Excerpta Medica

The American Journal of Surgery

The American Journal of Surgery 191 (2006) 128–133

Laparoscopy

A competency-based virtual reality training curriculum for the acquisition of laparoscopic psychomotor skill

Rajesh Aggarwal, M.B.B.S.[a,*], Teodor Grantcharov, Ph.D.[b], Krishna Moorthy, M.D.[a], Julian Hance, M.B.B.S.[a], Ara Darzi, M.D.[a]

[a]Department of Surgical Oncology and Technology, Imperial College, Imperial College, 10th Floor, QEQM Building, St. Mary's Hospital, Praed Street, London W2 1NY, UK

[b]Department of Surgical Gastroenterology, Glostrup University Hospital, Glostrup, Denmark

Manuscript received March 30, 2005; revised manuscript June 15, 2005

Abstact

Background: Studies have demonstrated the beneficial effect of training novice laparoscopic surgeons using virtual reality (VR) simulators, although there is still no consensus regarding an optimal VR training curriculum. This study aims to establish and validate a structured VR curriculum to provide an evidence-based approach for laparoscopic training programmes.

Methods: The minimally invasive VR simulator (MIST-VR) has 12 abstract laparoscopic tasks, each at 3 graduated levels of difficulty (easy, medium, and hard). Twenty medical students completed 2 sessions of all tasks at the easy level, 10 sessions at the medium level, and finally 5 sessions of the 2 most complex tasks at the hard level. At the medium level, subjects were randomized into 2 equal groups performing either all 12 tasks (group A) or the 2 most complex tasks (group B). Performance was measured by time taken, path length, and errors for each hand. The results were compared between groups, and to those of 10 experienced laparoscopic surgeons.

Results: Baseline performance of both groups was similar at the easy level. At the medium level, learning curves for all 3 parameters reached plateau at the second (group A, $P < .05$) and sixth (group B, $P < .05$) repetitions. Performance at the hard level was similar between the 2 groups, and all achieved the pre-set expert criteria.

Conclusion: A graduated laparoscopic training curriculum enables trainees to familiarise, train and be assessed on laparoscopic VR simulators. This study can aid the incorporation of VR simulation into established surgical training programmes.

Keywords: Laparoscopic skills; Training; Surgical competence; Virtual reality

Laparoscopic surgery has had a significant impact on the delivery of surgical care. It is now the gold standard for cholecystectomy and anti-reflux and bariatric surgery, leading to decreased patient morbidity when compared to open procedures [1,2]. However, the skills required for laparoscopic surgery are markedly different from those employed in open surgery [3]. It is now generally accepted that these skills must initially be learned in training laboratories prior to entering the operating theater.

Virtual reality (VR) simulators have been proposed to train participants in the basic psychomotor skills required for laparoscopic surgery [4–7]. Recent studies have shown the ability of novices to attain expert levels of laparoscopic skill [8,9], and also for the transfer of these skills to the operating theatre [10,11]. VR simulation also benefits from the incorporation of instant, objective feedback in terms of dexterity measures such as path length and number of movements, and error scores. It is thus possible to accurately chart a trainee's progress during a laparoscopic training program, and to ensure that learning has occurred to a defined level of proficiency.

Prior to the incorporation of these simulators into surgical training programs, there is a need to develop a validated VR training curriculum that can be shown to lead to the development of technical competence. Current studies demonstrating the beneficial effect of training on the MIST-VR laparoscopic simulator (Mentice, Gothenburg, Sweden) have employed a variety of training methods, none of which have been evidence-based [8–19].

* Corresponding author. Tel.: 00 44 207 886 1310; fax: 00 44 207 886 1810.

E-mail address: rajesh.aggarwal@imperial.ac.uk

0002-9610/06/$ – see front matter
doi:10.1016/j.amjsurg.2005.10.014

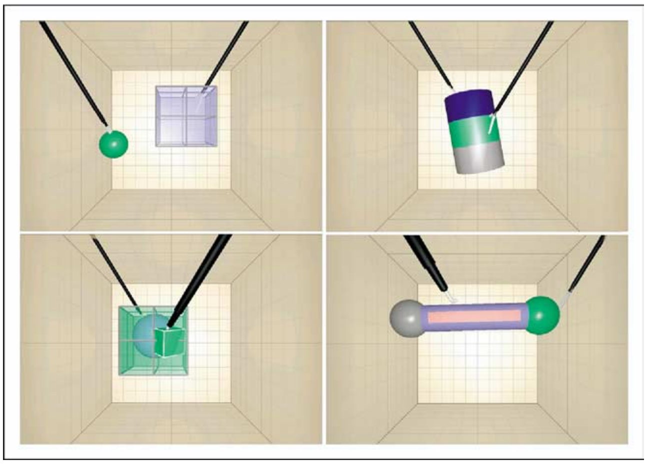

Fig. 1. Sample tasks on MIST-VR.

