**Abstract**

Introduction: This study reviews the current state of robotic surgery training for surgeons, including the various curricula, training methods, and tools available, as well as the challenges and limitations of these.

Methods: The authors carried out a literature search across PubMed, MEDLINE, and Google Scholar using keywords related to ‘robotic surgery’, ‘computer-assisted surgery’, ‘simulation’, ‘virtual reality’, ‘surgical training’, and ‘surgical education’. Full text analysis was performed on 112 articles.

Training Programmes: The training program for robotic surgery should focus on proficiency, deliberation, and distribution principles. The curricula can be broadly split up into pre-console and console-side training.

Pre-Console and Console-Side Training: Simulation training is an important aspect of robotic surgery training to improve technical skill acquisition and reduce mental workload, which helps prepare trainees for live procedures.

Operative Performance Assessment: The study also discusses the various validated assessment tools used for operative performance assessments.

Future Advances: Finally, the authors propose potential future directions for robotic surgery training, including the use of emerging technologies such as AI and machine learning for real-time feedback, remote mentoring, and augmented reality platforms like Proximie to reduce costs and overcome geographic limitations.

Conclusion: Standardisation in trainee performance assessment is needed. Each of the robotic curricula and platforms has strengths and weaknesses. The ERUS Robotic Curriculum represents an evidence-based example of how to implement training from novice to expert. Remote mentoring and augmented reality platforms can overcome the challenges of high equipment costs and limited access to experts. Emerging technologies offer promising advancements for real-time feedback and immersive training environments, improving patient outcomes.

## Introduction

Surgical practice has changed greatly in the last century with increasingly complex technology used to gain optimal outcomes for patients. At the same time, stress on healthcare systems, notably the recent COVID-19 pandemic, has made training more challenging. While practice has evolved rapidly to incorporate new technologies and handle stresses on the healthcare system, we examine how surgical training reflects this.

In particular, robotic-assisted surgery (RAS) has grown 10 – 40 times more than laparoscopic surgery in common general surgical procedures [1]. This rapid growth necessitates similar growth in the training standards and programmes to ensure there are enough practitioners to utilise this new modality and that they do so safely.

The purpose of this study is to review the current state of robotic surgery training for surgeons, including the various curricula, training methods and tools available, as well as the challenges and limitations of these. Additionally, we discuss potential future directions for robotic surgery training, including the use of emerging technologies.

The purpose of this narrative review is to study the current state of robotic surgery training, including the various training methods, tools, and challenges. We also discuss the potential future direction of surgical training.

## Methods

The authors carried out a literature search across PubMed, MEDLINE, and Google Scholar using keywords related to 'robotic surgery', 'computer-assisted surgery', 'simulation', 'virtual reality', 'surgical training', and 'surgical education'. Bibliographies of relevant review articles were also analysed to provide a wider understanding of the current landscape of robotic surgery training. Articles in English and involving aspects of robotic training were included. Abstract analysis was performed on 167 papers, of which 112 received full-text analysis and contributed to this review.

## Training programmes

The training program for robotic surgery should follow three key principles, which are proficiency, deliberation, and distribution. The program should aim to train novices to a high level of proficiency using the Dreyfus and Dreyfus model of skill acquisition, which includes recollection, recognition, decision, and awareness [2]. Deliberate practice should include five conditions: a clearly defined task, immediate feedback, motivation, variable task difficulty, and repetition opportunities [3]. The training program should be distributed over time to enhance retention and performance [4].

Training programmes aim to provide generic robotic skills and procedure/specialty-specific skills, through eLearning to unsupervised independent performance. However, existing platforms rarely achieve this goal. Once the training needs are identified, the curriculum should be validated as safe and fit for purpose before implementation. Subsequent retrospective analysis can provide additional learning needs and points of improvement for continuous iteration.

The Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) and Minimally Invasive Robotic Association (MIRA) first addressed the need for robotic surgical training in 2006, specifying that training programs should include didactic sessions, hands-on simulation training, and guided surgery in operating theatres [5]. Ahmed et al also advise a modular approach starting with eLearning, followed by simulation, assisting in live cases, supervised and then unsupervised independent performance [6]. This was further validated as feasible, acceptable and effective [7].

These curricula can be broadly split up into pre-console and console-side training.

