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Virtual reality simulation training can improve technical skills during laparoscopic salpingectomy for ectopic pregnancy

R Aggarwal,[a] A Tully,[a] T Grantcharov,[b] CR Larsen,[c] T Miskry,[d] A Farthing,[e] A Darzi[a]

[a] Department of Biosurgery and Surgical Technology, Imperial College London, London, UK [b] Department of Surgical Gastroenterology, Copenhagen University Hospital, Glostrup, Denmark [c] Department of Obstetrics and Gynaecology, Rigshospitalet, Copenhagen University Hospital, Copenhagen, Denmark [d] Department of Obstetrics and Gynaecology, St Mary's Hospital, London, UK [e] Department of Gynaecology, Queen Charlotte's Hospital, London, UK

Correspondence: Dr R Aggarwal, Department of Biosurgery and Surgical Technology, Imperial College London, 10th Floor, QEQM Building, St Mary's Hospital, Praed Street, London W2 1NY, UK. Email rajesh.aggarwal@imperial.ac.uk

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Objectives To assess the first commercially available virtual reality (VR) simulator to incorporate procedural modules for training of inexperienced gynaecological surgeons to perform laparoscopic salpingectomy for ectopic pregnancy.

Design Prospective cohort study.

Setting Departments of surgery and gynaecology in central London teaching hospitals.

Sample Thirty gynaecological surgeons were recruited to the study, and were divided into novice (<10 laparoscopic procedures), intermediate (20–50) and experienced (>100) groups.

Methods All subjects were orientated to the VR simulator with a basic skills task, followed by performing ten repetitions of the virtual ectopic pregnancy module, in a distributed manner.

Main outcome measures Operative performance was assessed by the time taken to perform surgery, blood loss and total instrument path length.

Results There were significant differences between the groups at the second repetition of the ectopic module for time taken (median 551.1 versus 401.2 versus 249.2 seconds, $P = 0.001$), total blood loss (median 304.2 versus 187.4 versus 123.3 ml, $P = 0.031$) and total instrument path length (median 17.8 versus 8.3 versus 6.8 m, $P = 0.023$). The learning curves of the experienced operators plateaued at the second session, although greater numbers of sessions were necessary for intermediate (seven) and novice (nine) surgeons to achieve similar levels of skill.

Conclusions Gynaecological surgeons with minimal laparoscopic experience can improve their skills during short-phase training on a VR procedural module. In contrast, experienced operators showed nonsignificant improvements. Thus, VR simulation may be useful for the early part of the learning curve for surgeons who wish to learn to perform laparoscopic salpingectomy for ectopic pregnancy.

Keywords Laparoscopic salpingectomy, simulation, technical skills, training, virtual reality.

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Introduction

Diagnostic laparoscopy has played a fundamental role in gynaecology since the 1970s, but in 2003 the laparoscopic approach has been viewed as a preferable option for therapeutic procedures.[1] Laparoscopic removal of an ectopic pregnancy using salpingectomy was first performed in 1973 by Shapiro and Adler, followed in 1978 by the first laparoscopic salpingotomy.[2] Nonetheless, laparotomy remains a more widespread approach in the UK.[2] This is despite three randomised controlled trials of 228 women resulting in a proven benefit to the laparoscopic approach in terms of less pain, blood loss and a shorter hospital stay.[3–5]

Guidelines published in 2004 state that 'a laparoscopic approach to the surgical management of tubal pregnancy, in the haemodynamically stable patient, is preferable to an open approach'.[6] Nonetheless, only 35% of all ectopic pregnancies in the UK are managed laparoscopically despite 90% of gynaecologists stating that laparoscopic management of an ectopic pregnancy could be performed if the necessary resources were in place.[7] Two explanations for this disparity between guidelines and practice are the unpredictability of operating

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times[8] and the lack of specialist training required for laparoscopy.[2] The latter has been singled out as a major hurdle to the wider introduction of laparoscopic techniques into gynaecology and other specialities.

For surgeons to perform laparoscopic procedures they must operate while viewing a two-dimensional image, on a screen up to five feet away.[9] This, coupled with minimal force feedback through long, rigid instruments and the fulcrum effect,[10] makes the conventional apprenticeship method of learning through observation somewhat redundant.[11] It is further stated that although complications associated with laparoscopy clearly depend on the particular procedure being performed, it is apparent that most problems are encountered during the 'early learning phase for laparoscopy'.[12,13] A successful open operation is said to be based on 75% decision making and 25% dexterity, although in laparoscopic surgery dexterity forms a greater component.[14] It has been suggested that early training could more safely, efficiently and not to mention more cheaply, occur outside the operating theatre.[15] These theories led to the development of skills laboratories in which junior surgeons could practice basic skills and whole procedures using synthetic materials in box trainers and on animal models.[16] In the past 5 years, there has been burgeoning interest in the use of virtual reality (VR) simulators as adjuncts to conventional training.