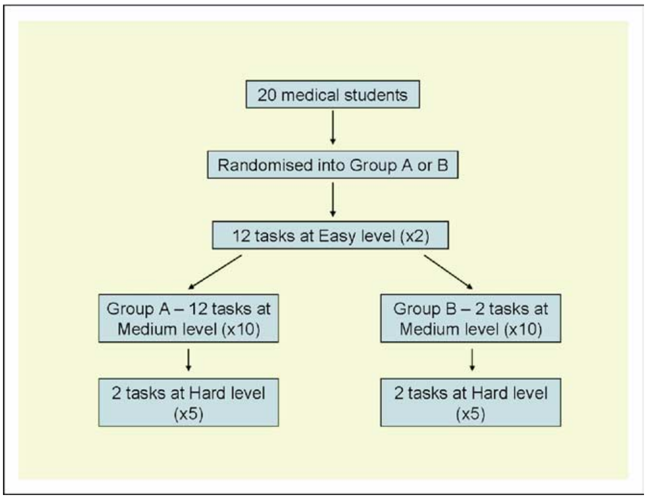

Fig. 2. Study design; "12 tasks" denotes all 12 tasks from core skills 1 and 2; "2 tasks" denotes the 2 most complex tasks from each of core skills 1 and 2.

In order to train in the most beneficial and efficient manner, it is necessary to know which tasks should be performed, at which level of difficulty, and how often they should be repeated. Previous studies have shown a plateau of the learning curves after the second repetition at the easy level [12], and at between the fifth and seventh repetition at the medium level [8,9]. However, no studies to date have defined the nature of a structured training program from the easy level through medium and onto the hard levels. This study hypothesizes that a proficiency-based VR training program for novice laparoscopic surgeons on the MIST-VR simulator can lead to improvements in psychomotor skill. This can then form an evidence-based approach to the standardization of future training programs, leading to consensus definitions of proficiency prior to operating on real patients.

Methods

Twenty medical students with no previous laparoscopic experience were recruited to undergo a training program on the MIST-VR simulator. Training sessions were delivered over a maximum period of 14 days, with 2 sessions per day, each at least 1 hour apart. A study coordinator was present during all training sessions to provide technical assistance.

MIST-VR is the most widely validated laparoscopic VR simulator and has 12 basic tasks at 3 levels of difficulty: easy, medium, and hard (Fig. 1) [20–22]. For example, "Transfer Place" involves grasping a virtual sphere with 1 instrument and transferring it to the other; the task becomes more difficult by a reduction in the size of the sphere, and thus requires greater accuracy for task completion. "SD Diathermy" requires diathermy of a virtual length of tissue; the task becomes more difficult by reducing the area that is safe to diathermy. The tasks are divided into 2 sets of 6: core skills 1 and 2. Each set of 6 tasks is complementary, and the sixth task from each group is the most complex, integrating aspects of the previous 5.

To familiarize themselves with the simulator, all participants initially performed 2 sessions of all 12 tasks at the easy level (Fig. 2). The subjects were then randomized into 2 equal groups using the sealed envelope technique. Both groups performed 10 sessions on the medium level, although group A continued to train on all 12 tasks while group B only trained on the two most complex tasks, i.e., task 6 from core skills 1 and 2. Finally, all participants completed the 2 most complex tasks at the hard level for a further 5 sessions.

Assessment of progress throughout the training program was measured by the simulator in terms of time taken, economy of movement, and number of errors for each hand. In order to maintain uniformity of assessment between the sessions, all comparisons were made on the 2 most complex tasks only. This enabled comparison between groups A and B, and definition of the number of sessions required prior to flattening of the learning curve for each parameter.

In order to define whether the novices had achieved expert levels of psychomotor skill, their performance at the hard level was compared to that of benchmark scores derived from the performance of 10 expert laparoscopic surgeons. The expert criterion was defined as having performed more than 100 laparoscopic cholecystectomies in total.

