Validation of open inguinal hernia repair simulation model: a randomized controlled educational trial


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**KEYWORDS:** Surgical simulation; Surgical education; Randomized controlled educational trial; Hernia repair

**Abstract**

**BACKGROUND:** A hernia repair open surgical simulation computer software was developed at Imperial College London. A randomized controlled educational trial was conducted to investigate the benefit of the simulation on the development of procedural knowledge.

**METHODS:** Medical students in their clinical years were invited to participate in the trial. Students were block randomized to 4 groups: G1 - Interactive Simulation; G2 - Non-interactive Simulation; G3 - Video Tutorial; G4 - Control. On completion, they were objectively assessed on their ability to recall the tasks involved in an open inguinal hernia repair in the form of a multiple choice question (MCQ) and a simulated discussion with a consultant surgeon.

**RESULTS:** Fifty-six students completed the study. Each arm carries similar baseline scores (pre-intervention MCQ) with means 43.33, 38.92, 38.33, and 39.57 in G1 to G4, respectively. MCQ score improvements and final assessment scores proved better in the intervention groups (1, 2, and 3) compared to controls.

**CONCLUSION:** The interactive simulation has shown an objective benefit in teaching medical students the anatomical and procedural knowledge in performing an open inguinal hernia repair.

E-learning offers a new paradigm to educators capable of enhancing learning by allowing trainees to relate new learning to previous experiences, linking learning to specific needs, and practically applying it to real-life examples or case studies. A well-designed interactive E-learning experience can motivate learners to become more engaged with the content. Key advantages of E-learning are improved learning delivery, simplification of course content standardization and updating, and learning enhancement.1

Although some evidence suggests that E-learning is more efficient because learners gain knowledge, skills, and attitudes faster than through traditional instructor-led methods, such evidence is by no means conclusive. This study compares different formats of a hernia repair surgical simulation and a tutorial with the aim of investigating the educational efficiency of a range of E-learning tools developed as part of the Imperial...
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Surgical simulation has come to the forefront of surgical education in recent years. The combination of technological advances, increase in number of surgical trainees, the importance of surgical safety, and medico-legal concerns has contributed to the necessity of such an educational tool.\textsuperscript{3,4} Research projects on validation of various laparoscopic surgical simulators are in abundance;\textsuperscript{5} however, objective evidence of the benefit of open surgical simulators is lacking.\textsuperscript{6} It is imperative to highlight that competence in open surgical procedures is a prerequisite for competence in laparoscopic forms of the same procedure, as many laparoscopic procedures have to be abandoned intraoperatively and converted to an open procedure. Leaders in surgical education and leaders in manufacturing of simulators must target the void present in open surgical simulation.

In the United Kingdom, the implementation of the European Working Time Directive which limits trainees to an average of 56 hours a week of clinical work has restricted the amount of surgical exposure.\textsuperscript{7,8} Similarly, the implementation of the Accreditation Council for Graduate Medical Education duty hours in the United States of America that limits residents’ clinical work to 80 hours a week has also reduced the quality of education received by residents and decreased the amount of exposure in the operating room,\textsuperscript{9} thus highlighting the importance of surgical simulation as an adjunct to surgical training.

Inguinal hernia repair is one of the most common general surgical procedures and accounts for 10% of the general surgical workload in the United Kingdom. Twenty-seven percent of men and 3% of women will undergo an inguinal hernia repair in their lifetime.\textsuperscript{10} Inguinal hernia repair is deemed as a core index procedure by the Royal College of Surgeons of England and attainment of competence by junior surgical trainees in uncomplicated inguinal hernia repairs is essential.

In 2011, Imperial College London developed a Hernia Repair Open Surgical Simulation (HeROSS)\textsuperscript{11} software that provides a computer-based simulation of an uncomplicated inguinal hernia repair. The software aids users in understanding the 3-dimensional spatial relations of the complex anatomy of the inguinal region. The simulation is based on the Liechtenstein tension-free open hernia repair, providing users with stepwise instructions on how to perform the procedure with warnings when important structures are damaged and links for further reading. The simulation offers different levels of instruction that can be controlled by the user and scores various aspects of the user’s performance, which enables users to track their progress.

