International Journal of Surgery 13 (2015) 60–64

Contents lists available at ScienceDirect

International Journal of Surgery

journal homepage: www.journal-surgery.net

Review

Virtual reality simulators and training in laparoscopic surgery

Eugenia Yiannakopoulou [a,*], Nikolaos Nikiteas [b], Despina Perrea [c], Christos Tsigris [d]

[a] Faculty of Health and Caring Professions Technological Educational Institute of Athens, Agiou Spyridonos, 12210, Aigaleo Athens, Greece
[b] 2nd Department of Propedeutic Surgery School of Medicine NKUA, Greece
[c] Laboratory for Experimental Surgery and Surgical Research NKUA, Greece
[d] 1st Department of Surgery School of Medicine NKUA, Greece

HIGHLIGHTS

- Virtual reality simulators provide basic surgical skill training.
- Skills obtained through virtual reality simulation training can be transferred on the operating room.
- No data exist on the effect of virtual reality simulation on performance on advanced surgical procedures.

ARTICLE INFO

Article history:
Received 5 August 2014
Received in revised form
12 October 2014
Accepted 12 November 2014
Available online 18 November 2014

Keywords:
Virtual reality simulators
Laparoscopic surgery
Surgical education

ABSTRACT

Virtual reality simulators provide basic skills training without supervision in a controlled environment, free of pressure of operating on patients. Skills obtained through virtual reality simulation training can be transferred on the operating room. However, relative evidence is limited with data available only for basic surgical skills and for laparoscopic cholecystectomy. No data exist on the effect of virtual reality simulation on performance on advanced surgical procedures. Evidence suggests that performance on virtual reality simulators reliably distinguishes experienced from novice surgeons Limited available data suggest that independent approach on virtual reality simulation training is not different from proctored approach. The effect of virtual reality simulators training on acquisition of basic surgical skills does not seem to be different from the effect the physical simulators. Limited data exist on the effect of virtual reality simulation training on the acquisition of visual spatial perception and stress coping skills. Undoubtedly, virtual reality simulation training provides an alternative means of improving performance in laparoscopic surgery. However, future research efforts should focus on the effect of virtual reality simulation on performance in the context of advanced surgical procedure, on standardization of training, on the possibility of synergistic effect of virtual reality simulation training combined with mental training, on personalized training.

1. Introduction

Laparoscopic techniques have created a new paradigm in laparoscopic training with a move away from the apprenticeship model towards structured programs of teaching new skills outside the operating room in the laparoscopic training institute. Traditionally residents have been trained in the classical apprenticeship format with hands on training in the operating room. Technical skill training in general surgery progresses through the phase of gradual participation to the role of first assistant. Unfortunately in laparoscopy, the first assistant may manipulate one or more fixed instruments and has little opportunity during the operation to practice the actual maneuvers involved in laparoscopic surgery, which differ significantly from those practiced in open procedures [1]. Moreover, laparoscopic surgery is technically demanding and requires specific psychomotor abilities and skills that are different from those needed in conventional surgery [2]. These skills include: altered tactile feedback, different eye-hand co-ordination, translation of two dimensional video image to a three dimensional working area, and the fulcrum effect [3,4]. All these skills are difficult to be obtained in the operating room [5].

Currently, there are several training models available, that roughly can be categorized as box trainers, hybrid simulators, virtual reality simulators, augmented reality simulators, laboratory

* Corresponding author.
E-mail address: nyiannak@teiath.gr (E. Yiannakopoulou).

http://dx.doi.org/10.1016/j.ijsu.2014.11.014

animals and cadaver models [Table 1]. Inanimate box trainers are often used for laparoscopic simulator training and the performance on these trainers has been found to be well correlated with intraoperative assessments of residents performing a laparoscopic procedure. However, traditional box-trainers lack objective assessment of performance [6]. Hybrid simulators, by combining real instruments and physical training models with computer mentoring offer objective software generated evaluation of task performance through instrument motion analysis while retaining the features of a simple box trainer [7].