The use of VR simulators was inspired by the successful use of such tools to train airline pilots. The simulators have the ability to create a 'realistic, real-time' environment, with inbuilt objective assessment of performance.[17] In addition, sessions can be modified according to individual level of skills, and delivered through a structured training curriculum. The majority of simulators are transportable and use ordinary computer equipment. Furthermore, skills learnt on the simulator have been shown to transfer to improved performance in the operating theatre.[18,19] Indeed, this concurs with suggestions to integrate simulator-based training into training curricula.[20] If guidelines are to be realised and laparoscopy is to be performed as the surgical procedure of choice for ectopic pregnancy, a curriculum for training needs to be devised which is valid, feasible, structured and efficacious.

In 1994, The Royal College of Obstetricians and Gynaecologists defined a classification of levels of skills required for laparoscopic procedures, from 1 (e.g. diagnostic laparoscopy) to 4 (e.g. incontinence reconstruction).[21] This does provide some information regarding the stepwise nature to acquisition of laparoscopic skill, but there is no mention of modes of credentialing at each level. It may be possible within this classification to use objective methods of skills assessment such as VR simulators for the definition of criteria at each level, which must be achieved prior to performing real cases.

The aim of this study was to evaluate a VR ectopic module (LAPSIM; Surgical Science, Gothenburg, Sweden), in terms of its validity as a training and assessment tool for gynaecological surgeons, and specifically whether it could viably be integrated into a skills curriculum. Ultimately, the question arises as to whether training on such a model would enable achievement of proficiency in a safer and more deliverable manner than current practice.

Methods

Subjects

Thirty gynaecological surgeons all of whom had performed more than 50 gynaecological laparoscopic procedures (at RCOG levels 1 and 2) were recruited to the study.[21] They were then subdivided into novice (<10 cases), intermediate (20–50 cases) and experienced (>100 cases) surgeons, dependent on the number of RCOG level 3 and level 4 cases they had performed. The aims of the study were explained to all the subjects, and informed consent was obtained prior to participation in the trial.

Tasks and skill levels

The ectopic module on the simulator provides a realistic image of the procedure, with which subjects can interact to perform a salpingectomy (Figure 1A, B). The difficulty of the module can be altered from level 1 (easy) to level 7 (difficult) by setting the size of the pregnancy, the initial bleeding rate (millilitre/second) and the bleeding rate (millilitre/second) when a cut is made in tissue. It was concluded from a pilot study that skill levels should be set to 7 for all above parameters.[22]

The subject interacts with the simulator through a virtual laparoscopic interface (VLI) (Figure 1A). This is a frame holding two standard laparoscopic instruments in an appropriate position. The nature of the instrument is changed virtually and thus a laparoscopic grasper, bipolar grasper, diathermy scissors, suction and rinsing device and bag are available for use. A pedal, which is operated by the surgeon can double as a diathermy, suction or rinsing device depending on which instrument has been selected.

The aim of the task is to perform a salpingectomy using the bipolar grasper to cauterise tissue, followed by diathermy scissors to cut. Once the ectopic has been fully separated from the fallopian tube, it should be placed in a virtual bag and any residual bleeding controlled. When the subject is satisfied that the task is completed, the simulation is ended. Summary metrics are subsequently recorded using the computer and can be downloaded into a spreadsheet format (Figure 2).

All participants initially performed one basic task on the simulator, 'instrument navigation'. This involves the use of instruments to touch coloured balls, placed onto a virtual background. The aim of this task was to familiarise subjects to the tools, and provide baseline information regarding generic laparoscopic skills. Each subject then carried out a series of ten simulated salpingectomies, over a variable number of sessions. In any one session, each subject could