**Pre-Console Training**

Developing basic laparoscopic skills forms the foundation for robotic surgery. The skills that are necessary for both types of surgery are achieving minimally invasive access, proper patient positioning, camera and instrument manipulation, spatial awareness, port placement and managing pneumoperitoneum. Focussed laparoscopic training has been shown to reduce the time taken to perform tasks robotically with better results and fewer mistakes [8,9]. Angell et al used medical students with no experience in either laparoscopic or robotic surgery, making it difficult to differentiate between the effect of the focussed laparoscopic training versus greater surgical training in general [8]. However, Kilic et al showed the improvement in robotic suturing time in groups of resident (registrar) doctors who had greater laparoscopic exposure compared to other similar residents, suggesting training for the fundamental skills of laparoscopic surgery should be incorporated into early robotic training [9].

Understanding the hardware and software components of the robotic system is necessary. Mistakes with the highly complex and delicate systems can lead to expensive damage or patient complications. ELearning is an effective method for this domain of robotic surgery training.

Patient-side pre-console training is essential for trainees. It promotes learning through observation and develops skills of operative assisting. Pre-console training promotes better console performance and a greater ability to troubleshoot issues intra-operatively [10]. However, the learning curve has not been characterised and there is no guideline on how many cases trainees should assist in. As such, a competency-based sign-off approach may be used to allow progression to console-side training.

Several attempts have been made to develop robotic training curricula, including the da Vinci Technology Training Pathway, Fundamentals of Robotic Surgery (FRS), and Fundamental Skills of Robotic-Assisted Surgery (FSRS) Training Programme. However, the lack of long-term results and validation studies often prevents the widespread uptake of these programmes [11–13].

The da Vinci Technology Training Pathway by Intuitive Surgical is an online training programme for their surgical systems. It has four didactic modules, requiring proficiency in initial modules to progress to later ones. While the program is designed to be flexible and adaptable to individual needs, it lacks clinical contextualisation and multistep simulation and can be time-consuming and costly.

The Fundamentals of Robotic Surgery (FRS) curriculum is a competency-based training program that includes both education and assessment, unlike the da Vinci training pathway. FRS also focuses on generic robotic skills training that is suitable for application in multiple specialties. FRS has four modules similar to da Vinci training, and a validation study by Satava et al showed better trainee performance (faster with fewer errors) using FRS than the control, specifically in the context of one specific movement task (transfer test) [14]. While the program is comprehensive and flexible, it is not proctored, and there is no clinical component to the training.

The Fundamental Skills of Robotic-Assisted Surgery (FSRS) is a simulation-based training program that offers basic (over 3 days – including skills simulation, and theatre observation), intermediate (over 4 days – adding robotic dry and tissue lab sessions), and advanced (over 3 weeks – adding robotic wet lab and machine maintenance training) accreditation levels. The program is hands-on, live, in-person, and inclusive of surgical staff such as nurses and technicians (unlike others). The FSRS has been validated to significantly improve performance in three tasks (ball placement, suture pass, and fourth arm manipulation), but the difference in proficiency or patient outcomes after each course has not been studied [15]. The developers of the simulator used in the validation study were also the authors, which raises the possibility of bias.

The reviewed training programs focus on basic knowledge and robotic skills, which is useful for early training, and should be followed by advanced procedure-specific training.

**Console-side Training**

The console in a robotic surgery system is the interface through which the operator interacts with the robotic arms and tools. Most training systems focus on translating pre-console training into effective console skills. To maximise efficiency and patient safety simulation is used at these early stages. As mentioned above, the FRS and FSRS incorporate both pre-console and console-side training.

The console-side training process is divided into pre-clinical and clinical stages, and simulation training is used to transition between them. Simulation training includes dry lab, wet lab, and virtual reality, and helps prepare trainees for live procedures. Task deconstruction is used to identify specific learning needs and facilitate progress from basic to advanced steps in procedures (for example separating prostatectomy into port insertion, dropping of the bladder, dissection of prostate/seminal vesicles/bladder neck, urethro-vesical anastomosis and pelvic lymph, node dissection).