Statistical Analysis

Data were analyzed by the Statistical Package for the Social Sciences version 11.5 (SPSS, Chicago, IL) using nonparametric tests. Data on learning curves were analyzed by the Friedman (nonparametric repeated measures analysis of variance [ANOVA]) test. Multiple comparisons were then made to identify when plateau of skills had occurred. Comparison of performance between groups A and B was

Table 1
Demographic data

	Age, y (median, range)	Sex (M:F)	Handedness (R:L)
Group A (12 tasks)	20 (18–22)	4:6	8:2
Group B (2 tasks)	20 (18–22)	8:2	9:1

undertaken using the Mann-Whitney U test. A level of $P < .05$ was considered statistically significant.

Results

All 20 participants completed the study curriculum, and there were no demographic differences between groups A (12 tasks) and B (2 tasks) (Table 1). At the easy level, baseline performance scores were similar for groups A and B in terms of time taken ($P = .588$), economy of movement ($P = .813$), and error scores ($P = .496$). Assessment of performance during training at the medium level for groups A and B on task 6 for core skills 1 revealed a statistically significant flattening of the learning curve at sessions 2 and 6, respectively, for all parameters of time taken, error scores, and economy of movement (Figs. 3 through 5). Similar scores were achieved for task 6 on core skills 2. At the medium level, there were no significant differences when comparing skill levels achieved by group A at the second session with those achieved by group B at the sixth session.

At the hard level, there was no evidence of significant improvement in skill for either group A or B, and again there were no differences in skill levels between the groups for error scores ($P = .914$) or economy of movement ($P = .152$). However, group A was significantly faster than group B ($P = .006$) at completing the tasks at the hard level. The median scores of 10 experienced laparoscopic surgeons were taken as benchmark levels (Fig. 6). Comparison of the participants' scores with these benchmark levels revealed that all students were able to achieve the set criteria at the hard level.

Comments

This study has established an evidence-based VR training curriculum for the acquisition of psychomotor skill. Previous studies have demonstrated plateau of skill acquisition at the easy and medium levels [8,9,12]. However, it was the aim of this study to define a stepwise curriculum moving from easy to medium and onto hard levels of difficulty, and to provide objective evidence regarding the most efficient use of the simulator.

This study has shown that it is possible to acquire the same level of skill whether one performs only the 2 most complex tasks, or all 12 tasks on the simulator. Subjects in the 12 tasks group took approximately 30 minutes to complete each session, whereas subjects in the 2 tasks group took about 5 minutes per session. However, it is evident that a greater number of sessions are required when only 2 tasks are practiced. Regardless of the training curriculum adopted at the medium level, all subjects in both groups managed to attain expert levels of skill when performing at the hard level.

Integrating the results of this study into a training curriculum can be achieved by alignment with a framework that describes 3 stages of motor skills learning proposed by Fitts and Posner [23]. During the first stage (cognition), the trainee gains an understanding of the task through instructor explanation and demonstration. This relates to the quality of the human–machine interaction, resulting in a short phase for a realistic model. In the second stage (association), the

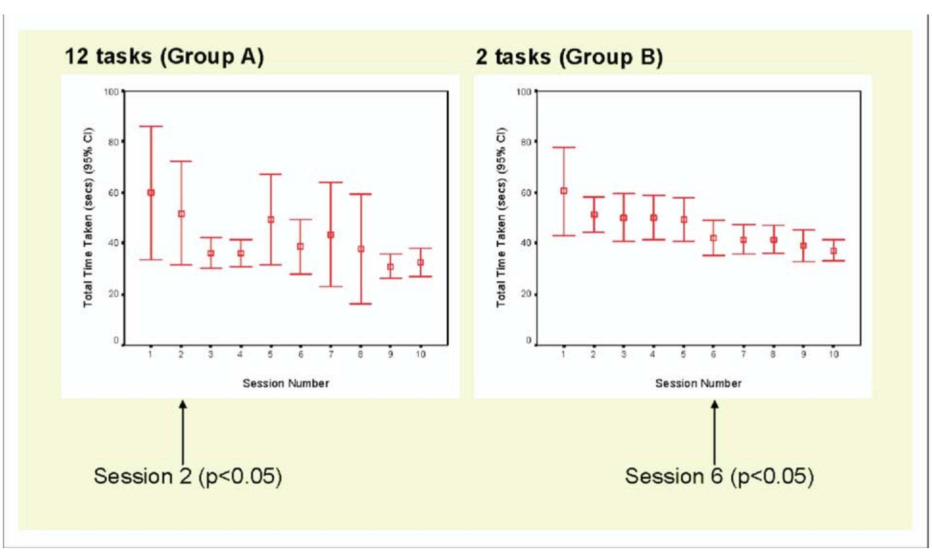

Fig. 3. Time taken at the medium level (2 vs 12 tasks).