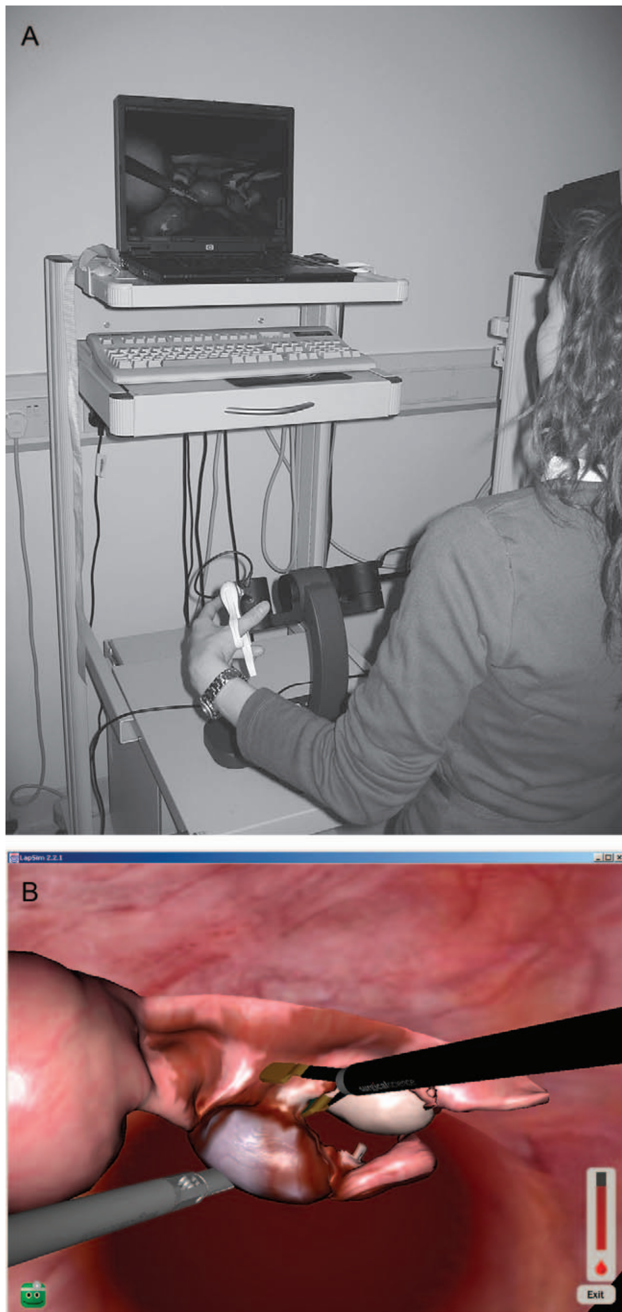

Figure 1. (A) The LAPSIM virtual reality simulator. (B) A demonstration of the simulated salpingectomy.

attempt up to three simulated procedures, each at least 1 hour apart.

Performance evaluation

Gimbals placed onto the VLI record the movements of the instruments. This enables the simulator to record total time taken to complete each task (seconds), path length of each hand (metre) and angular path length of each hand (degrees). The latter two parameters provide details regarding economy of movement, or dexterity, of the individual performing the task. The software also records total blood loss (millilitre), residual bleeding rate (millilitre/second), ovarian diathermy damage (seconds) and amount of unremoved dissected tissue (if any).

Statistical analysis

Data were analysed using the Statistical Package for the Social Sciences version 11.5 (SPSS Inc., Chicago, IL, USA). Due to the distribution of the data, results were analysed with nonparametric statistical tests. Construct validity was determined using the Kruskall–Wallis and Mann–Whitney *U* tests, as appropriate, to compare intergroup performance on the first and second sessions. The plateau in skill level for each group was established by plotting learning curves and performing statistical analysis using the Friedman (nonparametric repeated measures analysis of variance) test for all parameters. A level of $P < 0.05$ was considered to be statistically significant.

Results

A total of 23 of the 30 subjects recruited to the study managed to complete all ten sessions on the simulator, and the remainder citing timetabling constraints for their inability to fulfil the demands of the study.

Assessment of performance on the 'instrument navigation' task showed significant differences in time taken ($P = 0.002$) and instrument path length ($P = 0.014$) between the three groups of surgeons. Assessment of performance during the ectopic module for the first session showed significant differences solely for time taken (median 758.73 versus 477.385 versus 327.71 seconds, $P = 0.038$) between novice, intermediate and expert surgeons, respectively. The results for total blood loss (median 520.9 versus 328.7 versus 142.1 ml, $P = 0.060$) and total instrument path length (median 18.9 versus 13.3 versus 8.4 m, $P = 0.051$) showed a similar trend, although were not statistically significant.

