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Training and learning robotic surgery, time for a more structured approach: a systematic review

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Background Robotic assisted laparoscopic surgery is growing rapidly and there is an increasing need for a structured approach to train future robotic surgeons.

Objectives To review the literature on training and learning strategies for robotic assisted laparoscopic surgery.

Search strategy A systematic search of MEDLINE, EMBASE, the Cochrane Library and the *Journal of Robotic Surgery* was performed.

Selection criteria We included articles concerning training, learning, education and teaching of robotic assisted laparoscopic surgery in any specialism.

Data collection and analysis Two authors independently selected articles to be included. We categorised the included articles into: training modalities, learning curve, training future surgeons, curriculum design and implementation.

Main results We included 114 full text articles. Training modalities such as didactic training, skills training (dry lab, virtual reality, animal or cadaver models), case observation, bedside assisting, proctoring and the mentoring console can be used for training in robotic assisted laparoscopic surgery. Several training programmes in general and specific programmes designed for residents, fellows and surgeons are described in the literature. We provide guidelines for development of a structured training programme.

Authors' conclusions Robotic surgical training consists of system training and procedural training. System training should be formally organised and should be competence based, instead of time based. Virtual reality training will play an import role in the near future. Procedural training should be organised in a stepwise approach with objective assessment of each step. This review aims to facilitate and improve the implementation of structured robotic surgical training programmes.

Keywords Curriculum, education, learning, robotic surgery, training.

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Introduction

The introduction of robot assisted laparoscopic surgery has revolutionised the field of minimal invasive surgery and is growing rapidly in various fields of surgery.[1–3] The rapid introduction of robotic procedures necessitates new training methods. Next to the more traditional forms of surgical teaching, the robotic system seems ideal for integrating various forms of simulation.[4] While using simulation, surgeons can develop their skills and pass their basic learning curve on a simulator, hence avoiding the medico-legal aspects of surgical training.[5] Implementing simulation has the potential to create high-quality, competence-based robotic training programmes. This could shorten the learning curve and thereby ensure patient safety and surgical outcome.[6] Next, simulation allows experienced surgeons to develop or familiarise themselves with new instruments in a virtual environment.[7]

Recently, the Dutch Health Care Inspectorate (IGZ) has published its report *Insufficiently prepared introduction of robotic surgery*.[8] With regard to training, it is stated that 'in 50% of the hospitals were insufficient criteria for the surgeon's competence before starting with robotic surgery'. This is indicative for the growing need for competence-based training and assessment criteria. In 2007, an international multidisciplinary consensus group published a consensus statement on robotic surgery. Training and credentialling was one of the four main items addressed in this statement.[9]

The aim of this review is to reveal aspects involved with training and learning of robotic assisted laparoscopic surgery and to provide guidelines for optimal construction and implementation of future structured and competence-based training programmes.

Methods

Literature search

A systematic literature search was performed regarding training and learning of robotic assisted surgery. The following computerised bibliographic databases were searched: MEDLINE, EMBASE and the Cochrane database of systematic reviews. The search was performed within the following limits: reports in English and published between 1 January 1990 and 9 October 2010. To increase sensitivity, a 'text word search' was used.[10] The assessment of training and/or learning robotic surgery was carried out defined by search strings including robot* OR telesurg* AND train* OR learn* OR educat* with all possible extensions. To avoid missing recent and not yet indexed papers, MeSH-terms were not included in our search. Subsequently, full articles of each study selected as likely to be relevant were assessed including their respective reference list. Because articles published in the *Journal of Robotic Surgery* were not yet available in the searched databases, we performed the same search for articles published in this specific journal, on the journal's home page.[11]

Eligibility criteria

Relevant articles to be included had to clearly address aspects of training, learning, education, teaching or credentialling for robotic assisted laparoscopic surgery in any specialty. There are no large randomised trials regarding these issues so all types of studies were included.

Study selection

After removing duplicate articles, this search produced 1905 unique citations. Screening on title (RW) resulted in a total of 508 potentially appropriate citations. Screening on abstract (RW) resulted in exclusion of 342 citations. The remaining 166 potential articles were screened on full text (HS and RW). After exclusion of 62 full text articles, a total of 104 relevant articles were included. In addition, references of all included articles were screened, which provided another ten related articles, giving a total of 114 included full text articles used for this review (Figure S1). Eligibility assessment was performed independently in an (unblinded) standardised manner by two reviewers (HS and RW). Disagreements between reviewers were resolved by consensus.

Data collection process

We categorised the included articles into: training modalities, learning curve, training future surgeons, curriculum design and implementation. Within the main categories, the articles were subcategorised. Training modalities were categorised in skills-laboratory, virtual reality, animal and cadaver, live case observation, mentoring, serious gaming and assessment. Learning curves were subcategorised in urology, gynaecology and other. Training future surgeons was subcategorised in residents or fellows, training courses and training centres. Curriculum design and implementation were subcategorised in curriculum, implementation and costs.

Results

Training modalities

Several training modalities can be used when constructing a training programme for robotic surgery. In general a programme starts with knowledge development, followed by skills training using a combination of simulation modalities (Table S1), followed by real-life case observation in the operating room. When starting with actual robotic surgery there is a role for bedside assisting, proctoring and the mentoring console. Ten training courses for robotic surgery in a skills laboratory were identified (Table 1).

Knowledge (didactic)

When starting with robotic surgery the trainee/surgeon needs to gain knowledge and understand the robot technology, device functions, basic troubleshooting, device parameters and the limitations of the system. The next step will be the development of knowledge for specific surgical procedures. This includes patient selection and indications, preoperative preparation, patient and system positioning, port placement, procedural steps, complications and their management. To make sure every surgeon starting with robotic surgery has a basic level of theoretical knowledge, a theoretical examination on these items could be helpful.

Skills laboratory

Just as in laparoscopy, training for robotic surgery can be scheduled in a skills laboratory. In such facilities exercises on pelvic trainers and other exercises can be performed. A skills laboratory usually has the advantage of high accessibility, but a disadvantage is the need for an expensive robot for dedicated use in the training facility. With this in mind, most hospitals could probably not afford a separate robot for use in a skills laboratory only. In these cases the available robot at the operating room could be used for training after working hours or at scheduled times when no surgery is performed.

Table 1. Training courses in a laboratory setting

Author	Year	Participants	Model	Evaluation	Validation
Hanly et al.[54]	2004	23 surgeons	Standardised hand on dVSS training Self-guided learning in porcine model	Setup time, operating time, complications	No
Hernandez et al.[67]	2004	13 surgeons	Synthetic bowel anastomosis	OSATS score, motion analysis	No
Ro et al.[21]	2005	4 experts, 17 novices	7 designed drills	Calculated performance score	Construct
Narazaki et al.[19]	2006	7 students	3 designed tasks	Time, motion analysis and muscular activation pattern	No
Mehrabi et al.[53]	2006	4 trainees with varying experience	Porcine and rat model	Operating time, quality of operation, complications	No
Vlaovic et al.[55]	2008	35 urologists	4 exercises including suturing and cutting	OSATS score	No
Marecik et al.[24]	2008	11 residents	Porcine intestine for anastomosis	Time and leak pressure	No
Moles et al.[22]	2009	7 residents	Self-designed teaching model 5 exercises	Time and errors	No
Finan et al.[89]	2010	16 students	5 designed advanced drills for hysterectomy	Time	No
Chandra et al.[20]	2010	20 novices, 9 experts	ProMIS™ (Haptica Ltd, Dublin, Ireland) Hybrid Surgical Simulator	Time, pathlength and smoothness	Construct

dVSS, da Vinci® Surgical System; OSATS, Objective Structured Assessment of Technical Skills.