Virtual reality laparoscopic surgical simulators are considered to represent educational tools with great potential. Virtual reality simulators can provide basic skills training without supervision in a controlled environment and free of pressure of the operation on patients. They can also offer objective performance assessment without the need for monitored human supervision and directly measure multiple aspects of a subject's psychomotor performance on specific laparoscopic skills. However, they lack realistic haptic feedback [6]. On the other hand, augmented reality combines a virtual reality setting with real physical materials, instruments and feedback [6]. A number of studies have compared different training models with the main finding being that training based on a combination of models is more effective than one model based training [7–16].

Compared to aviation, where virtual reality training has been standardized and virtual reality simulators have proved their benefits, the objectives, needs and means of virtual reality simulation in laparoscopic surgery is still a matter of investigation. Training with virtual reality simulators should be effective, i.e. objectives have to be met and efficient i.e. minimization of time and cost. Different standards have to be met according to the level of surgeon's performance at which the training is to be achieved.

2. Virtual reality simulation training

Most of the published trials investigate the validity of virtual reality simulator trainers as assessment tools. Different virtual reality simulators have been investigated including MIST-VR, LaSim, Simsurgery, Lap-Mentor, Sinergia. MIST-VR enables performance of basic laparoscopic tasks, LapSim and Simsurgery enable teaching of basic laparoscopic skills i.e. camera navigation, instrument navigation, instrument co-ordination, clip application, intra-corporeal knots, vessel dissection, as well as training in laparoscopic cholecystectomy and bowel anastomosis. On the other hand, LapMentor besides the former basic tasks and basic laparoscopic procedures, provides simulation of laparoscopic sigmoidectomy and gastric bypass.

Training areas where the effect of virtual reality simulator trainers has been investigated include basic skill learning in laparoscopic surgery, basic skill training in robotic surgery, training in laparoscopic cholecystectomy, training in minimally invasive surgical techniques i.e. percutaneous renal access. Limited data exist on the effect of virtual reality simulation training on the acquisition of non technical skills such as visual spatial perception and psychomotor skills i.e. stress coping skills [17–19]. Limited data exist on the effect of virtual reality simulator training on performance on advanced laparoscopic procedures.

The effect of virtual reality simulator to improve skills has been proved at a novice level for basic laparoscopic and minimally invasive surgical skills and for advanced suturing skills. Pre-post training tests have been used for assessment of performance [7,20–29]. In addition, limited data suggest that independent approach on virtual reality simulation training is not different from proctored approach [30–33].

It seems, that skills obtained through virtual reality simulation training can be transferred on the operating room. It has been evidenced for laparoscopic cholecystectomy in the operating room although not for all parameters investigated [34–39]. It has also been evidenced for laparoscopic salpingectomy, endoscopic sinus surgery, minimally invasive techniques in urology i.e percutaneous renal access, cysteo-urethroscopic skills as well as for intracorporeal knot tying [40–45]. However, there is limited number of studies and limited number of participants. Moreover, in a number of studies, skill transferring ability has been evaluated in cadavers, ex vivo tissues in the case of robotic surgery or animal models, not in real patients [46,47]. In addition, there are studies that fail to demonstrate predictive validity of virtual reality simulation training [48].

Concerning the effect of virtual reality simulator training on clinical results, no relevant data have been published.

Although limited and contradictory data exist, the effect of virtual reality simulation training on acquisition of basic surgical skills has not been reliably proven to be different from the effect of physical simulators [9–16].

Performance on virtual reality simulators distinguishes experienced from novice surgeons. However, there are not objective standards to differentiate experienced from novices and arbitrary cut off points have been used in different trials [49–57].

Table 1
Comparative analysis of various training models.