At the second session, there were significant differences between novices, intermediates and experts for time taken (median 551.1 versus 401.2 versus 249.2 seconds, $P = 0.001$), total blood loss (median 304.2 versus 187.4 versus 123.3 ml, $P = 0.031$) and total instrument path length (median 17.8 versus 8.3 versus 6.8 m, $P = 0.023$) (Figure 3A–C).

Assessment of the learning curve for the experienced group showed a plateau for time taken at the second session (median 249.2 seconds, $P = 0.084$), the intermediate group at the seventh session (median 178.0 seconds, $P = 0.825$) and for the novices at the ninth session (median 244.5 seconds, $P = 0.057$). The results for learning curve plateaus on parameters of total blood loss for novice (fourth session, median 183.5 ml, $P = 0.118$), intermediate (seventh session, median

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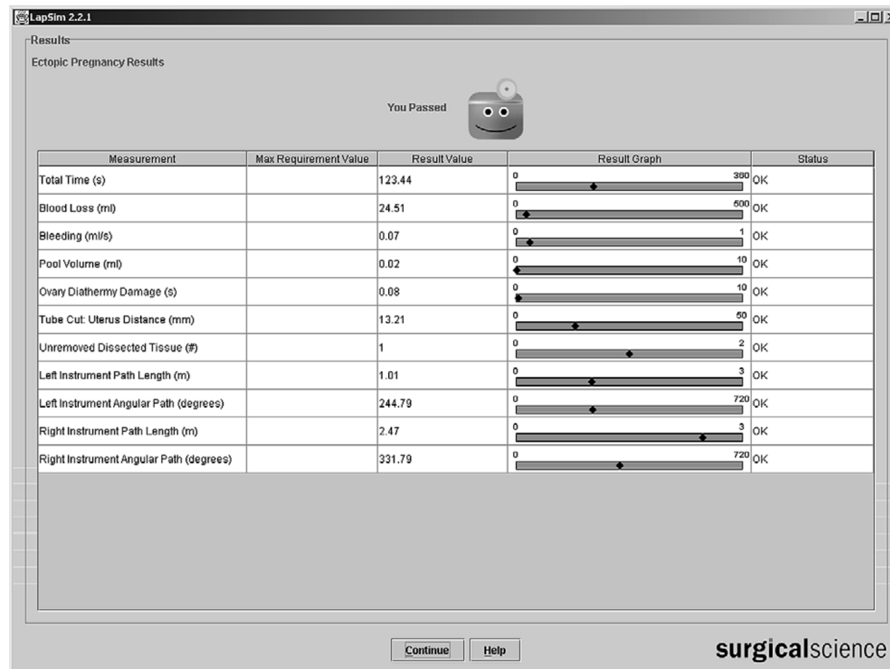

Figure 2. Performance parameters provided by the simulator.

104.6 ml, $P = 0.789$) and expert surgeons (third session, median 101.5 ml, $P = 0.162$) displayed a similar pattern, as did those for novice (fourth session, median 11.5 m, $P = 0.057$), intermediate (sixth session, median 7.4 m, $P = 0.099$) and expert (second session, median 6.8 m, $P = 0.258$) surgeons for total path length (Figure 4A–C).

Discussion

It is a well-described fact that novice surgeons undergo a learning curve when beginning to perform a new procedure, resulting in higher complication rates.[23] The complications that can occur during this learning phase may lead to increased operating times, longer hospital stays and ultimately greater costs. Most importantly, it has become unacceptable to put subjects at needless risk for the sake of learning. In combination with restrictions on working time, there is an immediate need to develop and integrate alternative modes of training outside the operating theatre.

Training on VR simulators has been shown to be a viable and valuable adjunct for general surgical education and there seems to be no reason why simulation should not offer similar advantages for trainee gynaecologists.[18,19] The intention of this study was to establish if a VR ectopic module could be a valid teaching tool for trainee gynaecological surgeons. The results have successfully supported this hypothesis.

The differences between the three groups in terms of total time and total path length for the instrument navigation task confirmed that there were significant differences between the groups in terms of generic laparoscopic skills. Upon performing the first simulated salpingectomy, total time was the only parameter, which was significantly different between the three groups and may be due to the experts requiring one session to become accustomed to the software on the simulator. By the second session, total time, blood loss and total path length showed statistically significant differences between the three groups. For this reason, it can be concluded that the module displays construct validity as the experts performed significantly better than the intermediates and in turn the novices. In other words, the simulation successfully distinguishes for both baseline and procedural technical skills.