Several authors compared conventional laparoscopy with robotic assisted laparoscopy in a skills laboratory. Conventional exercises for laparoscopy can be used and can actually be performed faster and more accurately with robotic surgery.[12–15] The exercises have a shorter learning curve and are performed more accurately with robot assistance.[16,17] Residents without any laparoscopic experience demonstrated the capacity to rapidly learn basic surgical manoeuvres.[18,19]

It is important that training exercises are validated and have a proper goal. Several levels of validation can be distinguished (Table S2) Exercises should at least have face validity (the simulation resembles the real task) and construct validity (the ability to differentiate between groups with different levels of competence), and translate well to the clinical setting, before they are used in a robotic training programme. Unfortunately, there are only a few reports of validated exercises.[20,21] A curriculum, consisting of five tasks for training basic robotic skills was developed by Moles et al.[22] They were not able to demonstrate a significant learning curve, although there was a trend suggesting that learning had taken place. A portable, reusable, relatively inexpensive pelvic model was developed to simulate the dissection phase of the rectum. This model could be used for mounting additional exercises and be prepared for other specific surgical procedures.[23] Another model that can be used is animal intestine, which is suitable for learning the suturing skills for an intestinal anastomosis.[24] Training for the difficult parts of an operation in such specifically designed models can have a positive impact on the learning curve for complex procedures.

Another aspect of skills laboratory training is the transferability of the basic skills acquisition to real surgical performance.[25] Surgeons tend to move slower, make more curved movements and use more grip force during human surgery. During robotic training it is possible to record objective measures of the robotic instruments. These parameters can be used to describe aspects of robotic surgical performance.[26] In addition, using real-time augmented visual feedback during training can enhance the actual surgical performance.[27–29]

Suzuki et al.[30,31] developed a tele-surgery simulation training system for cholecystectomy, which consists of a soft tissue model that reflects a person's anatomy and an operation console using an internet connection. The authors aim to apply the system to other surgical procedures in the future.

Virtual reality

Virtual reality (VR) training could play an important role in training and learning robotic surgery.[32] Since 2006, several, mainly small, studies with respect to VR systems for robotic surgery were published. Studies that address the validation or the learning capacity of the different simulators are summarised in Table 2. Depending on budget and training purpose, several simulators are commercially available, all yet to be validated.

Table 2. Training using virtual reality

Author	Year	VR-trainer	Participants	Model	Evaluation	Validation	Learning capacity
Halvorsen et al.[41]	2006	SEP-robot	26 medical students	Basic suturing skills (inanimate model)	Difference in number of stitches placed between pre-test and post-test	No	Yes
Fiedler et al.[36]	2007	VR environ vs dVSS	5 experienced users	2 standard tasks: bimanual carrying, needle passing	Time, instrument tip distance and speed, range of motion (elbow)	No	Yes
Balasundaram et al.[42]	2008	SEP-robot	10 surgical novices 2 experts	5 suturing tasks with increasing difficulty	Time, pathlength, errors	Construct	No
Brown-Clerk et al.[33]	2008	VR environ vs dVSS	9 subjects with no or limited prior dVSS experience	1 standard advanced surgical task: mesh alignment	Task completion time, distance travelled, instrument tip speed, range of motion (wrist and elbow), EMG	No	Yes
Kenney et al.[47]	2008	dVT	7 experts 19 novices	2 endowrist modules and 2 needle-driving modules	Post-task survey, time, maximal force, maximal strain, instrument motion, instrument collisions, time instrument out of view, number of targets reached or missed, total score percentage	Face, content, construct	No
Lendvay et al.[48]	2008	dVT vs dVSS	15 course enrollees in urology with varying experience	1 ring transfer module	Pre-task and post-task survey, time for placing first three rings on floor peg, economy of motion, peak ring strain, instrument collisions, time instruments out of view, time master tele-manipulators out of centre	Face, content, construct	No
Katsavelis et al.[37]	2009	VR-environ vs dVSS	8 novices	2 standard tasks: bimanual carrying, needle passing	Task completion time, travelling distance and speed of instrument tips, range of motion (wrist and elbow), EMG	No	Yes
Lin et al.[40]	2009	SEP-robot vs (ProMIS or SurgicalSIM)	14 experts 49 non-experts	Suture-knot tying	Post-task survey, time, path length, smoothness, errors	Face, construct	No
Mukherjee et al.[34]	2009	VR-environ	10 students	3 standard exercises	Instrument collisions, time instruments out of view, time master tele-manipulators out of centre	No	Yes
Seixas-Mikelus et al.[45]	2009	RoSS	15 experts 9 intermediates 6 novices	2 standard exercises	Post-task survey	Face	No
Sethi et al.[50]	2009	dVT	5 experts 15 novices	3 standard exercises	Post-task survey, time, time instruments out of view, TLX	Face, content, construct	No
Lerner et al.[51]	2010	dVT vs dVSS	11 minimal robotic experienced subjects 12 novices	5 standard exercises	Time, economy of motion, instrument collision, time instruments out of view, peak instrument force, number of targets reached or missed	No	Yes
van der Meijden et al.[43]	2010	SEP-robot	7 MIS experts 9 MIS novices	1 suturing task	Pre-task and post-task survey, time, path length	Face*, construct*	No

SEP-robot, SimSurgery Educational Platform robot; dVSS, da Vinci® Surgical System; VR, Virtual reality; VR-environ, VR environment; EMG, Electromyography; dVT, da Vinci® Trainer; RoSS, Robotic Surgical Simulator; TLX, NASA Task Load Index questionnaire; NASA, National Aeronautics and Space Administration; *Validity could not be demonstrated; MIS, Minimally Invasive Surgery.

Surgical skills training in a virtual environment had a significant learning effect and the learned skills are consistent with and transferable to actual robot-assisted procedures.[33–35] However, further research is needed to develop this as an effective and reliable VR environment.[36,37] Sun et al.[38] developed a prototype of a computer-based simulator to practice simple surgical skills and port placement.

The SEP Robot™ simulator (SimSurgery AS, Oslo, Norway) is part of a conventional VR trainer for laparoscopy, which can be converted into a simulator for robotic surgery.[39] Direct comparison of both trainer modalities showed no significant difference for a standardised suturing task.[40] Training of a robotic suturing skill on this simulator equalled training on a mechanical simulator[41] and practice sessions improved the technical performance of novices.[42] Concepts of face validity and construct validity for this simulator seem to be present.[43]

Recently two more advanced simulators were introduced. The Robotic Surgical Simulator (RoSS) (Figure S2)[44] demonstrated face validity.[45] The development of procedural tasks for the robotic prostatectomy and robotic hysterectomy are ongoing. The dV-Trainer™ (dVT) is a simulator that uses the same kinematics as the da Vinci® Surgical System (dVSS) (Figure S3).[46] During the development phase of this system several validation studies demonstrated face, content and construct validity.[47–50] Training on the dVT improved performance on the robot system equal to training with the robot itself.[51] The software of the dVT is suitable to use within the actual robotic console, allowing virtual tasks to be performed in a real-life environment.

Animal and human cadaver training

Animal and cadaver simulation models have the advantage of simulating the human anatomy and these models can be used for procedural training. This kind of training was considered one of the most important components of a robotic training programme[52] and has hence been incorporated in several courses.[53–55] These courses seem to enable participants to successfully incorporate robotic assisted surgery and maintain this technique in clinical practice in the short term and long term.[52,56] Although operating on animal models is almost similar to operating on people, it is expensive and there are ethical concerns (in some countries it is banned).[57] However, compared with performance assessment on human cadaver models, assessment in the animal laboratory is usual easier to schedule, cheaper and more reproducible. An animal laboratory requires a separate robotic system, which will raise costs substantially.