The aim of this study is to assess the educational benefit of using the HeROSS simulation by comparing it with a hernia video tutorial and traditional means of learning. In addition, the study aimed to compare different levels of interaction in the HeROSS simulation, assessing the benefit of developing a simulation of higher interactivity, as well as obtaining feedback about design, content, usability, and perceived value of the simulation.

### Methods

#### Study design

Medical students in their clinical years across London medical schools were invited to participate in a randomized controlled educational trial. Students showing interest in participating in the trial were given an online questionnaire to survey their experiences in performing or assisting in open inguinal hernia repair procedures or other common surgical procedures. Students were excluded from any further participation in the trial if they fulfilled any of the exclusion criteria detailed below:

- Performing or assisting in an open inguinal hernia repair
- Performing or assisting in an open appendicectomy
- Previous bachelor degree in anatomy
- Working as an anatomy demonstrator
- Score of >70% or <40% in the screening multiple choice question (MCQ) quiz

After screening, the medical students not excluded were formally invited to participate in the study. Students were randomized to 4 different groups using block randomization (Random Allocation Software, Isfahan, Iran).\textsuperscript{12} The 4 different groups are listed below:

1. **Group 1 – Interactive Simulation:** Students in this group were able to use the HeROSS software (Fig. 1, Video 1) and had the ability to interact with simulation and control the steps taken in the simulated surgical repair. After every try, students were given a score based on their performance during the simulation. Throughout the simulation, optional external links were provided for further reading.

2. **Group 2 – Non-interactive Simulation:** Students in this group used a non-interactive version of the HeROSS software that followed predefined steps in the simulation. Links for further reading were embedded in the software.

3. **Group 3 – Video Tutorial:** Participants in this group were shown a recorded video of an open mesh repair of an inguinal hernia with commentary from a consultant. The video was accompanied by anatomical illustrations that enabled the users to relate the procedure with the corresponding anatomy (Fig. 2, Video 2).

4. **Group 4 – Control Group:** Students in this group were provided with common educational material available in the medical school and university libraries. They had access to the Internet and were given excerpts from surgical anatomy and procedural textbooks pertaining to open inguinal hernia repairs.

At the start of the trial, participants in each group were given the following simulated scenario: They are the surgical senior house officer and have just finished the consultant ward round. They are asked by their consultant
to join for the afternoon hernia list in day surgery. The consultant informs them that they are expected to know the procedural steps and related anatomy for open inguinal hernia repairs. Students were then given further instructions tailored to their specific group.

Before commencing the educational element of the trial, participants were directed to a short quiz consisting of 20 MCQs assessing both anatomical and procedural knowledge focused on open inguinal hernia repair. After completing the pre-intervention quiz, they started the trial as follows:

1. Session 1: 90 minutes in their randomized method of teaching
2. Session 2 (48 hours after 1st session): 90 minutes in their randomized method of teaching
3. Session 3 (48 hours after 2nd session): 90 minutes in their randomized method of teaching
4. Assessment (24 hours after 3rd session)

Of note, it was stressed to participants not to study any related material for preparation outside the allocated sessions.

The assessment stage consisted of a simulated discussion with 2 senior surgeons. The senior surgeons were blinded to the method of education received by the participant. Participants were rated using an objective rating scale derived from a validated procedural task analysis for open inguinal hernia repairs. Following the simulated discussion, participants completed a post-intervention 20-question MCQ specific to open inguinal hernia repairs and related anatomy. They were then given the opportunity to provide feedback regarding the simulation and participants in groups 2 to 4 were allowed to use the HeROSS interactive simulation.

