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TOPIC PAPER

The safety of urologic robotic surgery depends on the skills of the surgeon

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Abstract

Purpose To assess the available literature evidence that discusses the effect of surgical experience on patient outcomes in robotic setting. This information is used to help understand how we can develop a learning process that allows surgeons to maximally accommodate patient safety.

Methods A literature search of the MEDLINE/PubMed and Scopus database was performed. Original and review articles published in the English language were included after an interactive peer-review process of the panel.

Results Robotic surgical procedures require high level of experience to guarantee patient safety. This means that, for some procedures, the learning process might be longer than originally expected. In this context, structured training programs that assist surgeons to improve outcomes during their learning processes were extensively discussed. We identified few structured robotic curricula and demonstrated that for some procedures, curriculum trained surgeons can achieve outcomes rates during their initial learning phases that are at least comparable to those of experienced surgeons from high-volume centres. Finally, the importance of non-technical skills on patient safety and of their inclusion in robotic training programs was also assessed.

Conclusion To guarantee safe robotic surgery and to optimize patient outcomes during the learning process, standardized and validated training programs are instrumental. To date, only few structured validated curricula exist for standardized training and further efforts are needed in this direction.

Keywords Safety · Robot-assisted surgery · Training · Surgical skills · Learning curve

Introduction

In the United States every year, more than 250,000 deaths occur due to medical error, as reported by a recent Johns Hopkins University's study [1]. Medical errors may lead to an estimated overall cost of about 17–29 billion dollars [2]. Combining the social and economic aspects of these errors strongly underlines that we should strive to provide a higher quality of care to our patients. However, measures to improve surgical safety are still largely missing or unknown. Improving patient safety represents a growing priority for health professionals and institutions. In 2009, the World Health Organization (WHO) created the safety guidelines for surgery to promote standardization of practice, to avoid errors during surgery and to ensure patient safety [3]. In this document, factors responsible for surgical errors were analysed and categorized as follows: high workload, inadequate knowledge, lack of skills or experience, inadequate supervision or education, stressful environment, and mental

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fatigue [3]. Despite the fact that the majority of these factors could potentially be mitigated by adequate training, surgeon training was not mentioned in the aforementioned safety guidelines.

The exponential growth of robot-assisted surgery revolutionized the world of minimally invasive surgery, establishing itself as a new reliable technology in many different specialties [4–6]. However, compared to more traditional open and laparoscopic surgical approaches, robot-assisted surgery brings a specific set of (new) safety features [7–9]. Indeed, between 2000 and 2013, approximately 10,624 adverse events related to robotic procedures were reported in the United States among different surgical specialties [10]. In the light of these data, the European Commission of WHO created the Patient Safety in Robotic Surgery (SAFROS) project [11]. The aim of this project was to explore whether robotic surgery, carried out in accordance with safety criteria can improve the level of safety currently achievable by traditional surgery. Specifically, it analysed safety in robotic surgery, formalized safety requirements, and established safety procedures and verifications protocols [11]. Moreover, since several studies demonstrated the importance of surgical experience on the improvement of patient outcomes [12–15], the attention focused also on adequate training and preparation of robotic surgeons. To achieve standardization of procedures that represent a recognized safety factor for patients, the development of structured robotic surgical training programs has become a priority [8]. Furthermore, in training, the surgeon should not be considered the sole author of a technical procedure. Rather, successful execution of a surgical procedure should be seen as a team effort; the whole environment of the operating room involves multiple professionals that interface with patients at different levels. Thus, training should not only address the technical skills of the surgeon, but also his/her ability to manage the collaboration between the team of health-care professionals.

The aim of the current review was to isolate key factors that allow a surgeon to perform a safe robot-assisted procedure. Specifically, we focused on the available evidence on the learning phase in robotic setting and how we could assist naïve surgeons to maximally improve patient safety and outcomes during their learning process. Subsequently, the available surgical training programs and the importance of non-technical skills were assessed.

Evidence acquisition

A literature search of the MEDLINE/PubMed and Scopus database was performed. The research process was divided into three main topics related to the acquisition of skills: learning curve, robotic training, and non-technical skills. For each topic, a systematic literature search was performed with subsequent analysis of the results obtained. The search terms used were (*urology* OR *robotic surgery*) AND (*training* OR *simulation* OR *learning curve* OR *skill* OR *curriculum*) AND (*safety*).

Only English-language original and review articles published between January 2000 and March 2019 were included. The relevant studies selected were analysed and summarized after an interactive peer-review process of the panel.

