Virtual Reality Simulators in Gynecological Endoscopy: a Surging New Wave
Liselotte L. Mettler, MD, Puja Dewan, MRCOG

INTRODUCTION

Virtual reality (VR) is a computer-based technology for training using simulators in various medical and surgical fields, and even in military, safety-critical industries like aviation, space navigation, and nuclear power.

VR-based surgical simulator systems offer a very elegant approach to enriching and enhancing traditional training in endoscopic surgery. They generate state-of-the-art “virtual” endoscopic views of surgical scenarios with high realism in surgical fields particularly in endoscopic surgery where they help in surgical navigation too. Thus, simulators help emulate with a high degree of accuracy the anatomy of “virtual” organs, “virtual” tissues, and “virtual” vessels not just in visualization but also in feel, now even possible using “virtual” instruments in a “virtual” operating theater with a “virtual” surgeon.

Technological Aspects: Is It a Maze?

VR involves geometrical and kinematic modeling techniques for quality and performance, real-time graphics, multi-body dynamics, elastodynamically deformable tissue models, and its data concepts allow for multiple detail levels.

Depending on the simulation needed, anatomical images can be derived from magnetic resonance images, video recordings, or the Visible Human Project (a computer-based model of a human developed by the National Library of Medicine in Bethesda, Maryland). The image can be digitally mapped onto a polygonal mesh representing whatever body part or organ is being examined. Each vertex of the polygon is assigned attributes, color, and reflectivity from the image of the organ.

For the user to interact with the graphics, there must be soft algorithms that can calculate the whereabouts of the virtual instruments and determine whether it has collided with the relevant part. To create graphics that move without flickering, collision detection and tissue deformation must be calculated at least 30 times per second.

Models of how various tissues behave when cut, prodded, and punctured are needed. Here, too, tissue as a polygonal mesh is portrayed that reacts like an array of masses connected by springs and dampers. The parameters of these models are then matched to the actual procedure experience. Many laboratories rely on a haptic (tactile forced feedback) interface called Phantom (Massachusetts Institute of Technology, Cambridge, sold by SensAble Technologies Inc., Woburn). A software package called Ghost translates elasticity and roughness into commands for the robotic arm and the arm’s actuators in turn produce the haptic force. Touch Lab has developed an algorithm that models virtual instruments as lines rather than points. This ray-based rendering calculates the forces from all the collisions along the line and delivers the resulting force and torque. 2 degrees to 3 degrees of freedom phantoms. A haptic feedback VR model helps create the illusion that the user has physical contact with the model and the user feels the patient and the simulator.

Virtual hysteroscopic bleeding simulation is based on graphical fluid solvers, software whereby the streamlines traced by fluid particles can be seen on the computer screen. Hydrometra simulation for VR-based hysteroscopy training is designed on the homogenous isotropic material laws implemented in the finite element model that causes distension of the uterine muscle and the deformation of the organ shape, and the liquid flow simulation in the cavity is based on the Navier-Stokes equation, which describes the motion of viscous incompressible fluid substances.

VR Simulator Training Models: What Is Available?

Though many VR simulators with and without haptic feedback exist for training, especially in laparoscopic surgery from a general surgeon’s requirement, unfortunately
those with a specific gynecological software training module are limited.

Endotower (Verefi Technologies) simulates driving an angled (0-, 30-, 45-, and 70-degree) laparoscopic camera and lens combination applicable to multiple specialties including gynecology. RapidFire also from Verefi Technologies simulates minimally invasive skills run on virtual laparoscopic interface.

Key Surgical Activities (KSA) (Mentice Medical) simulates laparoscopy including passing a needle and suturing tissue.

LapSim (Immersion Medical and Surgical Science) simulates laparoscopic surgery including camera navigation, grasping drills, suturing, and clip applications (Figures 1, 2).

Lap Mentor (Simbionix) simulates realistic intraabdominal cavity images allowing training in laparoscopy including basic skills like camera navigation, electrocauterization, organ manoeuvring, clipping, and cutting, and has a procedural module for cholecystectomy.