Data analysis

The scores of the participants were presented in medians and interquartile ranges. Given the small number of students within each intervention arm, it was deemed unlikely to follow a normal distribution. A new variable was created – the improvement score, which is equivalent to the post intervention MCQ minus the pre-intervention MCQ. The improvement and the final assessment scores (FAS; outcome variables) were compared between intervention groups. Because of the small sample sizes and departure from a normal distribution, a nonparametric form

Figure 1  Screenshots of the HeROSS interactive simulation. (A) Simulated patient supine before prepping and draping. (B) Exposure of external oblique aponeurosis. (C) Mobilization of spermatic cord and dissection of hernia sac from contents of the spermatic cord. (D) Suturing of divided external oblique aponeurosis.
Figure 2 Screenshots obtained from the video tutorial learning aid used by participants in Group 3. Initial incision (A). Exposing the inguinal canal (B). Identifying the hernia sac (C).
of the \( t \) test was chosen. The permutation \( t \) test was performed comparing each of the 1st 3 groups with the control (4th) group; once for the improvement variable, and once for the FAS. Subsequently, 3 permutated \( t \) tests were carried out between the 1st 3 groups for each of the outcome variables (1 and 2, 1 and 3, 2 and 3). Values of \( P < .05 \) were considered statistically significant. Statistical analysis was performed using STATA 12.1 statistical analysis software (STATA Corp, College Station, TX).

**Results**

Seventy-two medical students showed interest in participating in the study. Thirteen students were excluded as per the exclusion criteria. From the remaining 59 students, 3 did not complete the study, leaving the completed numbers for each group as follows:

- Group 1 – Interactive Simulation: 15
- Group 2 – Non-interactive Simulation: 15
- Group 3 – Video Tutorial: 12
- Group 4 – Control Group: 14

After randomization to individual groups, participants completed a 20-question MCQ quiz. Each intervention arm exhibited similar baseline scores (pre-intervention MCQ) with means 43.33 (±13.28), 38.92 (±9.93), 38.33 (±9.37), and 39.57 (±9.27) for groups 1 to 4, respectively (Table 1).

On the day of assessment, participants completed a post-intervention MCQ quiz consisting of 20 MCQs. They also had a final assessment in the form of a simulated discussion with 2 consultant surgeons. All 3 intervention groups showed a significant increase in their post-intervention MCQ scores, with an MCQ score improvement (MSI) of 30.15% (±13.68), 36.08% (±12.48), and 31.74% (±12.87) for groups 1 to 3, respectively. Group 4 showed a more modest MSI of 7.41% (±9.56). The mean FAS of both assessors of the simulated discussion of groups 1 to 4 were 76.92% (±9.9), 65.38% (±2.72), 59.67% (±8.86), and 42.93% (±9.54), respectively.

MSI and FAS proved better in the intervention groups (1, 2, and 3) compared to controls (group 4) (Table 1, Fig. 3). When comparing between intervention groups, there is no statistically significant difference in MSI. However, group 1 proves to have better FAS than both 2 and 3 by scores of 11.54 (\( P < .001 \)) and 17.25 (\( P < .001 \)), respectively. There is also strong evidence (\( P = .001 \)) that the FAS of group 2 is 5.71 points higher than that of group 3 (Table 2).

**Comments**

The traditional apprenticeship model of surgical training has been marginalized in modern training practices. The emphasis on patient safety and establishment of quality-assurance targets by governing bodies has diminished the opportunities available for junior surgical trainees to practice surgical skills on patients.\(^{14}\) In a study conducted by Robson et al in 2004, all inguinal hernia repairs carried out between 1994 and 2001 that were entered in the Lothian Surgical Audit Database were examined to investigate the correlation between seniority of the primary surgeon and hernia recurrence rates. From the 4,406 inguinal hernia repairs, there was an unacceptably high recurrence rate in procedures performed by unsupervised junior surgical trainees.\(^{15}\) This highlights the struggle present in modern surgical education between achieving high-quality patient care and providing high-quality education to surgical trainees. Surgical simulation offers a safe environment for trainees to perform newly acquired surgical skills and practice without the fear of committing errors.\(^{14}\) Simulation training has become a cornerstone in aviation and nuclear industries where safety is paramount.\(^{16}\) However, despite