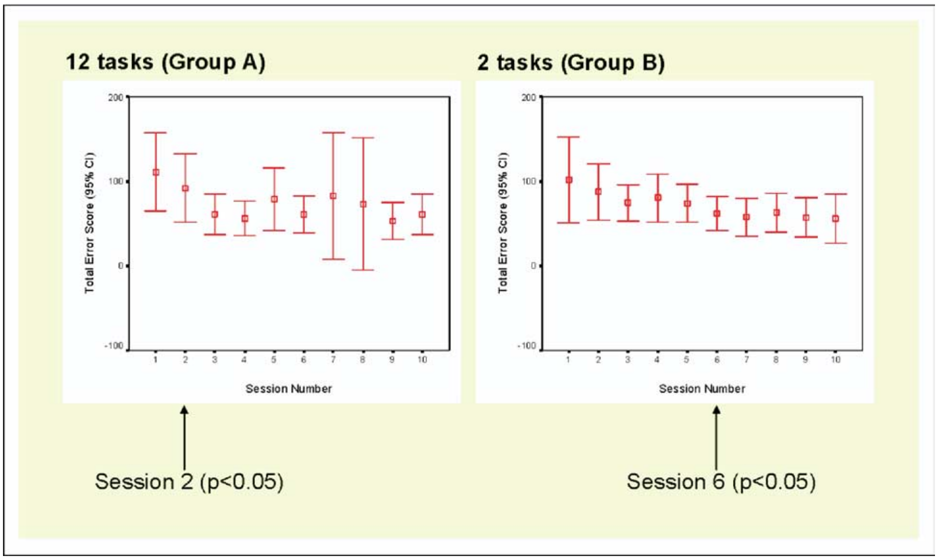

Fig. 4. Total error scores at the medium level (2 vs 12 tasks).

user practices the task to eliminate error, with the instructor providing feedback to identify errors and suggest corrective actions. The final phase (automation) occurs when the learner performs the tasks in a relatively automated fashion with little or no cognitive input.

Extrapolating the concept to this study, it can be seen that training at the easy level enables the trainees to familiarize themselves with the controls of the simulator and the nature of the tasks to be performed. This is in tandem with another study commenting on the high-quality user–computer interface of the MIST-VR simulator [24]. The medium level provides an opportunity to refine performance at the tasks, leading onto the hard level, by which time the skills have become second nature. This is evident from the fact that there was no further improvement in performance at the hard level.

It is thus possible to define this 3-stage curriculum as one that enables trainee surgeons to familiarize, train, and be assessed on a VR simulator (Fig. 6). Assessment of skill can be performed at the hard level by comparison with results of an expert group of surgeons. The results of this study confirm that all participants achieved levels of skill similar to those of a group of experienced laparoscopic surgeons. By increasing the numbers of experienced surgeons in the database, it will ultimately be possible to test the predictive validity of these criteria for a trainee surgeon's pathway to achievement of competence [25].

The curriculum charted here provides a prescriptive approach to training novice laparoscopic surgeons, to an evidence-based level of proficiency in basic psychomotor skills. The key point is that it is achievement of pre-set criteria, rather than time taken, that determines completion