Karlsruhe Endoscopic Virtual Surgery Trainer (Forschungszentrum Karlsruhe) is based on a 3-dimensional graphical simulation program KISMET (Kinematic Simulation Monitoring and offline programming Environment for TeleRobotics).

Some others, without haptic feedback and without a specific gynecological endoscopic module, in addition to the above mentioned are MIST VR (Virtual Presence Ltd.) (Figures 3, 4), LSW 3.0 (Surgical Science of Stockholm), BEST-IRIS Laparoscopy Surgery Training Simulator (Ban-
Haptic feedback is incorporated in newer models like LapSimGyn (Immersion Medical and Surgical Science Ltd.), Lap Mentor (Simbionix) (Figures 5, 6), ProMIS (Haptica), Procedicus MIST (Mentice Medical), and VIRGY (Swiss Federal Institute of Technology).

LapSimGyn is armed with the software for procedural tasks of laparoscopic salpingectomy for ectopic pregnancy removal, tubal occlusion, and laparoscopic suturing in a laparoscopic myomectomy (Figures 8, 9, 10, 11). Tubal sterilization by cauterization procedural module has also been developed.6

The LaHystotrain for training in both laparoscopy and hysteroscopy including hysteroscopic interventions is developed combining VR, multimedia technology, and the intelligent tutoring system.7,8

Virtual hysteroscopy with forced feedback and lately with simulated bleeding models has also arrived.1,9,10 The Hysteroscopy AccuTouch (Figure 7) system (Immersion Medical) equipped with forced feedback simulates hysteroscopic procedures like cervical dilatation, endometrial ablation, and removal of intrauterine lesions. The fluid management monitor tracks fluid overload. Case histories with specific instructions and metric score analysis are also present.

Comparative Analysis of Laparoscopic Trainers

The common trainers for laparoscopy are box trainers (with either innate models or animal tissues), animal and cadaveric laparoscopy, and VR trainers (with or without haptic feedback). The box trainers were the first basic training simulators. Operations on pigs are the gold standard for laparoscopy and open surgery, despite the limited number of expensive animals and the ethical issues.

The physical patient models like pelvi-trainers lack realistic anatomical features. What the surgeon sees is the 2-dimensional image; therefore, problems with depth per-
ception arise. VR armed with haptic feedback would allow some tactile force and feedback for the surgeon to get a better feel for the tools he is using. Most important however, is the lack of realistic tissue bleed. The trainee is thus unable to learn hemostasis techniques.

The box trainers, although low technologically, accurately simulate the confining rigid environment that limits the surgeon’s range of motion in actual surgery. The disadvantages are that they are 2-dimensional, re-equipping the box for each practical exercise is time consuming, and the results are not measurable, limiting progress assessment.

VR as a method of complimentary training has the advantages of unlimited possibility of practice in a 3-dimensional possibly haptic-adapted scenario with the complete freedom to compose programs of different content; tailored education adapted to the individual needs and goals; objective measurement of progress and competence; and quality assurance through certification of either operating surgeons of processes through comparison with the established expertise or well-defined standards of achievement.

Increasing constraints on time and resources, and decreased patient availability for training the surgeons has resulted in the new innovative emphasis on surgery ex vivo training with the aim to optimize the education prac-
VR trainers have resulted in fewer errors translating into better patient outcomes. The training curve is accelerated, and the time spent as a surgical resident is decreased. Because the VR training system is necessarily run on a computer, there is always the objective and distinct advantage of data collection and information on the trainee performance for identifying and recording operative efficiency and performance functioning in both as an educative tool and as a technical skill validation instrument. The outcome measures evaluated are economy of time (time taken to complete the task), economy of instrument movement (distance), economy of diathermy, error score, and total score. These user data are used to create critiques and generate a learning curve over time to compare the trainee with his cohort of peers.