Training Model	Advantages	Limitations	Effect
Box trainers	Inexpensive, provide realistic haptic feedback	Box-trainers lack objective assessment of performance	basic laparoscopic skill acquisition such as hand-eye coordination, depth perception, and knot-tying
Hybrid simulators	Provide objective metrics for laparoscopic task performance	Lack haptic feedback	Basic and advanced laparoscopic skill acquisition
Virtual reality simulators	Provide objective metrics for laparoscopic task performance; provide explanations of practiced tasks	Lack haptic feedback	Basic and advanced laparoscopic skill acquisition
Augmented reality simulators	Provide realistic haptic feedback and objective assessment of the performance of the trainee	Expensive	Basic and advanced laparoscopic skill acquisition; ideal for laparoscopic suturing training
Laboratory animals	Provide realistic operative training experience	Expensive, anatomical differences from human body	Advanced laparoscopic skill acquisition, such as dissection, cutting, coagulation, and stitching
Cadaver models	Provide perfect anatomy, normal tissue consistency and a realistic operative training experience	Limited number of available human cadavers	Advanced laparoscopic skill acquisition, such as dissection, cutting, coagulation, and stitching

3. Role of virtual reality simulators in surgical education

Virtual reality simulation training in laparoscopic surgery offers the possibility of training without the use of real patients. Simulation provides a means of risk free learning in complex, critical or rare situations as well as promoting team based and interdisciplinary approaches to learning in health care. Furthermore, simulation can play a significant role in outcome assessment and accreditation. Virtual reality means the simulation of different skills encountered in real life through computer. The trainee reacts in a scenario with elements that resemble real and that can be changed and adjusted according to the targeted level of performance. Thus, virtual reality simulators consist a promising means of training in laparoscopic surgery.

However, time and cost are invested for virtual reality simulation training and therefore its effectiveness as a means of training needs to be evidenced. In the context of minimally invasive surgery that is currently an ongoing evolving field, residents, novice surgeons as well as surgeons of different levels of expertise need to learn basic skills, to be trained in basic and advanced laparoscopic procedures or to be trained in rarely encountered situations. Thus, the effectiveness of virtual reality simulation training should be evidenced for different levels of human behavior. Rasmussen's model distinguishes three levels of human behavior: skills based, rule based and knowledge based behavior [58]. Skills based behavior concerns surgeon behaviors that take place without conscious control such as moving the instruments due to the fulcrum effect. Suturing is an example of skill based behavior. Training at this level can be performed on box trainers or virtual reality simulators. Rule based behavior concerns task execution that is controlled by rules or procedures. An example of task at this level is the operation protocol defining the sequence of steps to be performed. For example, in laparoscopic surgery the cystic duct and cystic artery have to be isolated and identified before divided. Knowledge based behavior concerns unfamiliar situations for which no formal rules exist, i.e. internal bleeding and damage to the tissue [58].

Evaluation of training tools or training methods often follows the Kirkpatrik's four level model that was developed to assess training effectiveness. According to this model, evaluation begins at the lowest level and information from each prior level serves as a basis for next level's evaluation. The levels are as follows: level 1: reactions measure how trainees react to the training program: face validity; level 2: learning-assesses the extent to which trainees have made progress to performance: construct validity; level 3: behavior/transfer: measures the change in behavior due to the training program; level-4: results: assesses training in terms of clinical results i.e. reduction in the number of complications [59]. In the context of Kirkpatrik's model, available data suggest that virtual reality simulation training positively affects trainee's progress to performance in terms of skill based behavior and rule based behavior. Predictive validity of virtual reality simulators i.e. skill transferring has also been evidenced in skill base behavior and rule based behavior. Virtual reality simulation training in the context of knowledge based behavior has not been attempted yet and possible relevant technology has to be evolved.

An interesting systematic review published by Gurusamy et al. [60] three years ago investigated whether virtual reality simulator training can supplement and/or replace conventional laparoscopic training in surgical trainees with limited or no previous experience. Twenty two trials involving 622 participants were identified comparing virtual reality simulator training with other means of training including video trainer training, no training, standard laparoscopic training or different methods of virtual reality training. The authors concluded that virtual reality simulation training improves standard surgical training and is at least as effective as video trainer training [60].