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Summary of group assessment and improvement scores</th>
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<tbody>
<tr>
<td>Group</td>
<td>Mean (Standard deviation)</td>
</tr>
<tr>
<td>Pre-intervention MCQ (%)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>43.33 (13.28)</td>
</tr>
<tr>
<td>2</td>
<td>38.92 (9.93)</td>
</tr>
<tr>
<td>3</td>
<td>38.33 (9.37)</td>
</tr>
<tr>
<td>4</td>
<td>39.57 (9.27)</td>
</tr>
<tr>
<td>Total</td>
<td>40.14 (10.58)</td>
</tr>
<tr>
<td>Score improvement in MCQ (%)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>30.15 (13.68)</td>
</tr>
<tr>
<td>2</td>
<td>36.08 (12.48)</td>
</tr>
<tr>
<td>3</td>
<td>31.74 (12.87)</td>
</tr>
<tr>
<td>4</td>
<td>7.41 (9.56)</td>
</tr>
<tr>
<td>Total</td>
<td>26.4 (16.41)</td>
</tr>
<tr>
<td>Assessment score (%)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>76.92 (9.9)</td>
</tr>
<tr>
<td>2</td>
<td>65.38 (2.72)</td>
</tr>
<tr>
<td>3</td>
<td>59.67 (8.86)</td>
</tr>
<tr>
<td>4</td>
<td>42.93 (9.54)</td>
</tr>
<tr>
<td>Total</td>
<td>61.63 (14.88)</td>
</tr>
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</table>

MCQ = multiple choice question.
the theoretical advantages that surgical simulation offers, it has yet to be globally adopted into surgical curricula.

Fitts and Posner’s established educational theory of how motor skills are learnt and developed is based on a 3-stage approach: cognitive, integrative, and autonomous. In the initial stage, performance of a learnt task is inconsistent and the task is carried out in distinct steps. The 2nd integrative stage is reached after several attempts, trial, and error, as well as feedback. Here, a learner still has to think about the steps in the procedure. The final autonomous stage is reached when a learner attains a fluid state of executing the task without having to think about the distinct steps. When applying this to surgical education, learning by trial and error on patients is no longer acceptable, paving the way for the role of surgical simulation in allowing trainees to reach the autonomous stage of learning before operating on a patient. Through simulation, a trainee is able to focus on more complicated surgical skills and refinement of operative skills without having to consciously think of the next steps in a rigid and interrupted manner.

Our study investigated the efficiency and educational benefit of using simulation-based learning tools in teaching medical students how to perform an open inguinal hernia repair and understand the complex spatial anatomy of the inguinal canal. High-interactivity and low-interactivity versions of the HeROSS simulation software were compared to a video tutorial and traditional methods of learning. After screening medical students and randomizing participants into the 4 aforementioned groups, they underwent a preintervention MCQ that consisted of 20 questions pertaining to the anatomy of the inguinal region and procedural steps of an open mesh repair of an inguinal hernia. The scores of all 4 groups yielded similar results as expected with a mean score of 40.14 (±10.58). After 3 educational sessions, participants in group 1 showed an MSI of 30.15% (±13.68). Comparing the MSI with groups 2 and 3, this shows no statistically significant difference in the improvement scores. Both a low-interactivity simulation and a video tutorial yielded similar MSI of 36.08% (±12.48) and 31.74% (±12.87), respectively. This is an important finding as it appears to question the return of investment in the development of high-interactivity simulations that require a longer process of development when compared to a low-interactivity version.