Studies to substantiate and negate the possible advantages of one over the other have been conducted. Munz et al.\(^{11}\) compared LapSim with the classic box trainer and found no significant difference between the two. Also, training of novices using MIST VR yielded similar results as with conventional training.\(^{12}\) Madan et al.\(^{13}\) found no statistically significant difference in the groups trained only with MIST VR or box trainer (LTS2000) when trainees were asked whether a specific trainer helped their skills. The group trained on both the trainers felt no statistically significant change except that 47% felt that VR was not realistic. VR trainers have some advantages, but most trainees felt the box trainers help more, are more interesting, and should be chosen over VR trainers if only one trainer is allowed.\(^{15}\)

Grantcharov et al.\(^{14}\) showed in their study that laparoscopic performance in the porcine animal model correlated significantly with performance on the MIST VR.

On comparison of the dominant and nondominant hand performance between the box and VR trainer, for the 1-hand tasks, it was difficult to assess individual hand performance with the box trainers alone, and box trainers did not correlate with the VR trainer. But, for the individual hand assessment during 2-handed tasks, the box trainers were comparable to the VR trainer.\(^{15}\)

A study has shown no significant improvement in intracorporeal knot tying time between the pelvic trainer and MIST VR.\(^{16}\)

**VR Trainers as Laparoscopic Skill Assessors**

Studies have demonstrated the beneficial affects of training novice laparoscopic surgeons using VR simulators, although there is no consensus regarding an optimal VR training curriculum. To establish and validate a structured VR curriculum to provide an evidence-based approach for laparoscopic training is the need of the hour. An insight into the following studies raises interest.

Aggarwal et al.\(^{17}\) concluded that a graduated laparoscopic training curriculum enables trainees to familiarize, train, and be assessed on laparoscopic VR trainers.

Currently, no accepted metrics for most surgical skills especially laparoscopic skills exist. Madan et al.\(^{18}\) concluded that VR may be an avenue for measuring laparoscopic surgical ability. VR thread simulation training is currently being validated.\(^{19}\)

Surgeons who received VR simulation training showed significantly greater improvement in performance in the operating room versus those who did not.\(^{20,21}\) Experienced laparoscopic surgeons performed the tasks significantly faster, with less error, more economy in movement and diathermy use, and with greater consistency in performance versus the inexperienced and novice laparoscopic surgeons after training on MIST VR.\(^{22–24}\) Similarly, surgeons scored consistently and significantly better than medical students and nonmedical personnel did.\(^{25}\)

Practice makes a man perfect. Current literature suggests that novices reach a plateau after 2 to 7 trials when training on MIST VR. The 6-task simulation model was found valid and reliable as a learning tool for acquisition of laparoscopic skills by Uchal et al.\(^{26}\) Trainees should perform at least 10 sets of the traversal task to get used to the equipment and 5 sets to stabilize and consolidate their performance on MIST VR in a study by Hackethal et al.\(^{27}\)

Brunner et al.\(^{28}\) found that initial plateaus were found for all tasks by the eighth repetition; however, ultimate plateaus were not reached until 21 to 29 repetitions. Overall best score was reached between 20 and 30 task repetitions and occurred beyond the ultimate plateau for 9 tasks on MIST VR, indicating a lengthy learning curve for the novices.\(^{29}\) Performance plateaus may not reliably determine training endpoints. Setting goals and providing feedback tended to motivate students to practice more compared with the self-directed group.\(^{29}\) The benefit of distributed practice over massed practice in learning laparoscopic skills has been demonstrated.\(^{30}\)

Psychomotor skill acquisition for those trained on MIST VR was significantly better than that in those trained in normal laparoscopic conditions.\(^{31}\) Perceptual ability and psychomotor skills significantly correlated with the number of trials required. Visuospatial ability did not significantly correlate with the training. However, the number of...
trials in manipulation of diathermy significantly related to perceptual and psychomotor aptitude.32 Novices with VR trainers adapt to the fulcrum effect faster and make significantly more correct incisions and fewer incorrect incisions.33

In a study by Grantcharov et al34 on MIST VR, men completed the task in less time than women did but no statistically significant difference between the sexes in the number of errors and unnecessary movements was seen. Individuals with right hand dominance performed fewer unnecessary movements, and a trend towards better results in time and errors in right hand dominance was observed.34 Users of computer games made fewer errors than nonusers did.34,35 Such studies unfortunately can lead to a bias in the selection of the minimally invasive surgery residents.