Table 2
Summary of findings table.

Question	Main finding	Suggestions for further research
What's the effect of virtual reality simulator training on basic and advanced laparoscopic skill acquisition?	At the novice level, virtual reality simulator training leads to the acquisition of basic laparoscopic skills and of advanced suturing skills.	Further research is needed on standardization of virtual reality simulation training; on the possibility of synergistic effect of virtual reality simulation in conjunction with mental training; on personalized training
What's the effect of virtual reality simulator training on skill transfer on the operating room?	Skill transfer has been evidenced for laparoscopic cholecystectomy in the operating room although not for all parameters investigated	Further research is needed especially for advanced laparoscopic procedures
What's the effect of virtual reality simulator training on performance on advanced laparoscopic procedures?	Limited data suggest that virtual reality simulator training improves performance on advanced laparoscopic procedures such as laparoscopic colectomy	Further research is needed in conjunction with detailed analysis of the technique of advanced laparoscopic procedures
What's the effect of virtual reality simulator training on the acquisition of non technical skills such as visual spatial perception and psychomotor skills?	Limited data suggest that virtual reality simulator training leads to the acquisition of non technical skills	Further research is needed especially in the field of stress coping skills
What's the effect of virtual reality simulator training on patient outcome?	There are no relevant data	Further research is needed

Undoubtedly, virtual reality simulators present a new paradigm in surgical education [Table 2]. Further research efforts should focus on the following issues: (i) on the effect of virtual reality simulation training on performance in the context of advanced laparoscopic procedures, (ii) on the effect of virtual reality simulation training on knowledge based behavior, (iii) on the effect of virtual reality simulation training on patient outcome (iv) on standardization of virtual reality simulation training (v) on the possibility of synergistic effect of virtual reality simulation in conjunction with mental training (vi) on personalized training.

Ethical approval

None required.

Funding

None.

Author contribution

Yiannakopoulou Eugenia: Study conception and design, acquisition of data, analysis and interpretation of data, drafting of the manuscript, critical revision of the manuscript.

Nikiteas Nikolaos:acquisition of data and critical revision of the manuscript.

Perrea Despina:analysis and interpretation of data.

Tsigris Christos: critical revision of the manuscript.

Conflicts of interest

None.