In contrast, when comparing the MSI of group 1 and 4, there is a statistically significant difference of 22.74% (P < .001). Similarly, a statistically significant improvement in MSI is seen when comparing groups 2 (28.67%, P < .001) and 3 (24.33%, P < .001) with the control group (Table 2). This highlights the important role of E-learning in the efficient acquisition of knowledge and the superiority of 3-dimensional illustrations in enabling students to visualize and understand complex human anatomy.

In the 2nd form of assessment, the simulated discussion with a consultant, participants were asked by the 2 simulated consultants to talk them through their stepwise approach to an open inguinal hernia repair. Assessors were prompted to ask specific questions during the discussion (see Appendix 1) to assess more in-depth knowledge. Scores from both assessors were recorded and the mean score used in the data analysis. When comparing the FAS of the different groups, participants in group 1 showed a statistically significant difference of 11.54%, 17.25%, and 33.99% (P < .001) when compared to groups 2 to 4, respectively. The difference in scores between group 2 and group 3 was less significant with a difference of 5.71%. The results indicated that participants in the high-interactivity simulation were able to recall the steps of an open inguinal hernia repair more fluidly. This is especially interesting when comparing groups 1 and 2. A higher level of interactivity in the former group and the need to perform the correct steps in order for the simulation to proceed will undoubtedly reinforce the steps of the procedure that are being learnt by the participants. This strengthens the case for the development of simulations of higher interactivity that enable participants to commit mistakes, challenging them to perform the correct steps to proceed, and complete the given tasks.

Despite our best efforts in reducing bias in the study, limitations do exist. Although it was stressed to participants that reading around the subject was not allowed outside of the allocated educational sessions, we are not able to ensure that participants have not read more about the procedure and the related anatomy. Furthermore, the final assessment rating scale was based on the original task analysis of open inguinal hernia repair, which was also used to develop the HeROSS simulation software in its earliest version. This might have disadvantaged participants in the control group.

### Table 2

<table>
<thead>
<tr>
<th>Group</th>
<th>MCQ improvement score</th>
<th>Assessment score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>−5.93</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P = .23</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>−1.59</td>
<td>4.34</td>
</tr>
<tr>
<td></td>
<td>P = .76</td>
<td>P = .34</td>
</tr>
<tr>
<td>4</td>
<td>22.74</td>
<td>28.67</td>
</tr>
<tr>
<td></td>
<td>P &lt; .001</td>
<td>P &lt; .001</td>
</tr>
</tbody>
</table>

MCQ = multiple choice question.
who were learning the operative steps from independent textbooks not directly linked to the task analysis. However, the significant difference in the FAS of group 1 and 2 diminishes the impact of this limitation as both simulations were based on the same task analysis.

Conclusions

The HeROSS interactive simulation showed a statistically significant benefit for novice students learning about open hernia repairs and understanding the relevant anatomy. It provided an efficient method of learning a new procedure and aiding medical students in understanding open hernia repairs in a fluid manner. The results of the study showed the superiority of the HeROSS interactive simulation, noninteractive simulation, and the video tutorial over traditional methods of learning via textbooks and online resources. When comparing the high-interactivity version of the HeROSS software, results showed that there was no significant added benefit of teaching anatomical and procedural concepts over the low-interactivity version and a video tutorial. However, the interactivity and ability to make errors proved to be a superior method of consolidating the steps of a hernia repair in participant’s thought process as reflected by their performance on the simulated discussion, thus justifying the added cost and production time for the development of the high-interactivity version of HeROSS, as it provides a better environment to support active learning where the learner remains engaged throughout.

Our research group envisages the development of simulations covering several core index procedures that would be offered to medical students and junior surgical trainees in a virtual operating theatre, in hopes of allowing them to practice basic concepts, learn the relevant surgical anatomy and steps of the operation in a safe environment, reaching a higher stage of technical ability and knowledge before consolidating them in a real operating theatre.

Appendix A

Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.amjsurg.2013.12.007.

References