Live case observation

Evaluation of a robotic training programme demonstrated that operating room observation is an important component.[52] There are several ways to implement operating room observation in a training programme. Watching live surgery and actually being present in the operating room or to watch the surgery in another room with the possibility to communicate with the surgeon gives a real-life experience. To watch a video registration of an operation together with a teacher is another option. The video recording has the advantage that illustrative surgeries are selected in advance and the educational moments can be planned ahead.[58]

Proctoring

Proctoring, that is providing direct supervision of an expert, takes place in the initial phase of a learning curve and the proctor is responsible for the assessment of skills and knowledge of the trainee. A review regarding proctoring, underlines the importance for robotic surgery and institutional credentialling, and addresses the medico-legal aspects. Although extended proctorship is an expensive way of training, it provides a relatively safe way to introduce a new technique and prevents surgeons from beginning to perform procedures before they have mastered the technique.[59]

There are different ways of proctoring. Usually the proctor will visit the hospital of the trainee, and surgery is performed together, giving the trainee more responsibilities depending on his or her skills. Sometimes the trainee visits the proctor first to view a number of cases. Proctoring is a very time-consuming and expensive way of teaching, so it is interesting to look at alternatives. Modern communication technology, tele-mentoring and tele-procotoring will save time and travelling. Alternatively, a trainee can make a video recording of the performed procedure and send it to a proctor; the evaluation can then be carried out by watching the video online together. Surprisingly, after a 5-day intensive robotic course only 37.5% of the attendees used the possibility of proctoring, even at no extra cost. This could be because most of the trainees attended as a team and on returning to their hospital they performed surgery together.[52]

Mentoring

Mentoring during actual performance of a robotic operation can be carried out in several ways. First, the mentor can observe the trainee closely while performing an operation and give verbal instruction and take over the operation when necessary. Another possibility is using the availability of the mentoring console (Figure S4). This is a second console, which facilitates the surgeon to collaborate with the trainee during surgery. The mentoring console has two collaborative modes: the 'swap' mode, which allows the mentor and the trainee to operate simultaneously and actively swap control of the robot arms, and the 'nudge' mode, which allows them both to have control over two robot arms. The 'nudge mode' seems to be particularly useful for guiding the trainee's hands during some steps of an operation.[60] There is also the possibility for the trainee to sit at the mentoring console and passively follow the motions of the telemanipulators of the instructor (haptic learning).[61]

Preliminary studies show that the teaching possibility of drawing lines over a moving picture (telestration) also seems possible in robotic surgery and does not negatively impact performance.[62]

Serious gaming

Previous video game experience shortens the time to learn laparoscopic skills on a simulator.[63] This association was, however, not found for robotic surgery and previous extensive video game experience was even inversely correlated with the ability to learn robotic suturing. This could be explained by the fact that the robotic system transforms intuitive three-dimensional (3D) hand motions into 3D hand movements on a 3D screen. Students who had significant experience in activities requiring intuitive hand movements (athletics and musical instruments) performed better in the robotic tasks.[64] Hagen et al.[65] confirmed this and showed that there is no correlation between robotic performance and logical thinking, 3D understanding or general dexterity.

Assessment of skills training

There are several options to assess performance of the trainee during skills training. Objective assessments can be carried out while using a validated rating scale. Most commonly used is the Objective Structured Assessment of Technical Skills (OSATS).[66] Several authors used this method to assess robotic training.[55,67] There is no robotic specific rating scale available yet. The Application Programming Interface (API) included in the robotic system can provide time and motion analysis of the robot.[19] These parameters showed an objective and accurate correlation between surgical performance and OSATS score.[67] This feature could be used for further development and validation of training exercises. A nonvalidated grading system for different steps of a robotic procedure was used to objectively demonstrate progression of the trainee, allowing them to proceed to the next step of the procedure.[68]

Learning curve

The 'learning curve' refers to the amount of surgical procedures performed before a surgeon reaches an accepted plateau in outcome parameters (operating time, blood loss, complication rate, quality of surgery). More complex procedures have a relatively long learning curve. The length of a learning curve may also vary as a result of surgeon-related factors (surgical experience with a similar technology, familiarity with the procedure) or hospital-related factors (availability of theatre time, available case load). Many series of robot assisted laparoscopic procedures have been reported upon, but only a minority of them addresses the aspect of the learning curve.

With respect to the outcome parameter 'operating time', there are the different phases of the operation. First, there is the aspect of time needed for the operating team to prepare and activate the robot system ('setup time'). Second, there is the time phase relating to positioning and installing the robot ('docking time'). Third, one can differentiate the actual time needed to complete the robotic surgery procedure ('console time'). Fourth, there is the whole time span in which the person is in the theatre ('theatre time'). Setup time and docking time can be reduced quickly, when working in a high-volume setting with a dedicated team.[69,70] Intraoperatively outcome parameters are blood loss, complication rate, and the conversion rate to open surgery. For the quality of oncological surgery, parameters like 'number of lymph nodes', 'tumour-free margins' and 'recurrence rate' are known to be used. Instead of the learning curve, Sammon et al.[69] suggest using the 'learning rate', which is defined as the percentage decrease in operative time (minutes) per doubling of cumulative procedure number.

Gynaecology

The learning curve for benign gynaecological procedures (mainly hysterectomy) in robotic surgery is considered to be around approximately 50 cases.[71] A significant improvement in operating time after 20 cases was found for the next 20 cases of hysterectomy and myomectomy.[72] For sacrocolpopexy only small series were published. A 25% reduction of operative time was found after ten cases.[73] Several authors address the learning curve for gynaecological oncology procedures. Proficiency for performing the robotic hysterectomy with combined pelvic–aortic lymph nodes dissection can be achieved in approximately 20 cases, but there is a continued gradual improvement in operative time from 50 to 70 cases.[70] Similar results were obtained for the radical hysterectomy including pelvic lymphadenectomy.[2,74,75] However, these series do not address all parameters regarding the quality of oncological surgery, such as recurrence rate. To achieve proficiency in these parameters the learning curve will probably be longer (like in urology) and still has to be established.

Other specialties

Until recently, it was thought that surgeons become proficient for robot-assisted laparoscopic radical prostatectomy (RALP) within 40 cases.[76] Samadi et al.[77] introduced an expert level after achieving proficiency, which is considered to be reached when operating outcome parameters no longer improve. The learning curve to attain this level is expected to be longer and will be in the order of 70 cases. The full procedural learning curve also includes patient outcome parameters for quality of surgery (positive margins and recurrence rate). When using these quality parameters much longer learning curves are recently described.[78] For positive margins, proficiency was not reached within 100 cases[79] and to achieve oncological outcomes comparable to that of an experienced open surgeon, the learning curve is expected to be 250–400 cases.[80,81] In a given hospital setting, the transition from open radical prostatectomy to RALP can be made without affecting oncological patient outcomes.[82] Doumerc et al.[83] found a flattening of the learning curve after 140 cases and a flattening for larger tumours after 170 cases. It is most likely that for other procedures the same principles can be taken into account. Surgeons should consider whether they can build enough experience to minimise suboptimal oncological outcomes, before embarking on or continuing a robotic programme.[78]

Until today, most studies in general surgery have been case series and only a few studies address the issue of a learning curve.[3] These studies present similar results before achieving proficiency in operating parameters.[84] Larger series are necessary to address a proper learning curve and the oncological quality parameters.