Evidence For VR in Gynecological Endoscopic Training

A response survey36 in the United States showed only 69% of the gynecological residency programs implementing formal laparoscopy training. A self-assessment questionnaire by the gynecologists showed that however basic laparoscopy is sufficiently mastered during residency training, advanced laparoscopy is not.37 Analysis of the perceived proficiency in endoscopic techniques amongst the gynecology residents showed significant benefit from formal curriculum in minimally invasive surgery, but they do not feel competent performing certain advanced procedures upon graduation.38

The merits and demerits of the use of VR trainers in gynecological endoscopy training is largely assessed through indirect evidence using the above studies primarily drawn from general laparoscopic surgery. Studies implicating direct evidence are few and far between due to the paucity of gynecological procedural software modules and module-armed models.

Recently, a study showed gynecology residents not reaching all performance standards for basic laparoscopic skills on the box trainers.39 This perhaps leaves a window open for VR trainers. In accordance, Gor et al40 found MIST 2 to be a good objective assessment tool for gynecological laparoscopic skills and showed a significant early learning curve that plateaued by the third session for the majority of tasks. LapSimGyn demonstrated construct validity on both the basic skills and the procedural module for ectopic pregnancy. Expert gynecologists performed significantly and consistently better with a higher starting level of the learning curve and more rapidly reaching the plateau than the intermediate and novice gynecological laparoscopists.5 During the short phase training on the ectopic pregnancy procedural module, gynecologists with minimal laparoscopic training improved their skills, in contrast with the experienced who showed no significant improvement.4 With the tubal sterilization by cautery module, stable performance was reached by the seventh trial.6

The Future and Long-term Objectives: What Awaits?

The long-term research objectives are technological advancements in geometric anatomical model building; graphical modeling of organ appearance using phong training, bump mapping, and texturing; tissue deformation modeling for simulating elastic tissue by finite-element modeling (FEM), element formulation, simulation experiments and in vivo measurements of tissue elasticity by measuring method, material law, and numerical methods; design of real-time FEM computation engine using a partitioning model for parallel computation and collision detection; and force-feedback manipulator.41

In clinical training, gynecological endoscopic surgeons are encouraged to necessarily incorporate VR computer simulation into training curriculum. Possibly, accreditation of endoscopic surgeons in the near future shall be adjudged through a comprehensive evidence-based simulation education program. Medically too, proof of technical proficiency is desirable. The designing of software for gynecological procedural modules is imminent.

References:

1. Zatonyi J, Paget R, Szekely G, Grassi M, Bajka M. Real-time synthesis of bleeding for virtual hysteroscopy. Med Image Anal. 2005;9(3):255–266.
2. Weiss S, Bajka M, Nava A, Mazza E, Neiderer P. A finite element model for the simulation of hydrometra. Technol Health Care. 2004;12(3):259–267.
3. Sierra R, Zatonyi J, Bajka M, Szekely G, Harders M. Hydrometra simulation for VR-based hysteroscopy. Med Image Comput Comput Assist Interv Int Conf Med Image Comput Comput Assist Interv. 8(Pt 2):575–582, 2005.
4. Aggarwal R, Tully A, Grantcharov T, et al. Virtual reality simulation training can improve technical skills during laparoscopic salpingectomy for ectopic pregnancy. BJOG. 2006;113(12):1382–1387.
5. Larsen CR, Grantcharov T, Aggarwal R, et al. Objective assessment of gynecologic laparoscopic skills using the Lap-
SimGyn virtual reality simulator. Surg Endosc. 2006;20(9):1460–1466.