The plateau of improvement for the experts was shorter than the other two groups for all parameters measured. The learning curves for intermediate and novice groups were steeper and longer when compared with the experts. However, inexperienced subjects managed to achieve similar levels of skill towards the end of the training period. It has thus been proven that training on this simulator can improve laparoscopic procedural skills, but only when measured using the simulator. It is necessary to corroborate these findings by assessing transfer of these skills to real procedures.

A structured and competency-based training curriculum for commencement of laparoscopic gynaecological surgery can thus be proposed. Initially, surgeons should be taught basic laparoscopic skills such as clipping, camera navigation, grasping and cutting. Upon satisfactory completion of training in basic skills, trainees can progress on to procedural tasks

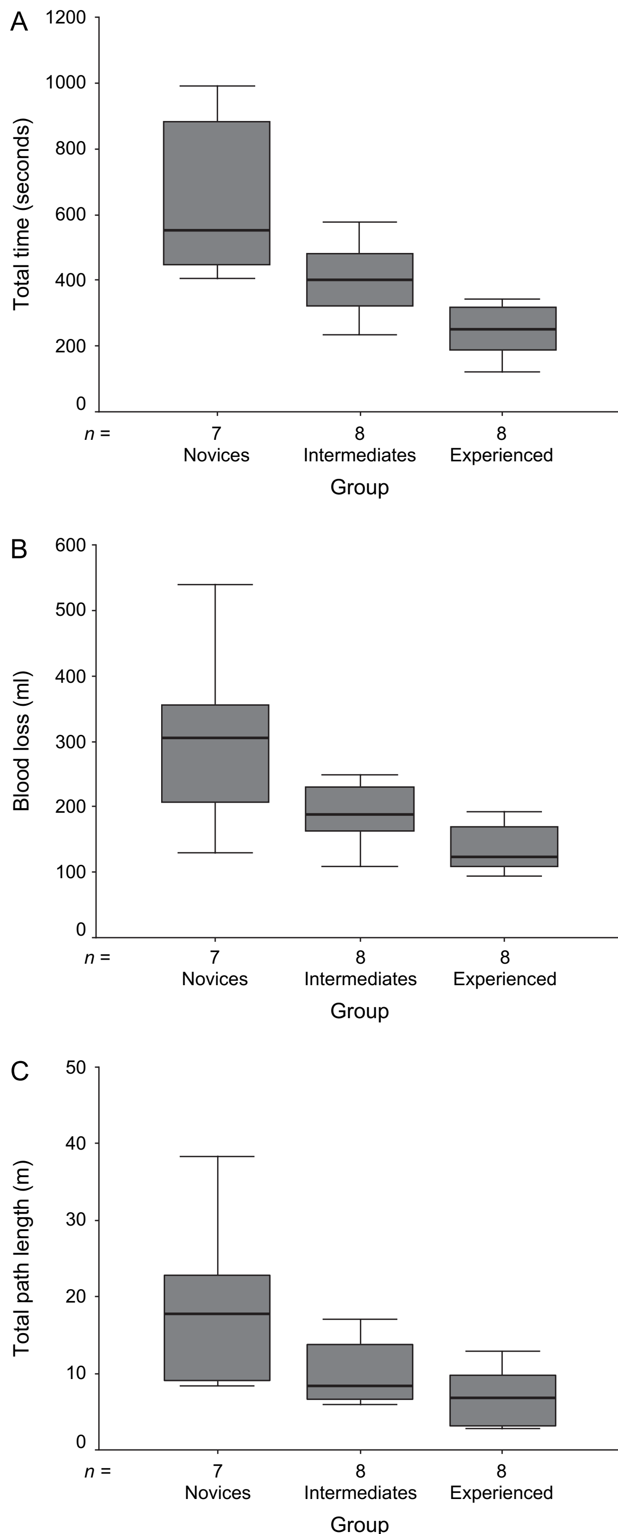

Figure 3. (A) Construct validity of the three groups for total time taken ($P = 0.001$). (B) Construct validity of the three groups for total blood loss ($P = 0.031$). (C) Construct validity of the three groups for total instrument path length ($P = 0.023$).