Training future surgeons

With the increasing popularity of robotic surgery there is a growing need for sophisticated training programmes for residents, fellows and surgeons. Ideally these training programmes should be competence based. Courses are commonly used to share new information and/or learn new skills. Some of them are pure didactic and other mainly consist of skills training, but many of them combine the two aspects. Several authors addressed the issue of training residents and fellows, and described their training programme (Table 3). In contrast to open surgery, robotic skills can improve significantly in a relatively short time.[53,55]

Table 3. Training approaches for robotic surgery

Author	Year	Spec	Trainee type	Trainee, *N*	Procedure type	Procedure, *N*	Knowledge module	Skills module	Bedside assistant (minimum cases)	Approach (*n*)***
Badani et al.[98]	2006	Urol	Trainee	NA	RALP	NA	Yes	Skills lab	15–20	Stepwise + proctoring
Rashid et al.[91]	2006	Urol	Resident	2	RALP	83	Intuitive course	Skills lab + animal lab	12	Stepwise (5)
Schroeck et al.[96]	2007	Urol	Resident + fellow	5	RALP	383	Yes	ND	10	Stepwise (3)
Thiel et al.[90]	2008	Urol	Resident	?	RALP	50	No	Yes	ND	Stepwise (9)
Yoshioka et al.[118]	2008	Urol	Urologist	2	RALP	14	Intuitive course + image training	Skills lab	ND	Mentorship after 12 cases
Hoekstra et al.[93]	2009	Gyn	Fellow	?	Gyn onc	75	No course, during bedside assistance	Yes	ND	Stepwise (5)
Lee et al.[94]	2009	Gyn	Fellow	2	Gyn onc	21	Yes	Skills lab + animal lab	ND	Stepwise (6)
Mirheydar et al.[95]	2009	Urol	Urologist + fellow	6 + 3	RALP	Phase 2. 5–6* (total each) Phase 3. 32** (mean each)	Intuitive course	Animal lab	5–6	Stepwise (8) extended mentorship
Davis et al.[68]	2009	Urol	Resident + fellow	4 + 3	RALP	124	ND	ND	ND	Stepwise (11)
Schachner et al.[109]	2009	Cardiac surg	Fellow	2	TECEB	44	ND	Skills lab + animal lab	ND	Stepwise (6)
Link et al.[97]	2009	Urol	Fellow	?	RALP	1833	Two separate intuitive courses	Skills lab	25	Stepwise (6)
Finan et al.[88]	2010	Gyn	Resident	16	Hyst	190	Yes	Skills lab	ND	Stepwise (5)***

Hyst, robot assisted laparoscopic hysterectomy; RALP, robot assisted laparoscopic radical prostatectomy; Gyn Onc, several procedures in gynaecological oncology; TECEB, robotic totally endoscopic coronary bypass; ND, not decribed; NA, not applicable; *phase 2, trainee assisting the proctor; **phase 3, trainee being proctored; ***number of procedural steps.

Training centres

With the approval of the dVSS by the Food and Drug Administration (FDA), the manufacturer was told to provide a comprehensive robotic training for all surgeons and their teams. The manufacturer has currently engaged 24 training centres located all over the world.[85] This training comprises two parts: on-site training, which highlights the key features of the system, preparation and management in your own hospital, and off-site training, which consists of a course to learn and practice procedural skills. From thereon, support of surgical proctoring in the first cases is provided. It is important to start quickly with regular scheduled cases after completion of a course, because otherwise the newly learned skills can fade away. At least one or two cases a week is recommended to overcome the first part of the learning curve. In addition to the registered training centres there are centres that developed their own training programme and in this way function as a training centre. Mostly these centres focus on specific procedures.

Training residents

With the expansion of robotic surgery, training for residents during their specialty training has become more and more an issue. In 2006 only 34% of the urology residents thought they would perform robotic surgery after residency.[86] A recent survey among residents in obstetrics and gynaecology showed that 79% of the residents feel robotic training should be included in their residency programme and 67% feel their training is not adequate.[87]

A preliminary programme for residents to train basic robotic skills consisted of a tutorial on the use of the robot and was followed by structured skills laboratory training.[22] A structured curriculum, to acquire the knowledge and skills for robot-assisted hysterectomy is described in detail by Finan et al.[88,89] The curriculum is divided into familiarisation with the robot itself and console components. The actual procedure is broken down into multiple segments that can be mimicked in a skills laboratory. Five exercises were developed: 1) dexterity, 2) bladder flap development, 3) seal and cut the ligaments, 4) skeletonising the vessels, and 5) suturing the vaginal cuff. During the training period, the residents were bedside assistant and observed a number of robotic surgeries. After completing the program, the residents started stepwise with surgery and no training-related patient complications were noted. Some residents could not complete the programme because of poor eye–hand coordination, these were not allowed to progress to surgery on people.

When using a systematic approach, urology residents can safely and effectively learn a complex procedure such as RALP.[90] It is possible to divide a procedure into steps with increasing difficulty and only proceed to the next step when proficiency has been reached. Performance can be rated using an analogue scale and every step can be recorded and reviewed with the trainee. This system based on appropriate supervision, graduate responsibility, real time feedback and objective measurement could also be used for other procedures.[91]

Training fellows

An increasing number of gynaecological oncology units incorporate robotic surgery in their practice. A survey among fellows and fellowship directors in gynaecological oncology showed that 95% of the responded training centres own a robot and are using it.[92] However, there is no standardised training curriculum for fellows and official guidelines for education of this new technology are lacking.

Hoekstra et al.[93] describe the transition period of a gynaecological oncology fellowship programme into a robotic programme. They underline the importance of commitment of the whole department during such a transition. The fellows started with limited observation, animal training, video observation and port-side assistant training, followed by operating at the console steps of the procedure with increasing difficulty. For the steps vaginal cuff closure, hysterectomy and pelvic lymph node dissection proficiency can be reached after each five to ten cases. For the para-aortic lymph node dissection approximately ten more cases were required to reach proficiency. A systematic approach was described by Lee et al.;[94] their fellow-training programme included 1) didactic and hands-on training with the robotic system, 2) instructional videos, 3) assistance at the operating table, and 4) performance of segments of several gynaecological procedures. The conclusion from this study was that the introduction with a systematic approach for training in robotic surgery is feasible.

In urology, an extended proctorship programme reported a high take-rate and training satisfaction.[95] A guideline of what to look for in a trainee's progression during the separate steps of the operation can be helpful. Although, training requires more operating time, it does not appear to diminish patient outcome and seems possible at a high-volume centre.[68] In contrast to these findings, other authors state that the implementation of a training programme will not cost extra operative time.[96] All authors reported that fellows can be trained in a complex procedure with no significant adverse impact on patient clinical outcome.[68,96,97] However, a structured and systematic approach to learn robotics in a safe and effective way is paramount.[98]

Costs of training

Robotic surgery is still expensive and several authors addressed the aspect of costs[1,2,99–101] or compared the costs of the robotic procedure with laparoscopic or open surgical procedures.[102–104] Most studies mainly focus on the costs of the robotic system (±$1,800,000) with the additional 10% per year of fixed service costs and instrument costs (±$700 to $1000 per case).

Rarely addressed are the costs of the learning curve of the surgeon and the surgical team. These are substantial costs that are often underestimated. Steinberg et al.[101] constructed a theoretical model to describe the cost associated with the learning curve of a single surgeon for RALP. In this model fixed costs for operating room time and anaesthesia services were used. The model was then applied to several learning curves described in the literature. The learning curves ranged from 13 to 200 cases. Costs associated with the least expensive learning curve were $49 613 and with the most expensive learning curve were $554 966. The average learning curve was 77 cases at a price of $217 034. Because of the diversity of the studies it is difficult to determine whether their conclusions are best applied to a single surgeon, a group practice or a hospital setting. This study illustrates the high costs that are involved with the learning curve for complex robotic procedures and underlines the need for sophisticated training programmes together with a high case load to overcome the learning curve.