Simulation training in medicine provides accurate visual, auditory, and tactile cues that mimic real-life experiences. The fidelity of simulation is an important factor that determines its impact and is a contentious topic. Low-fidelity simulators are limited in scope and provide no or unrealistic feedback, but are cheap and aid training of individual movement/control skills. High-fidelity simulators immerse trainees in the live setting with realistic feedback and provide multi-task training. Simulation fidelity levels correspond to different stages of clinical competence, which can be assessed as progression from knowledge to action [16]. High-fidelity simulation has been associated with the acquisition of the highest level of competency, and structured training with high-fidelity simulators has been shown to improve technical skill acquisition and reduce mental workload [17,18]. Additionally, studies have shown that higher-fidelity simulations, such as Procedural VR, result in better skill acquisition and training outcomes at the operative level compared to basic VR simulation.

Dry lab simulation involves the use of synthetic models on robotic consoles to develop specific skills, such as grasping, placement, suturing, cutting, and camera control. It is a cost-effective way of training basic psychomotor skills and provides consistent training internationally, but it provides the lowest surgical realism of simulation methods, diminishing returns for each skill, and has limitations in assessment beyond basic metrics such as time to completion or error avoidance.

Wet lab simulation involves the use of organic tissue to provide a more realistic training environment for developing tissue handling skills and learning about tissue response to instruments and diathermy. This type of simulation provides sensory cues that can be carried over to the operating theatre. Examples of wet lab training models include synthetic and cadaveric models of humans and animals. Cadavers provide the highest fidelity, but are expensive and lack physiological responses such as vascular injuries and tissue haemostasis. Animal models offer more realistic physiological responses, but are limited by anatomical, ethical, sample preparation and cost considerations. Examples of live porcine and ovine simulation models have also been used to simulate bleeding, showing increased trainee confidence with robotic surgery and greater uptake of future training [19,20]. However, all of these are limited by their high cost and limited availability.

Cadavers provide the highest fidelity to the actual operative conditions but are expensive and cannot emulate realistic physiological responses to actions such as vascular injury. Animal models address some of these issues as they can represent vascular injuries and tissue haemostasis far more accurately than cadavers, but are limited by their anatomical variation, high cost, ethical dilemmas around animal welfare, and the preparation necessary to use them to simulate human surgery.

Virtual reality (VR) is defined as technology which allows people to interact with three-dimensional deformable computerised databases in real-time, using their natural senses and skills. VR surgical training is becoming more widely available and immersive, allowing trainees to develop critical skills through repetition in a controlled environment, leading to reduced operative times, lower complication rates, and improved outcomes [21]. However, the level of immersion is variable, and it may also appear inanimate. There are currently 4 commercially available VR simulation platforms for surgical training, which have been validated and shown to be effective in developing skills for robotic surgery. These are the Robotic Surgical System (Simulated Surgical Systems, United States), the dV-Trainer (Mimic, United States), the da Vinci Skills Simulator (Intuitive Surgical, United States), and the recently introduced RobotiX Mentor (3D Systems, United States).

Novel robotic systems are offering their dedicated training programmes as well, such as the Hugo ASCEND training pathway by Medtronic and the CMR programme providing online and in-person training [22,23]. Both allow trainees to practice in a realistic, virtual environment, and progress from pre-console training to preceptored surgical cases. A notable strength of the Hugo ASCEND is the specific procedural simulation it offers, while one of the CMR programme is its emphasis on team training and communication, encouraging theatre staff to practice working together effectively in simulated surgical scenarios. More generally, the Robotics Training Network (RTN) is a collaborative effort across American centres that aims to generally upskill robotic surgeons with a two-phase accredited curriculum: bedside assistance and console surgeon. The curriculum is delivered through eLearning, dry lab sessions, and live operating theatre training, and assessments are performed using R-OSATS via review of performance videos [1]. Limitations of the RTN include it not offering a structured approach to technical and non-technical skill development, the online modules not providing sufficient feedback to trainees, and the training itself not being standardised across different training sites. There is also no clear evidence at present that any of these programmes lead to improved surgical outcomes.

In the operating theatre, training begins with observation, and trainees progress to performing simpler steps under the supervision of an expert surgeon. As they become more skilled, the supervisor's role changes from preceptor (who intervenes when required) to proctor (who supervises while allowing trainees to perform), allowing the trainees to perform with supervision.