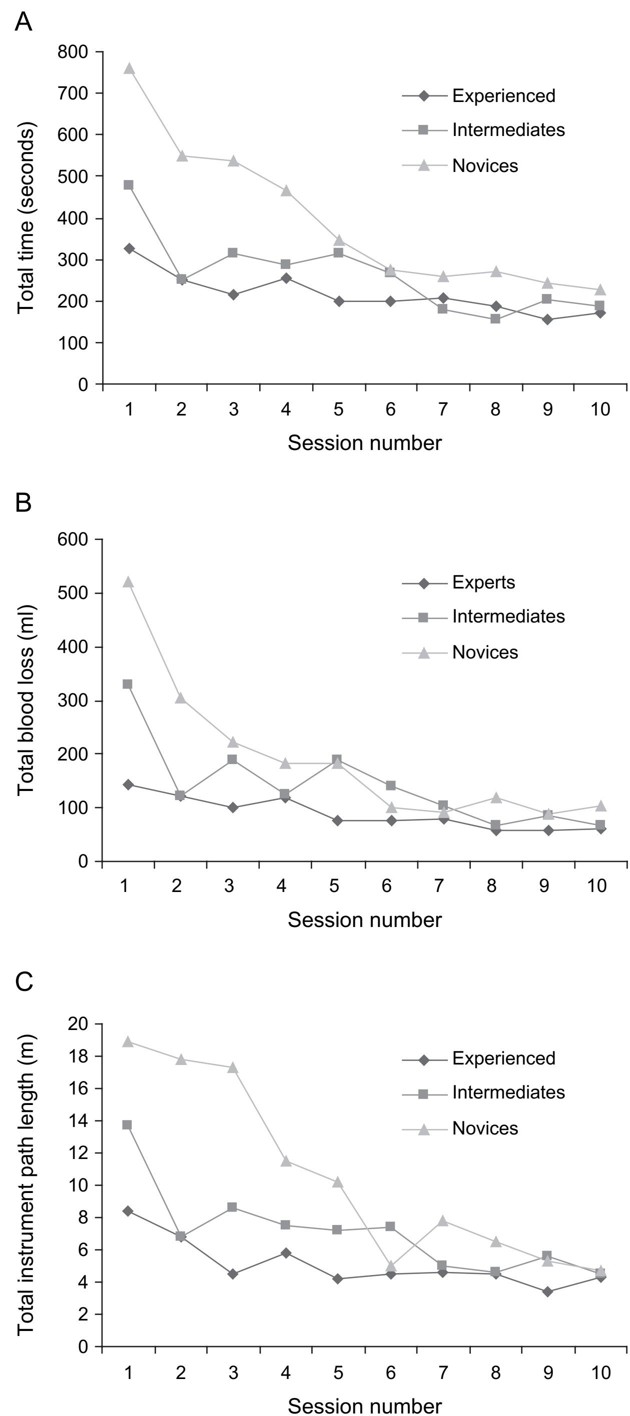

Figure 4. (A) Learning curves for total time taken to complete the 10 tasks. (B) Learning curves for total blood loss during the 10 tasks. (C) Learning curves for total instrument path length during the 10 tasks.

such as salpingectomy. Upon achievement of proficiency levels, surgeons can proceed to the operating theatre armed with the basic skills and knowledge to begin to perform the procedure on patients.

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At present, there are some technical limitations associated with the simulation, identified by the preliminary face validity study.[22] Many surgeons noted that the virtual bag was too simple to use, others remarking that bleeding during the simulation was easier to stop than during a real salpingectomy. The lack of camera control and tactile feedback also makes the procedure less realistic. Limitations to the size of the sample population due to timetabling constraints have led to groups, which were smaller than originally aimed for, and may have affected the statistical analyses.

The next stage of research is to incorporate the training curriculum into real-life procedures, by way of a randomised controlled trial. It is our aim to recruit novice gynaecological surgeons who are randomly assigned to VR training, or control, groups. Following initial assessment of laparoscopic skill in the operating theatre, the VR training group would undergo a standardised training curriculum. The control group would continue with traditional methods of training. At completion of the training period, all subjects would be assessed at their performance on a real laparoscopic salpingectomy. Comparison of performance between the two groups can confirm the role of VR training curricula in propelling young surgeons along the learning curve in a safe and educationally orientated environment, rather than continuation with the apprenticeship model of training on patients.

Conclusions

The need for objective assessment and competency-based training are important aspects of surgical education for laparoscopy. The virtual ectopic module can distinguish between initial skill levels in surgeons with differing amounts of surgical experience. In addition, training on the simulator has been shown to improve the proficiency of the surgeon to perform a simulated salpingectomy. Most notably, novice surgeons may be expected to reach a similar skill level as experts by the end of the training programme. ■

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