.50 (0.71)	Yes
2.	Identify ectopic pregnancy site	3.75 (0.46)	3.50 (0.71)	Yes
3.	Place suture ligature on fallopian tube	2.86 (0.90)	3.00 (1.41)	Yes
4.	Complete 1–2 cm longitudinal incision along ectopic pregnancy site opposite to mesosalpinx	3.50 (0.53)	3.50 (0.71)	Yes
5.	Complete salpingostomy without injury to ovary	2.67 (0.82)	2.00 (0.00)	Yes

[a]Obstetrics/gynecology participants.

Table 7. Value and relevance mean ratings, $n = 8$

No.	Item (task)	All ($n = 8$) Mean (SD)	Ob/gyn[a] ($n = 2$) Mean (SD)	Meet criteria? ($\geqslant 3.0$)
1.	Value as a training tool	3.88 (0.35)	4.00 (0.00)	Yes
2.	Value as a testing tool	3.57 (0.53)	3.00 (0.00)	Yes
3.	Relevance to practice	3.00 (1.07)	4.00 (0.00)	Yes

[a]Obstetrics/gynecology participants.

ALL-SAFE laparoscopic training system and evaluating its feasibility and value as a training tool.

These preliminary data show that the first iteration of the ALL-SAFE box trainer was easily built with materials that were readily available locally, was replicable and sturdy, and featured an ectopic pregnancy model that was anatomically and tactilely realistic. The angled scope view, the first published report of this type of feature to our knowledge, also scored well. The ALL-SAFE laparoscopic training system supported participants' ability to perform the targeted tasks, including salpingostomy and placement of a suture ligature on the fallopian tube and received high ratings as a training and testing tool relevant to surgical practice.

The convenience of at-home construction removes potential time delay in acquiring the materials, reliance on other organizations for a product, or logistical or cost barriers in acquisition and allows adult learners to build their own learning tool for practice and learning with autonomy and immediacy. As laparoscopy is conceptually novel in the low-resource setting, we anticipated that the simplified anatomic ectopic pregnancy task trainer would be perceived as more relevant and more directly applicable by the target learners over basic manual skills like pattern cutting or peg transfer. The final task of placing a suture ligature is a complex and difficult endeavor for a novice and incorporates many other foundational skills for its successful completion, including accurate depth perception, fine motor control, and bimanual dexterity. It is also a skill that would require video capability that is precise enough to support these more advanced and nuanced moves and so is a good test of a box trainer's functionality to handle more complex tasks.

There are several limitations to our study. First, although our participants were comprised of general surgeons and obstetrician-gynecologists with a range of experience levels from different low-resource countries and the United States, the small sample limits the generalizability of the findings. However, because both general surgeons and obstetrician-gynecologists perform this procedure in the low-resource setting, our sample set includes both proceduralists. Additionally, the limited scope of inquiry targeted the quality and value of the two primary components of the ALL-SAFE laparoscopic system for their feasibility for use in training, not for their value at supporting the development of skills associated with laparoscopic management of ectopic pregnancy. Further, the feasibility and quality of the ALL-SAFE laparoscopic training system were evaluated for a single, specific laparoscopic procedure, further limiting generalizability of findings, especially when the box trainer is ultimately intended to be used for a variety of procedures.

Despite the limitations, this work suggests that the low-tech, low-cost ALL-SAFE system may help fill the educational gap in the training of laparoscopy in the low-resource setting. This study details the component construction and presents feasibility evidence that was used in later iterations of the system. The assessment of the performance of the skills in laparoscopic salpingostomy was also conducted by video review and will be described in a subsequent article. In the next phase of this study, we will investigate the impact of the ALL-SAFE training system on clinical outcomes, including case numbers of open salpingostomy and laparoscopic salpingostomy procedures at the participating sites.[18]

Conclusion

The ALL-SAFE laparoscopic training system may create opportunities for collaboration with learners in locations where availability of expensive commercial trainers is limited and where such learning would potentially be most valuable. Our low-tech, low-cost laparoscopic training system may help to fill the educational gap in the training of laparoscopy in a low-resource setting.

Supplementary material

Supplementary Appendices A–C are available at https://doi.org/10.5281/zenodo.7806226.
Supplementary Appendix A: Build instructions ALL-SAFE laparoscopic box trainer;
Supplementary Appendix B: ALL-SAFE ectopic pregnancy task trainer;
Supplementary Appendix C: Supply list.

Conflict of interest

None declared.

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