The use of dual console robotic platforms can be particularly helpful in surgical training, despite the increased cost, as they allow trainees to observe procedures from the expert's perspective and allow for seamless collaboration and supervision. This was shown (in comparison to single console procedures) to lead to significantly lower operative times and intra-operative complication rates without any differences in blood loss, postoperative complication rates, surgical margins and recurrence rates of pathology [24]. Dual console training methods also presented unique interpersonal dynamics between trainees and supervisors which were reminiscent of cockpit interactions in aviation, with both trainees and trainers preferring dual over single console setups for training purposes [25].

Each of the simulation modalities (dry lab, wet lab, virtual reality) play a different role in console-side training and has been shown to demonstrate internal consistency. Hung et al showed significant correlation across the dry lab, VR, and live in-vivo (wet lab) performances by both novices and expert surgeons [26]. As there is no gold standard robotic training to compare to for concurrent validity, they proposed cross-method validity across these modalities with recommendations to have a multi-modality approach to robotic surgical training.

The high costs and preparation time associated with many robotic surgery training methods limit their accessibility to larger and more specialised centres. A recent study found that 74% of trainees would value greater access to robotic surgery training, as only 13.5% reported having access to such training [27]. Additionally, the novelty of robotic surgery means many consultants are also undergoing training to gain proficiency, leaving fewer opportunities for trainees. The increasing importance of robotic surgery across many surgical disciplines and the expectation that its utilization will only increase raised trainee concerns, with 77% in favour of formal robotic training being more incorporated into training programmes [27].

**Operative Performance Assessment**

Apprenticeship-style surgical training provides direct and indirect synchronous feedback to trainees. asynchronous feedback via video analysis and crowd-sourced assessments is being used to address the limitations of expert reviews. The manual feedback from supervisors and patient outcomes shape trainees' future actions, but assessments require a large time commitment and can be influenced by individual bias and differing metrics. While manual assessments can directly improve surgical performance, they are unable to determine the quality of operative technique with certainty.

Attempts to use existing assessment tools in the dry lab setting have shown positive results. The Global Evaluative Assessment of Robotic Skills (GEARS) is valid, demonstrating expert surgeons objectively outperformed trainees in each of the 6 metrics (depth perception, bimanual dexterity, efficiency, force sensitivity, robotic control, and autonomy) [28,29]. Similarly, the Robotic Objective Structured Assessments of Technical Skills (R-OSATS) have been validated in a dry lab setting when performing simulation exercises [30]. A benchmark score is measured in 4 domains: depth perception/accuracy, force/tissue handling, dexterity and efficiency.

Assessment using these tools and 'crowd sourcing' is also possible. This is where nonexpert 'crowd' assess videos of surgical performance, and has been found to correlate strongly with expert assessments in both dry lab and live surgical procedures [31–33]. Importantly, the impact on patient outcomes is not incorporated into either of these assessment tools, and direct correlation between assessment results and patient outcomes has not been demonstrated.

Virtual reality and robotic surgery have given rise to automated performance metric (APM) analysis of surgical techniques, which objectively measures operative technique through direct metrics such as kinematic efficiency data (metrics of instrument movement), system events data (operative/ instrument decisions) and instrument grip force [34]. This assessment method has shown good discrimination of expertise and is validated in procedure-specific cases. Examples include the Imperial College Surgical Assessment Device (ICSAD) and Robotic Video Motion Analysis Software (ROVIMAS) [35,36]. APM analysis provides more objective measurements of surgical technique compared to manual assessments, but it doesn't account for cognitive load or nontechnical skills, which are crucial for successful surgical outcomes. Therefore, automated metrics should not be the sole means of assessing surgical performance.

Nontechnical skills and cognitive load are important factors in surgical performance but are often overlooked. Nontechnical skills involve surgical cognitive skills and surgical social skills, and insufficient training in these is associated with adverse patient outcomes [34]. Cognitive load reflects the effort used by the working memory, with novices requiring relatively high cognitive loads to perform at a comparable level to experts which reduces with practice. Operating with high cognitive load may negatively impact patient outcomes [34]. Tools exist to measure these such as:

NOTSS (Non-Technical Skills for Surgeons) – a behaviour rating system allowing reliable assessment of situation awareness, decision making, communication & teamwork, and leadership. Research has demonstrated that trainees who received NOTSS training showed improved scores on behaviour ratings for decision-making, situational awareness, communication and teamwork, and leadership [37].