6. Sung WH, Fung CP, Chen AC, Yuan CC, Ng HT, Doong JL. The assessment of stability and reliability of a virtual reality-based laparoscopic gynecology simulation system. Eur J Gynaecol Oncol. 2003;24(2):143–146.

7. Voss G, Bockholt U, Los Arcos JL, Muller W, Oppelt P, Stahler J. LAHYSTOTRAIN intelligent training system for laparoscopy and hysteroscopy. Stud Health Technol Inform. 2000;70:359–364.

8. Muller-Wittig WK, Bisler A, Bockholt U, et al. LAHYSTOTRAIN development and evaluation of a complex training system for hysteroscopy. Stud Health Technol Inform. 2001;81:336–340.

9. Levy JS. Virtual reality hysteroscopy. J Am Assoc Gynecol Laparosc. 3(4,Supplement):25–26, 1996.

10. Harders M, Bajka M, Spaelter U, Tuchsmid S, Bleuler H, Szekley G. Highly realistic, immersive training environment for hysteroscopy. Stud Health Technol Inform. 2006;119:176–181.

11. Munz Y, Kumar BD, Moorthy K, Bann S, Darzi A. Laparoscopic virtual reality and box trainers: is one superior to the other? Surg Endosc. 2004;18(3):485–494.

12. Torkington J, Smith SGT, Rees BT, Darzi A. Skill transfer from virtual reality to a real laparoscopic task. Surg Endosc. 2001;15(10):1076–1079.

13. Madan AK, Frantzides CT, Tebbit C, Quiros RM. Participants' opinions of laparoscopic training devices after a basic laparoscopic training course. Am J Surg. 2005;189(6):758–761.

14. Grantcharov TP, Rosenberg J, Pahle P, Funch-Jensen P. Virtual reality computer simulation. Surg Endosc. 2001;15(3):242–244.

15. Madan AK, Frantzides CT, Shervin N, Tebbit CL. Assessment of individual hand performance in box trainers compared to virtual reality trainers. Am J Surg. 2003;186(12):1112–1114.

16. Kothari SN, Kaplan BJ, DeMaria EJ, Broderick TJ, Merrell RC. Training in laparoscopic suturing skills using a new computer-based virtual reality simulator (MIST VR) provides results comparable to those with an established pelvic trainer system. J Laparoendosc Adv Surg Tech A. 2002;12(3):167–173.

17. Aggarwal R, Grantcharov T, Moorthy K, Hance J, Darzi A. A competency-based virtual reality training curriculum for the acquisition of laparoscopic psychomotor skill. Am J Surg. 2006;191(1):128–133.

18. Madan AK, Frantzides CT, Sasso LM. Laparoscopic baseline ability assessment by virtual reality. J Laparoendosc Adv Surg Tech A. 2005;15(1):13–17.

19. Figueras Sola PJ, Rodriguez Bescos S, Lamata P, Pagador JB, Sanchez-Margallo FM, Gomez EJ. Virtual reality thread simulation for laparoscopic suturing training. Stud Health Technol Inform. 2006;119:144–149.

20. Grantcharov TP, Kristiansen VB, Bendix J, Bardram L, Rosenberg J, Funch-Jensen P. Randomised clinical trial of virtual reality simulation for laparoscopic skills training. Br J Surg. 2004;91(2):146–150.

21. Seymour NE, Gallagher A, Anthony G, et al. Virtual reality training improves operating room performance: results of a randomized, double blinded study. Ann Surg. 2002;236(4):458–464.

22. Gallagher AG, Satava RM. Virtual reality as a metric for the assessment of laparoscopic psychomotor skills. Surg Endosc. 2002;16(12):1746–1752.

23. Gallagher AG, Karen R, McClure N, McGuigan J. Objective psychomotor skills assessment of experienced, junior, and novice laparoscopists with virtual reality. World J Surg. 2001;25(11):1478–1483.