Curriculum design and implementation

Pioneers in robotic surgery provided an overview of robotic surgical training, identifying objective-based curriculum levels for system training and specific training for advanced procedures.[105,106] The importance of team training has been stressed and it was noted that training of the whole surgical team could be one of the highest barriers.[106] It is recommended to start with a cohesive and dedicated operating room team and two surgeons, which need to work closely together during the initial learning curve.[52] This team-based approach can reduce the learning curve of robotic assisted surgery.[107,108] Only when the initial team has achieved proficiency can new surgeons be introduced and a general strategy should be to avoid multiple learning curves running parallel.[109] The team should start with relatively easy cases, to be able to familiarise themselves with patient positioning, the setup of the robot, trocar and robot positioning, and the robotic instruments.[110,111] When these issues are mastered, the team can move on to more complex cases. A large case volume is required to maintain skills, not only for the console surgeon but for bedside assistant as well.[98] A well-trained bedside assistant is just as important as the console surgeon and requires a combination of open, laparoscopic and robotic skills.[112] Slow adoption of robotics and prolonged operative times may result from insufficient trained bedside assistants.[113]

The operating room nurses, anaesthesiology nurses and the anaesthetist also play an important role in robotic surgery and should be well trained before starting a robotic programme. There are many specific perioperative competencies that a scrub nurse or a circulating nurse must know.[114] Training too many nurses at once usually results in inadequate exposure to robot procedures and will delay the success of the programme.

Guzzo et al.[115] identified three essential phases in a structured robotic training programme: first the preclinical phase, second the bedside assistant phase, and last the operative console phase. In the preclinical phase, trainees should become familiar with the robotic system and learn basic skills through inanimate simulation models. This can be achieved in the course of several days consisting of didactic and skills training, which should be organised in a structured and competence-based way.[116] In the bedside assistant phase, the trainee functions as a co-surgeon, learning trocar and robot placement, instrumentation, troubleshooting and will progressively learn the different steps of the operation. In the console phase, the trainee starts performing parts of the robotic operation. In the ideal situation the operation is divided into multiple steps with increasing difficulty. Optimal proficiency of each step is objectively graded.[68] This structured approach allows optimal feedback from mentor to trainee. It is recommended to videotape the procedures, which allows proper reviewing of procedural steps afterwards.

From the urological literature we know a structured training programme for RALP will take 55–80 cases to train a future robotic surgeon. First, observing 10–20 cases before starting to participate as a bedside assistant.[98] Participation as a bedside assistant in 10–25 cases before starting with segments as a console surgeon,[77,91,97,98] As a console surgeon it will take 20–30 cases before a whole procedure can be performed.[98] From there, approximately ten cases should be performed under the direct supervision of an experienced robotic surgeon.[98] To maintain credentialling, a minimum of 20 cases a year is recommended.[117] Regular self-assessment of performed cases and complications will help to shorten the learning curve and will provide insight into the quality of surgery. It is most likely that these issues will be mandatory for future credentialling.

Discussion

Based on the literature used in this review, an extraction of the components that could be used in a structured training programme for robotic assisted laparoscopic surgery is shown in Table S3. Robotic surgical training consists of two equal parts: system training and procedural training. Each part has its own components, which should be incorporated in a structured programme. Table S3 could serve as a guideline to adjust existing programmes when necessary or to design future training programmes for robotic surgery.

Despite formal consensus statements of experts in the field of robotic surgery,[9,117] the implementation of robotic surgery is not always optimal. As long as there are no official guidelines for minimum requirements for hospital and surgeon credentialling, consensus-based statements should be used as a guide before implementing robotic surgery in daily practice. Both statements address the issue of training excessively. It is expected that certification of surgeons, also of those already performing robotic surgery, will become a requirement in the near future.

Implementing a new technology like robotic assisted laparoscopic surgery in a safe and efficient way is demanding. There are many factors that influence a successful implementation of a robotic training programme. Issues like training modalities, longer operative times, patient outcomes, cost, case volume, number of robotic cases to become proficient for operating and patient quality parameters are all items that require attention. The exponential growth of robotic surgery however, is not giving the surgical community much time to develop structured training programmes for future robotic surgeons. In the near future an increasing number of well-trained robotic surgeons will be needed.

Conclusion

Designing a competence-based training curriculum for robotic surgery remains a challenge, but with the exponential increase of robotic surgery the need for such certified curricula is increasing rapidly. There is a lack of validated training tools for robotic assisted laparoscopic surgery, and in the near future further research in this field needs to be performed. With the increasing quality of virtual reality simulators for robotic surgery it is expected, that this training modality will play an important role in training future robotic surgeons. Procedural training for robotic surgery needs to be carried out in a stepwise and systematic manner. In this way, introduction of this new technology can be performed in an efficient and safe way, and without compromising results for our patients.

Disclosure of interests

René Verheijen is a proctor for radical robot-assisted surgery, sponsored by Intuitive Surgery. For all other authors there is no conflict of interest.

Contribution to authorship

All authors meet the criteria to qualify for authorship. In detail: HS designed the study, collected the data and wrote the manuscript; RW collected the data and wrote the manuscript; RZ, MS and RV revised the manuscript.

Details of ethics approval

No ethical approval was necessary for this study.

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Supporting information

The following supplementary materials are available for this article:

Figure S1. Flowchart of literature search.

Figure S2. Virtual reality training, the Robotic Surgical Simulator™ (image provided by Simulated Surgical Systems, Buffalo, NY, USA).[44]

Figure S3. Virtual reality training, the dVT-Trainer™ (image provided by Mimic Technologies, Seattle, WS, USA).[46]

Figure S4. Da Vinci Surgical System™ with separate mentoring console (image provided by Intuitive Surgical Inc., Sunnyvale, CA, USA).[85]

Table S1. Types of simulation.

Table S2. Levels of validity.

Table S3. Guidelines for robotic training curriculum.

Additional Supporting Information may be found in the online version of this article.

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References

1 Ahmed K, Khan MS, Vats A, Nagpal K, Priest O, Patel V, et al. Current status of robotic assisted pelvic surgery and future developments. *Int J Surg* 2009;7:431–40.

2 Schreuder HW, Verheijen RH. Robotic surgery. *BJOG* 2009;116:198–213.

3 Wilson EB. The evolution of robotic general surgery. *Scand J Surg* 2009;98:125–9.

4 Kunkler K. The role of medical simulation: an overview. *Int J Med Robot* 2006;2:203–10.

5 Al bareeq R, Jayaraman S, Kiaii B, Schlachta C, Denstedt JD, Pautler SE. The role of surgical simulation and the learning curve in robot-assisted surgery. *J Robotic Surg* 2008;2:11–5.

6 Hance J, Aggarwal R, Undre S, Darzi A. Skills training in telerobotic surgery. *Int J Med Robot* 2005;1:7–12.

7 Gallagher AG, Traynor O. Simulation in surgery: opportunity or threat? *Ir J Med Sci* 2008;177:283–7.

8 Dutch Health Care Inspectorate. [www.igz.nl/zoeken/document.aspx?doc=Onvoldoende_zorgvuldigheid_bij_introductie_operatierobots&URL=]. Last accessed 27 March 2011.