References

[1] R.L. Friedman, B.W. Base, Resident education in laparoscopic cholecystectomy, Surg. Endosc. 10 (1996) 26–28.
[2] P.L. Figert, A.E. Park, D.B. Witzke, R.W. Schwartz, Transfer of training in acquiring laparoscopic skills, J. Am. Coll. Surg. 193 (2001) 533–537.
[3] I.R. Crothers, A.G. Gallagher, N. McClure, D.T. James, J. McGuigan, Experienced laparoscopic surgeons are automated to the "fulcrum effect": an ergonomic demonstration, Endoscopy 31 (1999) 365–369.
[4] A.G. Gallagher, N. McClure, J. McGuigan, I. Crothers, J. Browning, Virtual reality training in laparoscopic surgery: a preliminary assessment of minimally invasive surgical trainer virtual reality (MIST VR), Endoscopy 31 (1999) 310–313.
[5] D.J. Scott, P.C. Bergen, R.V. Rege, R. Laycock, S.T. Tesfay, R.J. Valentine, D.M. Euhus, D.R. Jeyarajah, W.M. Thompson, D.B. Jones, Laparoscopic training on bench models: better and more cost effective than operating room experience? J. Am. Coll. Surg. 191 (2000) 272–283.
[6] S.M. Botden, J.J. Jakimowicz, What is going on in augmented reality simulation in laparoscopic surgery? Surg. Endosc. 23 (2009) 1693–1700.
[7] A. Feifer, A. Al-Ammari, E. Kovac, J. Delisle, S. Carrier, M. Anidjar, Randomized controlled trial of virtual reality and hybrid simulation for robotic surgical training, BJU Int. 108 (2011) 1652–1656.
[8] S.M. Botden, S.N. Buzink, M.P. Schijven, J.J. Jakimowicz, Augmented versus virtual reality laparoscopic simulation: what is the difference? A comparison of the ProMIS augmented reality laparoscopic simulator versus LapSim virtual reality laparoscopic simulator, World J. Surg. 31 (2007) 764–772.
[9] D.L. Diesen, L. Erhunmwunsee, K.M. Bennett, K. Ben-David, B. Yurcisin, E.P. Ceppa, P.A. Omotosho, A. Perez, A. Pryor, Effectiveness of laparoscopic computer simulator versus usage of box trainer for endoscopic surgery training of novices, Surg. Endosc. 68 (2011) 282–289.
[10] Y. Munz, B.D. Kumar, K. Moorthy, S. Bann, A. Darzi, Laparoscopic virtual reality and box trainers: is one superior to the other? Surg. Endosc. 18 (2004) 485–494.
[11] R.E. Willis, P.P. Gomez, S.J. Ivatury, H.S. Mitra, K.R. Van Sickle, Virtual reality simulators: valuable surgical skills trainers or video games? J. Surg. Educ. 71 (2014) 426–433.
[12] N. Orzech, V.N. Palter, R.K. Reznick, R. Aggarwal, T.P. Grantcharov, A comparison of 2 ex vivo training curricula for advanced laparoscopic skills: a randomized controlled trial, Ann. Surg. 255 (2012) 833–839.
[13] K. Jensen, C. Ringsted, H.J. Hansen, R.H. Petersen, L. Konge, Simulation-based training for thoracoscopic lobectomy: a randomized controlled trial: virtual-reality versus black-box simulation, Surg. Endosc. 28 (2014) 1821–1829.
[14] M.W. Khan, D. Lin, N. Marlow, M. Altree, W. Babidge, J. Field, P. Hewett, G. Maddern, Laparoscopic skills maintenance: a randomized trial of virtual reality and box trainer simulators, J. Surg. Educ. 71 (2014) 79–84.
[15] C. Loukas, N. Nikiteas, D. Schizas, V. Lahanas, E. Georgiou, A head-to-head comparison between virtual reality and physical reality simulation training for basic skills acquisition, Surg. Endosc. 26 (2012) 2550–2558.
[16] M. Mulla, D. Sharma, M. Moghul, O. Kailani, J. Dockery, S. Ayis, P. Grange, Learning basic laparoscopic skills: a randomized controlled study comparing box trainer, virtual reality simulator, and mental training, J. Surg. Educ. 69 (2012) 190–195.
[17] M. Pellen, L. Horgan, J. Roger Barton, S. Attwood, Laparoscopic surgical skills assessment: can simulators replace experts? World J. Surg. 33 (2009) 440–447.