24. McNatt SS, Smith CD. A computer-based laparoscopic skills assessment device differentiates experienced from novice laparoscopic surgeons. Surg Endosc. 2001;15(10):1085–1089.

25. Chaudhry A, Sutton C, Wood J, Stone R, McCoy R. Learning rate for laparoscopic surgical skills on MIST VR, a virtual reality simulator: quality of human-computer interface. Ann R Coll Surg Engl. 1999;81(4):281–286.

26. Uchal M, Raftopoulos Y, Tjugum J, Bergamaschi R. Validation of a six-task simulation model in minimally invasive surgery. Surg Endosc. 2005;19(1):109–116.

27. Hackethal A, Immenroth M, Burger T. Evaluation of target scores and benchmarks for the traversal task scenario of the Minimally Invasive Surgical Trainer-Virtual Reality (MIST VR) laparoscopy simulator. Surg Endosc. 2006;20(4):645–650.

28. Brunner WC, Korndorfer JR Jr., Sierra R, et al. Laparoscopic virtual reality training: are 30 repetitions enough? J Surg Res. 2004;122(2):150–156.

29. Gonzalez R, Bowers SP, Smith CD, Ramshaw BJ. Does setting specific goals and providing feedback during training result in better acquisition of laparoscopic skills? Am Surg. 2004;70(1):35–39.

30. Mackay S, Morgan P, Datta V, Chang A, Darzi A. Practice distribution in procedural skills training: a randomized controlled trial. Surg Endosc. 2002;16(6):957–961.

31. Jordan JA, Gallagher AG, McGuigan J, McGlade K, McClure N. A comparison between randomly alternating imaging, normal laparoscopic imaging, and virtual reality training in laparoscopic psychomotor skill acquisition. Am J Surg. 2000;180(3):208–211.

32. McClusky DA 3rd, Ritter EM, Lederman AB, Gallagher AG, Smith CD. Correlation between perceptual, visuo-spatial, and psychomotor aptitude to duration of training required to reach
performance goals on the MIST VR surgical simulator. Am J Surg. 2005;71(1):13–20.

33. Jordan JA, Gallagher AG, McGuigan J, McClure N. Virtual reality training leads to faster adaptation to the novel psychomotor restrictions encountered by laparoscopic surgeons. Surg Endosc. 2001;15(10):1080–1084.

34. Grantcharov TP, Bardram L, Funch-Jensen P, Rosenberg J. Impact of hand dominance, gender, and experience with computer games on performance in virtual reality laparoscopy. Surg Endosc. 2003;17(7):1082–1085.

35. Enochsson L, Isaksson B, Tour R, et al. Visuospatial skills and computer game experience influence the performance of virtual endoscopy. J Gastrointest Surg. 2004;8(7):876–882.

36. Stovall DW, Fernandez AS, Cohen SA. Laparoscopy training in United States obstetric and gynecology programs. JSLS. 2006;10(1):11–15.

37. Kolkman W, Wolterbeek R, Jansen FW. Implementation of advanced laparoscopy into daily gynecologic practice: difficulties and solutions. J Minim Invasive Gynecol. 2006;13(1):4–9.

38. Einarsson JI, Young A, Tsien L, Sansi-Haghpeykar H. Perceived proficiency in endoscopic techniques among senior obstetrics and gynecology residents. J Am Assoc Gynecol Laparosc. 2002;9(2):158–164.

39. Kolkman W, Van de Put MA, Van den Hout WB, Trimbos JB, Jansen FW. Implementation of the laparoscopic simulator in gynecological residency curriculum. Surg Endosc. 2007;21(8):1363–1368.

40. Gor M, McCloy R, Stone R, Smith A. Virtual reality laparoscopic simulator for assessment in gynaecology. BJOG 2003;110(2):181–187.

41. Szekely G, Brechbuhler CH, Dual J, et al. Virtual reality-based simulation of endoscopic surgery. Presence. 2000;9(3):310–333.