9 Herron DM, Marohn M. A consensus document on robotic surgery. *Surg Endosc* 2008;22:313–25.

10 Heneghan C. *Evidence-based Medicine Toolkit*. Oxford: Blackwell Publishing, 2006.

11 *Journal of Robotic Surgery*. [www.springerlink.com/content/1863-2483]. Accessed 9 October 2010.

12 Heemskerk J, van Gemert WG, de VJ, Greve J, Bouvy ND. Learning curves of robot-assisted laparoscopic surgery compared with conventional laparoscopic surgery: an experimental study evaluating skill acquisition of robot-assisted laparoscopic tasks compared with conventional laparoscopic tasks in inexperienced users. *Surg Laparosc Endosc Percutan Tech* 2007;17:171–4.

13 Nguan C, Girvan A, Luke PP. Robotic surgery versus laparoscopy; a comparison between two robotic systems and laparoscopy. *J Robotic Surg* 2008;1:263–8.

14 Obek C, Hubka M, Porter M, Chang L, Porter JR. Robotic versus conventional laparoscopic skill acquisition: implications for training. *J Endourol* 2005;19:1098–103.

15 Sarle R, Tewari A, Shrivastava A, Peabody J, Menon M. Surgical robotics and laparoscopic training drills. *J Endourol* 2004;18:63–6.

16 Blavier A, Gaudissart Q, Cadiere GB, Nyssen AS. Comparison of learning curves and skill transfer between classical and robotic laparoscopy according to the viewing conditions: implications for training. *Am J Surg* 2007;194:115–21.

17 Rashid TG, Kini M, Ind TE. Comparing the learning curve for robotically assisted and straight stick laparoscopic procedures in surgical novices. *Int J Med Robot* 2010;6:306–10.

18 Di LN, Coscarella G, Faraci L, Konopacki D, Pietrantuono M, Gaspari AL. Robotic systems and surgical education. *JSLS* 2005;9:3–12.

19 Narazaki K, Oleynikov D, Stergiou N. Robotic surgery training and performance: identifying objective variables for quantifying the extent of proficiency. *Surg Endosc* 2006;20:96–103.

20 Chandra V, Nehra D, Parent R, Woo R, Reyes R, Hernandez-Boussard T, et al. A comparison of laparoscopic and robotic assisted suturing performance by experts and novices. *Surgery* 2010; 147:830–9.

21 Ro CY, Toumpoulis IK, Ashton RC Jr, Imielinska C, Jebara T, Shin SH, et al. A novel drill set for the enhancement and assessment of robotic surgical performance. *Stud Health Technol Inform* 2005; 111:418–21.

22 Moles JJ, Connelly PE, Sarti EE, Baredes S. Establishing a training program for residents in robotic surgery. *Laryngoscope* 2009;119: 1927–31.

23 Marecik SJ, Prasad LM, Park JJ, Pearl RK, Evenhouse RJ, Shah A, et al. A lifelike patient simulator for teaching robotic colorectal surgery: how to acquire skills for robotic rectal dissection. *Surg Endosc* 2008;22:1876–81.

24 Marecik SJ, Prasad LM, Park JJ, Jan A, Chaudhry V. Evaluation of midlevel and upper-level residents performing their first robotic-sutured intestinal anastomosis. *Am J Surg* 2008;195:333–7.

25 Judkins TN, Oleynikov D, Stergiou N. Objective evaluation of expert performance during human robotic surgical procedures. *J Robotic Surg* 2008;1:307–12.

26 Judkins TN, Oleynikov D, Stergiou N. Objective evaluation of expert and novice performance during robotic surgical training tasks. *Surg Endosc* 2009;23:590–7.

27 Judkins TN, Oleynikov D, Stergiou N. Real-time augmented feedback benefits robotic laparoscopic training. *Stud Health Technol Inform* 2006;119:243–8.

28 Judkins TN, Oleynikov D, Stergiou N. Enhanced robotic surgical training using augmented visual feedback. *Surg Innov* 2008;15: 59–68.

29 Judkins TN, Oleynikov D, Stergiou N. Electromyographic response is altered during robotic surgical training with augmented feedback. *J Biomech* 2009;42:71–6.

30 Suzuki S, Suzuki N, Hashizume M, Kakeji Y, Konishi K, Hattori A, et al. Tele-training simulation for the surgical robot system ''Da Vinci''. *Int Congr Ser* 2004;1268:86–91.

31 Suzuki S, Suzuki N, Hattori A, Hayashibe M, Konishi K, Kakeji Y, et al. Tele-surgery simulation with a patient organ model for robotic surgery training. *Int J Med Robot* 2005;1:80–8.

32 Albani JM, Lee DI. Virtual reality-assisted robotic surgery simulation. *J Endourol* 2007;21:285–7.

33 Brown-Clerk B, Siu KC, Katsavelis D, Lee I, Oleynikov D, Stergiou N. Validating advanced robot-assisted laparoscopic training task in virtual reality. *Stud Health Technol Inform* 2008;132:45–9.

34 Mukherjee M, Siu KC, Suh IH, Klutman A, Oleynikov D, Stergiou N. A virtual reality training program for improvement of robotic surgical skills. *Stud Health Technol Inform* 2009;142:210–4.

35 Suh IH, Siu KC, Mukherjee M, Monk E, Oleynikov D, Stergiou N. Consistency of performance of robot-assisted surgical tasks in virtual reality. *Stud Health Technol Inform* 2009;142:369–73.

36 Fiedler MJ, Chen SJ, Judkins TN, Oleynikov D, Stergiou N. Virtual reality for robotic laparoscopic surgical training. *Stud Health Technol Inform* 2007;125:127–9.

37 Katsavelis D, Siu KC, Brown-Clerk B, Lee IH, Lee YK, Oleynikov D, et al. Validated robotic laparoscopic surgical training in a virtual-reality environment. *Surg Endosc* 2009;23:66–73.

38 Sun LW, Van MF, Schmid J, Bailly Y, Thakre AA, Yeung CK. Advanced Da Vinci surgical system simulator for surgeon training and operation planning. *Int J Med Robot* 2007;3:245–51.

39 SimSurgery. [www.simsurgery.com]. Last accessed 27 March 2011.

40 Lin DW, Romanelli JR, Kuhn JN, Thompson RE, Bush RW, Seymour NE. Computer-based laparoscopic and robotic surgical simulators: performance characteristics and perceptions of new users. *Surg Endosc* 2009;23:209–14.

41 Halvorsen FH, Elle OJ, Dalinin VV, Mork BE, Sorhus V, Rotnes JS, et al. Virtual reality simulator training equals mechanical robotic training in improving robot-assisted basic suturing skills. *Surg Endosc* 2006;20:1565–9.

42 Balasundaram I, Aggarwal R, Darzi A. Short-phase training on a virtual reality simulator improves technical performance in tele-robotic surgery. *Int J Med Robot* 2008;4:139–45.

43 van der Meijden OA, Broeders IA, Schijven MP. The SEP ''Robot'': a valid virtual reality robotic simulator for the Da Vinci surgical system? *Surg Technol Int* 2010;19:51–8.

44 Simulated Surgicals. [www.simulatedsurgicals.com]. Last accessed 27 March 2011.

45 Seixas-Mikelus SA, Kesavadas T, Srimathveeravalli G, Chandrasekhar R, Wilding GE, Guru KA. Face validation of a novel robotic surgical simulator. *Urology* 2010;76:357–60.

46 Mimic Technologies. [www.mimic.ws]. Last accessed 27 March 2011.

47 Kenney PA, Wszolek MF, Gould JJ, Libertino JA, Moinzadeh A. Face, content, and construct validity of DV-trainer, a novel virtual reality simulator for robotic surgery. *Urology* 2009;73:1288–92.