[18] J.L. Moyano-Cuevas, F.M. Sánchez-Margallo, L.F. Sánchez-Peralta, J.B. Pagador, S. Enciso, P. Sánchez-González, E.J. Gómez-Aguilera, J. Usón-Gargallo, Validation of SINERGIA as training tool: a randomized study to test the transfer of acquired basic psychomotor skills to LapMentor, Int. J. Comput. Assist. Radiol. Surg. 6 (2011) 839–846.
[19] D.M. Sinitsky, B. Fernando, P. Berlingieri, Establishing a curriculum for the acquisition of laparoscopic psychomotor skills in the virtual reality environment, Am. J. Surg. 204 (2012) 367–376.e1.
[20] L. Panait, N.J. Hogle, D.L. Fowler, R.L. Bell, K.E. Roberts, A.J. Duffy, Completion of a novel, virtual-reality-based, advanced laparoscopic curriculum improves advanced laparoscopic skills in senior residents, Surg. Endosc. 68 (2011) 121–125.
[21] C. Loukas, N. Nikiteas, M. Kanakis, E. Georgiou, Deconstructing laparoscopic competence in a virtual reality simulation environment, Surgery 149 (2011) 750–760.
[22] A. Gavazzi, A.N. Bahsoun, W. Van Haute, K. Ahmed, O. Elhage, P. Jaye, M.S. Khan, P. Dasgupta, Face, content and construct validity of a virtual reality simulator for robotic surgery (SEP Robot), Ann. R. Coll. Surg. Engl. 93 (2011) 152–156.
[23] M.G. Munro, D.P. Behling, Virtual reality uterine resectoscopic simulator: face and construct validation and comparative evaluation in an educational environment, JSLS 15 (2011) 142–146.
[24] A.J. Hung, P. Zehnder, M.B. Patil, J. Cai, C.K. Ng, M. Aron, I.S. Gill, M.M. Desai, Face, content and construct validity of a novel robotic surgery simulator, J. Urol. 186 (2011) 1019–1024.
[25] H.W. Schreuder, P.D. van Hove, J.A. Janse, R.R. Verheijen, L.P. Stassen, J. Dankelman, An "intermediate curriculum" for advanced laparoscopic skills training with virtual reality simulation, J. Minim. Invasive Gynecol. 18 (2011) 597–606.
[26] A. Chellali, L. Zhang, G. Sankaranarayanan, V.S. Arikatla, W. Ahn, A. Derevianko, S.D. Schwaitzberg, D.B. Jones, M. Demoya, C.G. Cao, Validation of the VBLaST peg transfer task: a first step toward an alternate training standard, Surg. Endosc. (2014) (in press).
[27] N.S. Sandy, J.A. Cruz, C.C. Passerotti, H. Nguyen, S.T. Reis, E.M. Gouveia, R.J. Duarte, H. Bruschini, M. Srougi, Can the learning of laparoscopic skills be quantified by the measurements of skill parameters performed in a virtual reality simulator? Int. Braz. J. Urol. 39 (2013) 371–376.
[28] K.B. Pitzul, T.P. Grantcharov, A. Okrainec, Validation of three virtual reality Fundamentals of Laparoscopic Surgery (FLS) modules, Stud. Health Technol. Inf. 173 (2012) 349–355.
[29] W.M. Brinkman, S.Y. Havermans, S.N. Buzink, S.M. Botden, J.J. Jakimowicz, B.C. Schoot, Single versus multimodality training basic laparoscopic skills, Surg. Endosc. 26 (2012) 2172–2178.
[30] C.W. Snyder, M.J. Vandromme, S.L. Tyra, J.R. Porterfield Jr., R.H. Clements, M.T. Hawn, Effects of virtual reality simulator training method and observational learning on surgical performance, World J. Surg. 35 (2011) 245–252.
[31] C.W. Snyder, M.J. Vandromme, S.L. Tyra, M.T. Hawn, Proficiency-based laparoscopic and endoscopic training with virtual reality simulators: a comparison of proctored and independent approaches, J. Surg. Educ. 66 (2009) 201–207.
[32] M.W. von Websky, D.A. Raptis, M. Vitz, R. Rosenthal, P.A. Clavien, D. Hahnloser, Access to a simulator is not enough: the benefits of virtual reality training based on peer-group-derived benchmarks–a randomized controlled trial, World J. Surg. 37 (2013) 2534–2541.
[33] J. Strandbygaard, F. Bjerrum, M. Maagaard, P. Winkel, C.R. Larsen, C. Ringsted, C. Gluud, T. Grantcharov, B. Ottesen, J.L. Sorensen, Instructor feedback versus no instructor feedback on performance in a laparoscopic virtual reality simulator: a randomized trial, Ann. Surg. 257 (2013) 839–844.