OTAS (Observational Teamwork Assessment for Surgery) – has been shown to improve teamwork during surgery. Providing real-time feedback to team members, it helps to improve team communication and coordination. Studies have shown that teams who receive OTAS training show improved teamwork and communication during simulated surgeries [38].

NASA-TLX (National Aeronautics and Space Administration Task Load Index) – has been used to improve the cognitive workload of surgeons. Measuring cognitive load, it can help to identify areas where surgeons may be struggling and provide targeted training to improve performance.

While these tools provide important information, they are subject to the same limitations as manual assessments, including the potential for assessor bias and the time required for assessment. They also require significant investment of time and resources, both in terms of training assessors and surgeons in their use and in terms of the equipment and software required. Additionally, these tools must be validated across a range of surgical procedures and populations to ensure that they are reliable and effective in all contexts.

A randomized controlled trial by Raison et al showed the benefits of first-person kinaesthetics mental imagery in performing a robotic urethrovesical anastomosis task, resulting in significant improvements in technical performance (mainly in the aspects of the task that presented cognitive challenge) [39]. Practising the mental rehearsal aspect of a physical task without physical execution leads to similar neural activation and physiological responses as performing the task normally [39]. This suggests a place for mental imagery within existing robotic surgical training programs to enhance technical skill acquisition and promote further improvements through self-directed mental imagery performed by trainees for future training.

Some of these techniques are already used to assess operative performance and in a credentialing process. The future may point towards more automated performance metrics being incorporated into this credentialing and feedback cycle as ever-increasing research is showing associations with patient outcomes for individual assessment tools mentioned earlier.

**Example Curricula**

The European Association of Urology (EAU) Robotic Urology Section (ERUS) proposed the 'Robotic Curriculum' (RC) as a comprehensive training framework that addresses all aspects of a robust training program, validated to train surgeons to perform robot-assisted radical prostatectomy independently (RARP) [7]. The training program includes e-learning, procedure observation, didactic teaching, dry lab/VR simulation, non-technical skills training, wet lab simulation, and modular operative training (assisting and operating) over 180 days. The training involves key steps being performed in vivo under supervision, with progression to full procedural training when proficiency is demonstrated. To complete the fellowship the trainee must independently perform a full RARP which is recorded and assessed by two blinded international experts. This training programme exemplifies the ideals set forth by Ahmed et al for robotic training programmes [6].

This presents a departure from many previous training initiatives in robotic surgery which focus on combining theoretical courses with simulation training, and generally are seen as preliminary adjuncts to local training programmes [11–13]. The ERUS RC offers a stand-alone course with proficiency-based progression and supervision from qualified mentors. Figure 1 shows the training pathway of this course. Although initial results show it to be acceptable, valid and effective, more long-term, highly powered studies are needed to further support validity [7].

The modular nature of this training programme integrates each of the simulation modalities, proficiency-based progression, integration of assessment of technical skills with GEARS and non-technical skills with NOTSS, and the modular live surgical training which can be implemented at local host centres. This comprehensively supports trainees to achieve proficiency in independent practice [40]. Evidence of surgeons who have navigated the novice to expert learning curve via these training programme now shows the ERUS RC provides safe and sufficient training [41].