48 Lendvay TS, Casale P, Sweet R, Peters C. Initial validation of a virtual-reality robotic simulator. *J Robotic Surg* 2008;2:145–9.

49 Lendvay TS, Casale P, Sweet R, Peters C. VR Robotic surgery: randomized blinded study of the DV-trainer robotic simulator. *Stud Health Technol Inform* 2008;132:242–4.

50 Sethi AS, Peine WJ, Mohammadi Y, Sundaram CP. Validation of a novel virtual reality robotic simulator. *J Endourol* 2009;23:503–8.

51 Lerner MA, Ayalew M, Peine WJ, Sundaram CP. Does training on a virtual reality robotic simulator improve performance on the Da Vinci surgical system? *J Endourol* 2010;24:467–72.

52 McDougall EM, Corica FA, Chou DS, Abdelshehid CS, Uribe CA, Stoliar G, et al. Short-term impact of a robot-assisted laparoscopic

prostatectomy ‘mini-residency’ experience on postgraduate urologists’ practice patterns. *Int J Med Robot* 2006;2:70–4.
53 Mehrabi A, Yetimoglu CL, Nickkholgh A, Kashfi A, Kienle P, Konstantinides L, et al. Development and evaluation of a training module for the clinical introduction of the Da Vinci robotic system in visceral and vascular surgery. *Surg Endosc* 2006;20:1376–82.
54 Hanly EJ, Marohn MR, Bachman SL, Talamini MA, Hacker SO, Howard RS, et al. Multiservice laparoscopic surgical training using the DaVinci surgical system. *Am J Surg* 2004;187:309–15.
55 Vlaovic PD, Sargent ER, Boker JR, Corica FA, Chou DS, Abdelshehid CS, et al. Immediate impact of an intensive one-week laparoscopy training program on laparoscopic skills among postgraduate urologists. *JSLS* 2008;12:1–8.
56 Gamboa AJ, Santos RT, Sargent ER, Louie MK, Box GN, Sohn KH, et al. Long-term impact of a robot assisted laparoscopic prostatectomy mini fellowship training program on postgraduate urological practice patterns. *J Urol* 2009;181:778–82.
57 Hart R, Karthigasu K. The benefits of virtual reality simulator training for laparoscopic surgery. *Curr Opin Obstet Gynecol* 2007;19:297–302.
58 Rocco B, Lorusso A, Coelho RF, Palmer KJ, Patel VR. Building a robotic program. *Scand J Surg* 2009;98:72–5.
59 Zorn KC, Gautam G, Shalhav AL, Clayman RV, Ahlering TE, Albala DM, et al. Training, credentialing, proctoring and medicolegal risks of robotic urological surgery: recommendations of the Society of Urologic Robotic Surgeons. *J Urol* 2009;182:1126–32.
60 Hanly EJ, Miller BE, Kumar R, Hasser CJ, Coste-Maniere E, Talamini MA, et al. Mentoring console improves collaboration and teaching in surgical robotics. *J Laparoendosc Adv Surg Tech A* 2006;16:445–51.
61 Jacobs S, Holzhey D, Strauss G, Burgert O, Falk V. The impact of haptic learning in telemanipulator-assisted surgery. *Surg Laparosc Endosc Percutan Tech* 2007;17:402–6.
62 Ali MR, Loggins JP, Fuller WD, Miller BE, Hasser CJ, Yellowlees P, et al. 3-D telestration: a teaching tool for robotic surgery. *J Laparoendosc Adv Surg Tech A* 2008;18:107–12.
63 Shane MD, Pettitt BJ, Morgenthal CB, Smith CD. Should surgical novices trade their retractors for joysticks? Videogame experience decreases the time needed to acquire surgical skills. *Surg Endosc* 2008;22:1294–7.
64 Harper JD, Kaiser S, Ebrahimi K, Lamberton GR, Hadley HR, Ruckle HC, et al. Prior video game exposure does not enhance robotic surgical performance. *J Endourol* 2007;21:1207–10.
65 Hagen ME, Wagner OJ, Inan I, Morel P. Impact of IQ, computer-gaming skills, general dexterity, and laparoscopic experience on performance with the Da Vinci surgical system. *Int J Med Robot* 2009;5:327–31.
66 Martin JA, Regehr G, Reznick R, MacRae H, Murnaghan J, Hutchison C, et al. Objective structured assessment of technical skill (OSATS) for surgical residents. *Br J Surg* 1997;84:273–8.
67 Hernandez JD, Bann SD, Munz Y, Moorthy K, Datta V, Martin S, et al. Qualitative and quantitative analysis of the learning curve of a simulated surgical task on the Da Vinci system. *Surg Endosc* 2004;18:372–8.
68 Davis JW, Kamat A, Munsell M, Pettaway C, Pisters L, Matin S. Initial experience of teaching robot-assisted radical prostatectomy to surgeons-in-training: can training be evaluated and standardized? *BJU Int* 2010;105:1148–54.
69 Sammon J, Perry A, Beaule L, Kinkead T, Clark D, Hansen M. Robot-assisted radical prostatectomy: learning rate analysis as an objective measure of the acquisition of surgical skill. *BJU Int* 2010;106:855–60.
70 Seamon LG, Fowler JM, Richardson DL, Carlson MJ, Valmadre S, Phillips GS, et al. A detailed analysis of the learning curve: robotic hysterectomy and pelvic-aortic lymphadenectomy for endometrial cancer. *Gynecol Oncol* 2009;114:162–7.
71 Lenihan JP Jr, Kovanda C, Seshadri-Kreaden U. What is the learning curve for robotic assisted gynecologic surgery? *J Minim Invasive Gynecol* 2008;15:589–94.
72 Pitter MC, Anderson P, Blissett A, Pemberton N. Robotic-assisted gynaecological surgery-establishing training criteria; minimizing operative time and blood loss. *Int J Med Robot* 2008;4:114–20.
73 Akl MN, Long JB, Giles DL, Cornella JL, Pettit PD, Chen AH, et al. Robotic-assisted sacrocolpopexy: technique and learning curve. *Surg Endosc* 2009;23:2390–4.
74 Fanning J, Fenton B, Purohit M. Robotic radical hysterectomy. *Am J Obstet Gynecol* 2008;198:649–4.
75 Feuer G, Beningo B, Krige L, Alvarez P. Comparison of a novel surgical approach for radical hysterectomy: robotic assistance versus open surgery. *J Robotic Surg* 2009;3:179–86.
76 Bivalacqua TJ, Pierorazio PM, Su LM. Open, laparoscopic and robotic radical prostatectomy: optimizing the surgical approach. *Surg Oncol* 2009;18:233–41.
77 Samadi D, Levinson A, Hakimi A, Shabsigh R, Benson MC. From proficiency to expert, when does the learning curve for robotic-assisted prostatectomies plateau? The Columbia University Experience. *World J Urol* 2007;25:105–10.
78 Hong YM, Sutherland DE, Linder B, Engel JD. ‘‘Learning curve’’ may not be enough: assessing the oncological experience curve for robotic radical prostatectomy. *J Endourol* 2010;24:473–7.
79 Ou YC, Yang CR, Wang J, Cheng CL, Patel VR. Robotic-assisted laparoscopic radical prostatectomy: learning curve of first 100 cases. *Int J Urol* 2010;17:635–40.
80 Freire MP, Choi WW, Lei Y, Carvas F, Hu JC. Overcoming the learning curve for robotic-assisted laparoscopic radical prostatectomy. *Urol Clin North Am* 2010;37:37–47, Table.
81 Herrell SD, Smith JA Jr. Robotic-assisted laparoscopic prostatectomy: what is the learning curve? *Urology* 2005;66:105–7.
82 Nadler RB, Casey JT, Zhao LC, Navai N, Smith ZL, Zhumkhawala A, et al. Is the transition from open to robotic prostatectomy fair to your patients? a single-surgeon comparison with 2-year follow-up. *J Robotic Surg* 2010;3:201–7.
83 Doumerc N, Yuen C, Savdie R, Rahman MB, Rasiah KK, Pe BR, et al. Should experienced open prostatic surgeons convert to robotic surgery? the real learning curve for one surgeon over 3 years. *BJU Int* 2010;106:378–84.
84 Huettner F, Rawlings AL, McVay WV, Crawford DL. Robot-assisted laparoscopic colectomy: 70 cases—one surgeon. *J Robotic Surg* 2008;2:226–34.
85 Intuitive Surgical. [www.intuitivesurgical.com]. Last accessed 27 March 2011.
86 Duchene DA, Moinzadeh A, Gill IS, Clayman RV, Winfield HN. Survey of residency training in laparoscopic and robotic surgery. *J Urol* 2006;176:2158–66.
87 Smith AL, Schneider KM, Berens PD. Survey of obstetrics and gynecology residents’ training and opinions on robotic surgery. *J Robotic Surg* 2010;4:23–7.
88 Finan MA, Silver S, Otts E, Rocconi RP. A comprehensive method to train residents in robotic hysterectomy techniques. *J Robotic Surg* 2010;4:183–90.
89 Finan MA, Clark ME, Rocconi RP. A novel method for training residents in robotic hysterectomy. *J Robotic Surg* 2010;4:33–9.
90 Thiel DD, Francis P, Heckman MG, Winfield HN. Prospective evaluation of factors affecting operating time in a residency/fellowship