[34] P. Kanumuri, S. Ganai, E.M. Wohaibi, R.W. Bush, D.R. Grow, N.E. Seymour, Virtual reality and computer-enhanced training devices equally improve laparoscopic surgical skill in novices, JSLS 12 (2008) 219–226.
[35] N.E. Seymour, A.G. Gallagher, S.A. Roman, M.K. O'Brien, V.K. Bansal, D.K. Andersen, R.M. Satava, Virtual reality training improves operating room performance: results of a randomized, double-blinded study, Ann. Surg. 236 (2002) 458–463.
[36] P.H. Cosman, T.J. Hugh, C.J. Shearer, N.D. Merrett, A.V. Biankin, J.A. Cartmill, Skills acquired on virtual reality laparoscopic simulators transfer into the operating room in a blinded, randomised, controlled trial, Stud. Health Technol. Inf. 125 (2007) 76–81.
[37] P.L. Youngblood, S. Srivastava, M. Curet, W.L. Heinrichs, P. Dev, S.M. Wren, Comparison of training on two laparoscopic simulators and assessment of skills transfer to surgical performance, J. Am. Coll. Surg. 200 (2005) 546–551.
[38] V.N. Palter, T.P. Grantcharov, Individualized deliberate practice on a virtual reality simulator improves technical performance of surgical novices in the operating room: a randomized controlled trial, Ann. Surg. 259 (2014) 443–448.
[39] V.N. Palter, N. Orzech, R.K. Reznick, T.P. Grantcharov, Validation of a structured training and assessment curriculum for technical skill acquisition in minimally invasive surgery: a randomized controlled trial, Ann. Surg. 257 (2013) 224–230.
[40] M.P. Fried, B. Sadoughi, M.J. Gibber, J.B. Jacobs, R.A. Lebowitz, D.A. Ross, J.P. Bent 3rd, S.R. Parikh, C.T. Sasaki, S.D. Schaefer, From virtual reality to the operating room: the endoscopic sinus surgery simulator experiment, Otolaryngol. Head Neck 142 (2010) 202–207.
[41] S. Mishra, A. Kurien, R. Patel, P. Patil, A. Ganpule, V. Muthu, R.B. Sabnis, M. Desai, Validation of virtual reality simulation for percutaneous renal access training, J. Endourol. 24 (2010) 635–640.
[42] B.M. Schout, H.J. Ananias, B.L. Bemelmans, F.C. d'Ancona, A.M. Muijtjens, V.E. Dolmans, A.J. Scherpbier, A.J. Hendrikx, Transfer of cysto-urethroscopy skills from a virtual-reality simulator to the operating room: a randomized controlled trial, BJU Int. 106 (2010) 226–231.
[43] Y. Munz, A.M. Almoudaris, K. Moorthy, A. Dosis, A.D. Liddle, A.W. Darzi, Curriculum-based solo virtual reality training for laparoscopic intracorporeal knot tying: objective assessment of the transfer of skill from virtual reality to reality, Am. J. Surg. 193 (2007) 774–783.
[44] C.R. Larsen, J.L. Soerensen, T.P. Grantcharov, T. Dalsgaard, L. Schouenborg, C. Ottosen, T.V. Schroeder, B.S. Ottesen, Effect of virtual reality training on laparoscopic surgery: randomised controlled trial, BMJ 338 (2009) b1802.
[45] E.G. Verdaasdonk, J. Dankelman, J.F. Lange, L.P. Stassen, Transfer validity of laparoscopic knot-tying training on a VR simulator to a realistic environment: a randomized controlled trial, Surg. Endosc. 22 (2008) 1636–1642.
[46] S. Lucas, A. Tuncel, K. Bensalah, I. Zeltser, A. Jenkins, M. Pearle, J. Cadeddu, Virtual reality training improves simulated laparoscopic surgery performance in laparoscopy naïve medical students, J. Endourol. 22 (2008) 1047–1051.
[47] A.J. Hung, M.B. Patil, P. Zehnder, J. Cai, C.K. Ng, M. Aron, I.S. Gill, M.M. Desai, Concurrent and predictive validation of a novel robotic surgery simulator: a prospective, randomized study, J. Urol. 187 (2012) 630–637.
[48] G. Ahlberg, T. Heikkinen, L. Iselius, C.E. Leijonmarck, J. Rutqvist, D. Arvidsson, Does training in a virtual reality simulator improve surgical performance? Surg. Endosc. 16 (2002) 126–129.