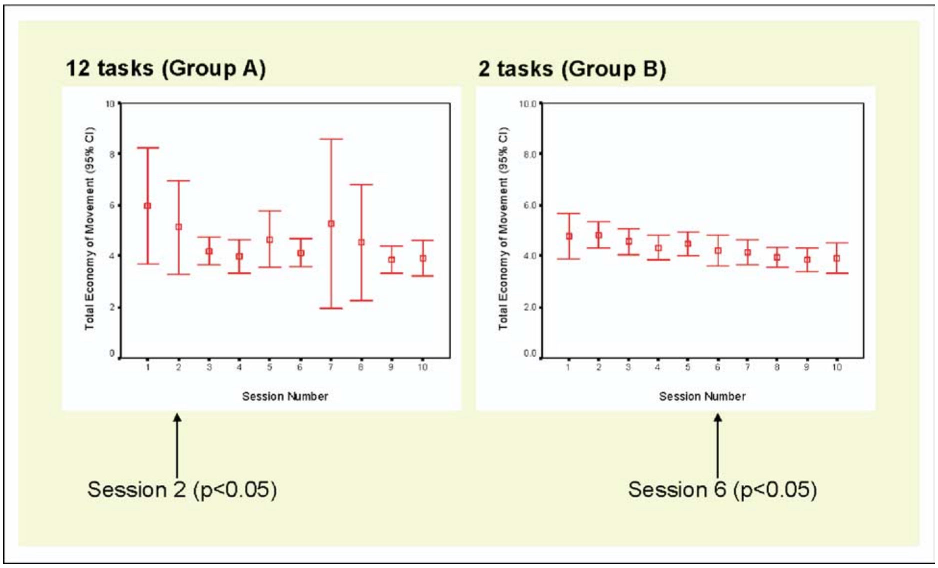

Fig. 5. Economy of movement at the medium level (2 vs 12 tasks).

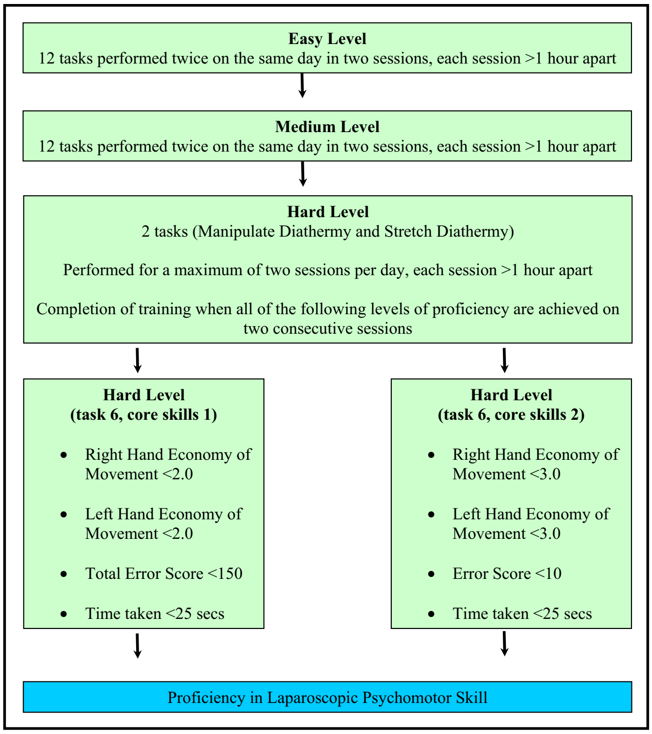

Fig. 6. A virtual reality training curriculum for acquisition of basic laparoscopic skills.

of the training period. It is thus irrelevant how long one takes to complete the program, and some trainees shall of course attain proficiency faster than others. However, all trainees who have achieved the pre-set criteria will have the psychomotor skills necessary to assist in, and learn to perform, real laparoscopic procedures.

This model of skills training enables the development of proficiency in basic laparoscopic skills. Some centers have sought to define the requirements of basic and advanced laparoscopic training programs, with a move away from 2-day courses toward an extended curriculum over a period of weeks to months [26–28]. However, the structure of these programs has been developed in a largely arbitrary manner rather than through scientific evaluation. The next stage of our research is to define a VR training curriculum for higher level surgical tasks such as laparoscopic suturing. These curricula can then be the nuts and bolts of a validated and competency-based laparoscopic training program incorporating the use of video trainers, VR simulators, porcine models, and ultimately training in the operating theater.