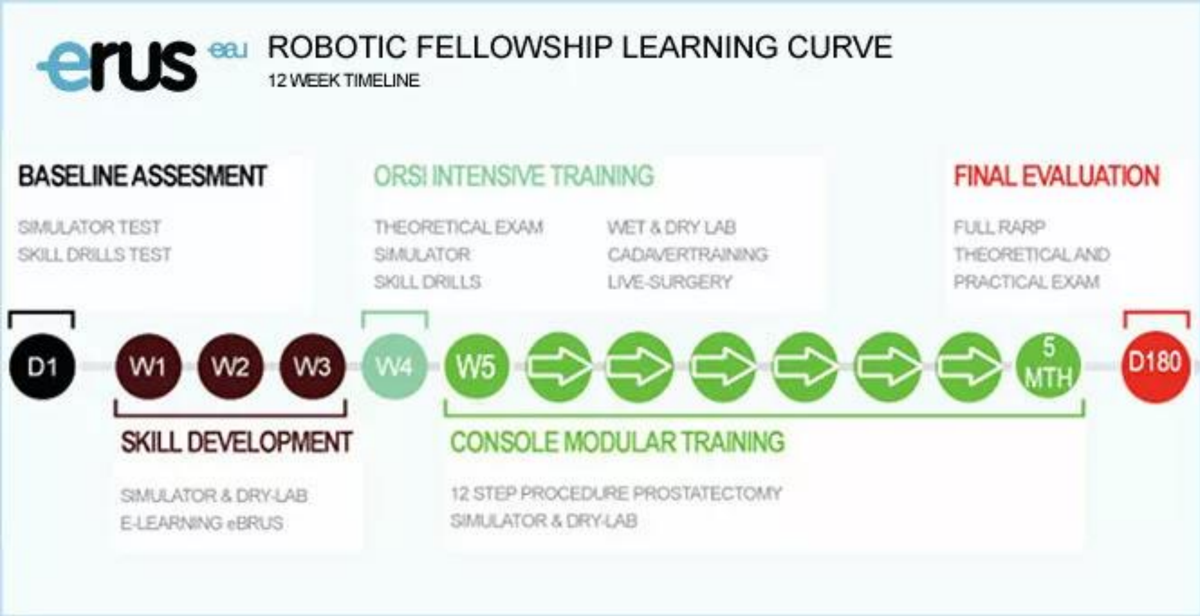


Figure 1: Showing the timeline of the ERUS Robotic Curriculum [40].

**Validity**

The types of validity used for assessing surgical simulators and their definitions are summarised below:

- Face - Realism
- Content – Accurately simulates test condition
- Construct - Can differentiate performance between novices and experts
- Concurrent - A measure that reflects whether test scores between different instruments or simulators are in broad agreement
- Discriminant - Can differentiate ability levels within a group with similar experience
- Predictive - Ability to select those who will or will not be able to perform surgical operations well despite training

There is no predefined scale on which to assess face validity; whether it is 'somewhat/very close' for RoSS or the visual analogue scale for DVSS [42]. Similarly, there are no strict definitions for 'novices' and 'experts' to help differentiate them in construct validity. Face and content validity are also measured subjectively using questionnaires. This introduces heterogeneity and bias, worsened by similar ambiguity regarding many other metrics measured in simulation, preventing rigorous testing and the provision of evidence-based solutions.

Table 1. Commercially available robotic surgery simulators, cost, and validation status [43].

| Platform | Estimated Cost | Validation Status |
|---|---|---|
| dV-Trainer | $110,000 | Face, content, construct, and concurrent |
| da Vinci Skills Simulator (DVSS) | $80,000 (console not included) | Face, content, construct, concurrent, and predictive |
| Robotic Surgery Simulator (RoSS) | $125,000 | Face and content |
| RobotiX Mentor | $137,000 | Face, content, construct |

Table 1 summarises the costs and validation statuses of robotic surgery simulators. Most platforms are standalone, except for the Da Vinci Skills Simulator (DVSS) which uses the authentic console and interface from da Vinci's surgical platform, providing high fidelity and improved 3D vision compared to others. It can assess trainees using percentage and proficiency scores, but it is the most expensive as it requires the full surgical platform, and simulation use is limited to when the platform is not in use for surgery, while the other systems are standalone.

The dV-Trainer is an independent virtual simulator that emulates the hardware of the da Vinci surgical platforms (Si and Xi versions) and offers benefits such as close supervision without interrupting via a supervisor screen, team training with a secondary simulator, and augmented reality videos of procedures which allow trainee interaction (partial nephrectomy, hysterectomy, inguinal hernia repair, and prostatectomy). It can also assess trainees via percentage or proficiency-based systems.

The Robotic Surgical Simulator (RoSS) is another standalone simulator with a 3D viewer, force feedback controls and an external monitor to facilitate supervision and guidance. It includes video-based training modules utilising force feedback to guide hands to follow simulated instruments for VR procedural training in prostatectomy and hysterectomy. This system uses a numeric score and a pass mark for its exercises to assess trainees.