[49] N. Iwata, M. Fujiwara, Y. Kodera, C. Tanaka, N. Ohashi, G. Nakayama, M. Koike, A. Nakao, Construct validity of the LapVR virtual-reality surgical simulator, Surg. Endosc. 25 (2011) 423–428.
[50] L.F. Sánchez-Peralta, F.M. Sánchez-Margallo, J.L. Moyano-Cuevas, J.B. Pagador, S. Enciso-Sanz, P. Sánchez-González, E.J. Gómez-Aguilera, J. Usón-Gargallo, Construct and face validity of SINERGIA laparoscopic virtual reality simulator, Int. J. Comput. Assist. Radiol. Surg. 5 (2010) 307–315.
[51] R. Moldovanu, E. Târcoveanu, C. Lupaşcu, G. Dimofte, V. Filip, N. Vlad, A. Vasilescu, Training on a virtual reality simulator–is it really possible a correct evaluation of the surgeons' experience? Rev. Med. Chir. Soc. Med. Nat. Iasi 113 (2009) 780–787.
[52] R. Dănilă, B. Gerdes, H. Ulrike, E. Domínguez Fernández, I. Hassan, Objective evaluation of minimally invasive surgical skills for transplantation. Surgeons using a virtual reality simulator, Chirurgia 104 (2009) 181–185.
[53] K. Kawaguchi, H. Egi, M. Hattori, H. Sawada, T. Suzuki, H. Ohdan, Validation of a novel basic virtual reality simulator, the LAP-X, for training basic laparoscopic skills, Minim. Invasive Ther. Allied Technol. 23 (2014) 287–293.
[54] J.M. Luursema, M.M. Rovers, M. Groenier, H. van Goor, Performance variables and professional experience in simulated laparoscopy: a two-group learning curve study, J. Surg. Educ. 71 (2014) 568–573.
[55] S. Shanmugan, F. Leblanc, A.J. Senagore, C.N. Ellis, S.L. Stein, S. Khan, C.P. Delaney, B.J. Champagne, Virtual reality simulator training for laparoscopic colectomy: what metrics have construct validity? Dis. Colon Rectum 57 (2014) 210–214.
[56] D. Giannotti, G. Patrizi, G. Casella, G. Di Rocco, M. Marchetti, F. Frezzotti, M.G. Bernieri, A.R. Vestri, A. Redler, Can virtual reality simulators be a certification tool for bariatric surgeons? Surg. Endosc. 28 (2014) 242–248.
[57] C. Perrenot, M. Perez, N. Tran, J.P. Jehl, J. Felblinger, L. Bresler, J. Hubert, The virtual reality simulator dV-Trainer(®) is a valid assessment tool for robotic surgical skills, Surg. Endosc. 26 (2012) 2587–2593.
[58] M. Wentink, L.P. Stassen, I. Alwayn, R.J. Hosman, H.G. Stassen, Rasmussen's model of human behavior in laparoscopy training, Surg. Endosc. 17 (2003) 1241–1246.
[59] L. Hutchinson, Evaluating and researching the effectiveness of educational interventions, BMJ 318 (1999) 1267–1269.
[60] K.S. Gurusamy, R. Aggarwal, L. Palanivelu, B.R. Davidson, Virtual reality training for surgical trainees in laparoscopic surgery, Cochrane Database Syst. Rev. 1 (2009) CD006575.