References

[1] Hinder RA, Filipi CJ, Wetscher G, et al. Laparoscopic Nissen fundoplication is an effective treatment for gastroesophageal reflux disease. Ann Surg 1994;220:472–81.
[2] Vander Velpen GC, Shimi SM, Cuschieri A. Outcome after cholecystectomy for symptomatic gall stone disease and effect of surgical access: laparoscopic v open approach. Gut 1993;34:1448–51.
[3] Figert PL, Park AE, Witzke DB, et al. Transfer of training in acquiring laparoscopic skills. J Am Coll Surg 2001;193:533–7.
[4] Coleman J, Nduka CC, Darzi A. Virtual reality and laparoscopic surgery. Br J Surg 1994;81:1709–11.
[5] Haluck RS, Krummel TM. Computers and virtual reality for surgical education in the 21st century. Arch Surg 2000;135:786–92.
[6] Satava RM. Accomplishments and challenges of surgical simulation. Surg Endosc 2001;15:232–41.
[7] Torkington J, Smith SG, Rees BI, et al. The role of simulation in surgical training. Ann R Coll Surg Engl 2000;82:88–94.
[8] Gallagher AG, Satava RM. Virtual reality as a metric for the assessment of laparoscopic psychomotor skills. Learning curves and reliability measures. Surg Endosc 2002;16:1746–52.
[9] Grantcharov TP, Bardram L, Funch-Jensen P, et al. Learning curves and impact of previous operative experience on performance on a virtual reality simulator to test laparoscopic surgical skills. Am J Surg 2003;185:146–9.
[10] Grantcharov TP, Kristiansen VB, Bendix J, et al. Randomized clinical trial of virtual reality simulation for laparoscopic skills training. Br J Surg 2004;91:146–50.
[11] Seymour NE, Gallagher AG, Roman SA, et al. Virtual reality training improves operating room performance: results of a randomized, double-blinded study. Ann Surg 2002;236:458–63.
[12] Ali MR, Mowery Y, Kaplan B, et al. Training the novice in laparoscopy. More challenge is better. Surg Endosc 2002;16:1732–6.
[13] Chaudhry A, Sutton C, Wood J, et al. Learning rate for laparoscopic surgical skills on MIST VR, a virtual reality simulator: quality of human-computer interface. Ann R Coll Surg Engl 1999; 81:281–6.
[14] Hamilton EC, Scott DJ, Fleming JB, et al. Comparison of video trainer and virtual reality training systems on acquisition of laparoscopic skills. Surg Endosc 2002;16:406–11.
[15] Jordan JA, Gallagher AG, McGuigan J, et al. Virtual reality training leads to faster adaptation to the novel psychomotor restrictions encountered by laparoscopic surgeons. Surg Endosc 2001;15:1080–4.
[16] Kothari SN, Kaplan BJ, DeMaria EJ, et al. 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: 167–73.
[17] McNatt SS, Smith CD. A computer-based laparoscopic skills assessment device differentiates experienced from novice laparoscopic surgeons. Surg Endosc 2001;15:1085–9.
[18] Pearson AM, Gallagher AG, Rosser JC, et al. Evaluation of structured and quantitative training methods for teaching intracorporeal knot tying. Surg Endosc 2002;16:130–7.
[19] Torkington J, Smith SG, Rees BI, et al. Skill transfer from virtual reality to a real laparoscopic task. Surg Endosc 2001;15:1076–9.
[20] Gallagher AG, McClure N, McGuigan J, et al. Virtual reality training in laparoscopic surgery: a preliminary assessment of minimally invasive surgical trainer virtual reality (MIST VR). Endoscopy 1999; 31:310–3.
[21] Gallagher AG, Richie K, McClure N, et al. Objective psychomotor skills assessment of experienced, junior, and novice laparoscopists with virtual reality. World J Surg 2001;25:1478–83.
[22] Taffinder N, Sutton C, Fishwick RJ, et al. Validation of virtual reality to teach and assess psychomotor skills in laparoscopic surgery: results from randomised controlled studies using the MIST VR laparoscopic simulator. Stud Health Technol Inform 1998;50:124–30.
[23] Fitts AM, Posner MI. *Human Performance.* Belmont, CA: Brooks-Cole; 1967.
[24] Gor M, McCloy R, Stone R, et al. Virtual reality laparoscopic simulator for assessment in gynaecology. BJOG 2003;110:181–7.
[25] Gallagher AG, Smith CD, Bowers SP, et al. Psychomotor skills assessment in practicing surgeons experienced in performing ad-

vanced laparoscopic procedures. J Am Coll Surg 2003;197:479–88.

[26] Coleman RL, Muller CY. Effects of a laboratory-based skills curriculum on laparoscopic proficiency: a randomized trial. Am J Obstet Gynecol 2002;186:836–42.

[27] Lin E, Szomstein S, Addasi T, et al. Model for teaching laparoscopic colectomy to surgical residents. Am J Surg 2003;186:45–8.

[28] Powers TW, Murayama KM, Toyama M, et al. Housestaff performance is improved by participation in a laparoscopic skills curriculum. Am J Surg 2002;184:626–9.