The RobotiX Mentor is an independent virtual simulator platform with 2 separate units. The console replicates the da Vinci surgical system console while the other unit hosts the computer running the software and the external monitor used for supervision and guidance. It shares some exercises with DVSS but also has its own fully simulated VR procedures such as hemicolectomy and prostatectomy. This system measures the performance metrics of trainees without a threshold or a benchmark to be achieved to pass.

**Future Advances:**

Technological advancements in robotic surgery training have increased accessibility, reduced costs, and allowed for individual skill training. However, more work is needed to evaluate parameters such as depth perception, bimanual dexterity, efficiency, force sensitivity, autonomy, and robotic control. The use of tools such as GEARS can help with evaluation [29]. Further research is needed to standardize how trainee performance is assessed, potentially using machine learning or crowdsourcing with assessment tools and APMs. Risk analysis and management are being translated from other high-risk sectors to the operating theatre. This includes the use of a 'Black Box' to capture APMs, equipment and environment data, and identify causes for mistakes individually or systemically [44].

Simulation training requires a proficiency-based approach for optimal skill acquisition, similar to the aviation and nuclear energy sectors. This approach involves formal assessment and meeting predefined proficiency benchmarks, which has resulted in over 40% improvement in laparoscopic performance [45]. Regular, objective feedback is the largest contributor to reducing intra-operative errors [46]. Integrating this approach into training programs can maximize efficiency and reduce training time, improve outcomes, and balance cost-effectiveness.

Challenges to widespread robotic surgery training are high equipment costs, limited access to training, and expert supervision requirements. However, advancing technology and smaller, more accessible solutions are reducing costs and increasing access to experts over greater distances. Greater consultant uptake is also expected to improve access to training and supervision, democratising robotic surgery training.

Remote mentoring allows experts to transfer knowledge to less experienced individuals in an educational or clinical setting. This reduces costs, addresses the shortage of trained experts, and overcomes geographic limitations (and other causes of reduced educational opportunities such as the COVID-19 pandemic). Successful implementation has been observed across multiple specialties, including super-specialised care where the resources are limited or the caseload is limited, and has led to increased proficiency and confidence in procedures [47]. Platforms like Proximie (London, UK) allow for remote surgical education through augmented reality, enabling real-time virtual guidance and training [48]. Augmented reality has also been validated in a clinical robotic surgery setting, improving operative performance and cognitive workload [49]. Remote mentoring is limited by latency, but it has been shown that up to 10 milliseconds of latency is tolerable [50]. 5G networking technologies have improved range to up to 500km while maintaining minimal latency. AI trained to form a predictive model of surgical movements can give the perception of a zero-delay network and allow for greater distance participation in remote mentoring or remote performance of robotic surgery [50].

The growth of artificial intelligence and machine learning may open new possibilities for video analysis of surgical performance, providing a sensitive assessment of surgical performance, and precise, individual, real-time feedback to foster a personalised surgical training program [51]. This approach also addresses the disparity in expert availability to assess trainee performance and overcome the subjectivity and time-consuming nature of traditional assessment tools. This is currently used for procedure-specific assessment, but future work will assess increasingly complex procedures with more complex kinematic and event metrics [52].

Finally, there is still a need for the highest quality evidence through randomised control trials that training on virtual reality simulators leads to better performance than traditional training through live supervision intraoperatively, as was done for laparoscopic surgery [53].

**Conclusion:**

The multi-modality approach to robotic-assisted surgical training seeks to address the growing demand for competent and safe robotic-assisted surgeons. Training programs for robotic surgery should focus on proficiency, deliberation, and distribution principles, providing generic and procedure-specific skills through eLearning to unsupervised independent performance. Pre-console training, basic knowledge, and skills training should be followed by advanced procedure-specific training. Simulation training is an important aspect of robotic surgery training to improve technical skill acquisition and reduce mental workload, which helps prepare trainees for live procedures. The ERUS Robotic Curriculum represents an evidence-based example of how to implement training from novice to expert. APM analysis provides live, objective, personalized measures of surgical performance in a time and cost-efficient manner. The study highlights the need for standardisation in trainee performance assessment through machine learning or crowdsourcing. The challenges to widespread training include high equipment costs and limited access to experts, but remote mentoring and augmented reality platforms can reduce costs and overcome geographic limitations. The future of robotic surgery training looks promising, with advancements in emerging technologies offering real-time feedback and immersive training environments, leading to improved patient outcomes.

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