training program incorporating robot-assisted laparoscopic prostatectomy. *J Endourol* 2008;22:1331–8.

91 Rashid HH, Leung YY, Rashid MJ, Oleyourryk G, Valvo JR, Eichel L. Robotic surgical education: a systematic approach to training urology residents to perform robotic-assisted laparoscopic radical prostatectomy. *Urology* 2006;68:75–9.

92 Sfakianos GP, Frederick PJ, Kendrick JE, Straughn JM, Kilgore LC, Huh WK. Robotic surgery in gynecologic oncology fellowship programs in the USA: a survey of fellows and fellowship directors. *Int J Med Robot* 2010;6:405–12.

93 Hoekstra AV, Morgan JM, Lurain JR, Buttin BM, Singh DK, Schink JC, et al. Robotic surgery in gynecologic oncology: impact on fellowship training. *Gynecol Oncol* 2009;114:168–72.

94 Lee PS, Bland A, Valea FA, Havrilesky LJ, Berchuck A, Secord AA. Robotic-assisted laparoscopic gynecologic procedures in a fellowship training program. *JSLS* 2009;13:467–72.

95 Mirheydar H, Jones M, Koeneman KS, Sweet RM. Robotic surgical education: a collaborative approach to training postgraduate urologists and endourology fellows. *JSLS* 2009;13:287–92.

96 Schroeck FR, de Sousa CA, Kalman RA, Kalia MS, Pierre SA, Haleblian GE, et al. Trainees do not negatively impact the institutional learning curve for robotic prostatectomy as characterized by operative time, estimated blood loss, and positive surgical margin rate. *Urology* 2008;71:597–601.

97 Link BA, Nelson R, Josephson DY, Lau C, Wilson TG. Training of urologic oncology fellows does not adversely impact outcomes of robot-assisted laparoscopic prostatectomy. *J Endourol* 2009;23:301–5.

98 Badani KK, Hemal AK, Peabody JO, Menon M. Robotic radical prostatectomy: the Vattikuti Urology Institute training experience. *World J Urol* 2006;24:148–51.

99 Boggess JF. Robotic surgery in gynecologic oncology: evolution of a new surgical paradigm. *J Robotic Surg* 2007;1:31–7.

100 Patel HR, Linares A, Joseph JV. Robotic and laparoscopic surgery: cost and training. *Surg Oncol* 2009;18:242–6.

101 Steinberg PL, Merguerian PA, Bihrle W III, Seigne JD. The cost of learning robotic-assisted prostatectomy. *Urology* 2008;72:1068–72.

102 Curet MJ, Solomon H, Lui G, Morton JM. Comparison of hospital charges between robotic, laparoscopic stapled, and laparoscopic handsewn Roux-en-Y gastric bypass. *J Robotic Surg* 2009;3:75–8.

103 Joseph JV, Leonhardt A, Patel HRH. The cost of radical prostatectomy: retrospective comparison of open, laparoscopic, and robot-assisted approaches. *J Robotic Surg* 2008;2:21–4.

104 Prewitt R, Bochkarev V, McBride CL, Kinney S, Oleynikov D. The patterns and costs of the Da Vinci robotic surgery system in a large academic institution. *J Robotic Surg* 2008;2:17–20.

105 Chitwood WR Jr, Nifong LW, Chapman WH, Felger JE, Bailey BM, Ballint T, et al. Robotic surgical training in an academic institution. *Ann Surg* 2001;234:475–84.

106 Nifong LW, Chitwood WR Jr. Building a surgical robotics program. *Am J Surg* 2004;188:16S–8S.

107 Sim HG, Yip SK, Lau WK, Tan YH, Wong MY, Cheng CW. Team-based approach reduces learning curve in robot-assisted laparoscopic radical prostatectomy. *Int J Urol* 2006;13:560–4.

108 Trabulsi EJ, Zola JC, Gomella LG, Lallas CD. Transition from pure laparoscopic to robotic-assisted radical prostatectomy: a single surgeon institutional evolution. *Urol Oncol* 2010;28:81–5.

109 Schachner T, Bonaros N, Wiedemann D, Weidinger F, Feuchtner G, Friedrich G, et al. Training surgeons to perform robotically assisted totally endoscopic coronary surgery. *Ann Thorac Surg* 2009;88:523–7.

110 Ferguson JL, Beste TM, Nelson KH, Daucher JA. Making the transition from standard gynecologic laparoscopy to robotic laparoscopy. *JSLS* 2004;8:326–8.

111 Jayaraman S, Davies W, Schlachta CM. Robot-assisted minimally invasive common bile duct exploration: a canadian first. *Can J Surg* 2008;51:E93–4.

112 Kumar R, Hemal AK. The 'scrubbed surgeon' in robotic surgery. *World J Urol* 2006;24:144–7.

113 Steers WD, LeBeau S, Cardella J, Fulmer B. Establishing a robotics program. *Urol Clin North Am* 2004;31:773–80, x.

114 Zender J, Thell C. Developing a successful robotic surgery program in a rural hospital. *AORN J* 2010;92:72–83.

115 Guzzo TJ, Gonzalgo ML. Robotic surgical training of the urologic oncologist. *Urol Oncol* 2009;27:214–7.

116 Benson AD, Kramer BA, Boehler M, Schwind CJ, Schwartz BF. Robot-assisted laparoscopic skills development: formal versus informal training. *J Endourol* 2010;24:1351–5.

117 Valvo JR, Madeb R, Gilbert R, Nicholson C, Oleyourryk G, Perrapato S, et al. Policy guidelines suggested for robot-assisted prostatectomy. *J Robotic Surg* 2007;1:173–6.

118 Yoshioka K, Hatano T, Nakagami Y, Ozu C, Horiguchi Y, Yonou H, et al. Robotic-assisted laparoscopic radical prostatectomy: initial 15 cases in Japan. *J Robotic Surg* 2008;2:85–8.