Discussion

Technical learning curve

A learning curve is a graphical representation of the concept of the improvement of surgical outcomes with the increasing of surgical experience [16]. The surgical outcomes that are generally assessed in a learning curve are related to technical aspects (i.e., operative time and transfusion rate), complications, oncological, and/or functional results [17, 18]. Theoretically, the performance of a training naïve/novice surgeon is expected to improve over time—in line with the learning curve—with each surgical procedure. Therefore, the learning curve is characterized by an initial learning phase, where the outcomes are significantly affected by the surgical experience, and by a subsequent plateau phase, where the impact of surgical experience becomes marginal. However, given the complexity of some surgical procedures, it may take substantially longer to reach the plateau phase, especially for stronger outcomes such as severe complications or oncological outcomes.

Several studies attempted to evaluate the relationship between surgeon experience and patient outcomes in different urologic robotic procedures [10, 14, 19–27] (Table 1). Unfortunately, instead of assessing the learning process as the number of prior robotic surgeries performed by the surgeon at the time of the index patient's operation [16], the majority of these studies divided the patient population into different categories [14, 20, 28, 29]. This has been demonstrated to draw unwarranted conclusions [30], underestimating the number of the procedures needed to reach the potential plateau of the learning curve [31]. For instance, in the setting of robot-assisted radical prostatectomy (RARP), the number of robotic procedures for a novice surgeon/naïve laparoscopic surgeon needed to stabilize the operative time varied between 30 and 250 [21, 23–26], while the number of procedures needed to master urethra-vesical anastomosis was 10 [23]. Moreover, the number of surgeries needed to significantly reduce the overall rate of postoperative complications varied between 30 and 175 among different studies [20, 22, 25]. The wide ranges of these data may be related to the lack of standardized statistical methodology that analyse expertise in a continuous fashion accounting for potential

Table 1 Learning curve studies on robot-assisted urological procedures

Study	No. of patients	No. of surgeons	Previous surgical experience	Operation	Outcomes	No. of cases needed to observe an improvement and a plateau phase in the outcomes measured
Di Pierro et al. [20]	233	2	Open + laparoscopic	RARP	Complication	175
Sivaraman et al. [28]	5547: (1701 RARP)	9	–	RARP	PSM, BCR	PSM, BCR: 100
Ou et al. [29]	200	1	–	RARP	OT, BL, BT, Complications	OT: significant improvement, plateau not reached BL–BT: 50 Complications: 150
Gumus et al. [26]	120	1	Open	RARP	OT, LOS, PSM, BL, EC, potency	80–120 for all the outcomes
Monnerat et al. [21]	133	1	Laparoscopic	RARP	PSM, OT, potency, EC	OT, potency, EC: 100 PSM: plateau not reached
Sharma et al. [24]	500	2	Open + laparoscopic	RARP	OT, BL, PSM, EC, potency	OT, BL: significant improvement, plateau not reached EC, potency: 100 PSM: 450
Giberti et al. [25]	200		–	RARP	OT, PSM, EC, potency, Complications	OT, Complications, potency, EC: 100 PSM: 200
O'Malley et al. [23]	110	2	Open	RARP	OT, PSM, VUAT	OT:40 VUAT:10 PSM: 200
Bravi et al. [32]	2857	9	Open	RARP	PSM, BCR	PSM > 200[a] BCR: no significant improvement, plateau not reached
Thompson et al. [33]	1520	1	Open	RARP	PSM, SF, SB, EC, UB, UF	PSM: T2: 108, > 400–500[a]; T3-4 > 200–300[a] SF: 99 > 600–700[a] SB: 123 > 300–400[a] EC: 182 > 700–800[a] UF: 144 > 300–400[a] UB: 58 > 300–400[a]
Thompson et al. [13]	1520	1	Open	RARP	PSM, BCR, SF, SB, EC, UF, UB	PSM: 382 > 484[a] BCR: 191 > 226[a] SF: 139 > 405[a] SB: 191 > 330[a] EC: 124 > 365[a] UF: 151 > 659[a] UB: 47 > 360[a]
Mottrie et al. [35]	62	1	Robotic	RAPN	WIT, OT, BL, complications	Short learning curve for all the outcomes
Dias et al. [36]	108	1	Laparoscopic	RAPN	WIT, OT, BL, trifecta	WIT > 44[a] OT > 44[a] BL > 54[a] Trifecta > 44[a]
Xie et al. [37]	144	1	Laparoscopic	RAPN	MIC	90
Hanzly et al. [39]	116	1	Laparoscopic + Robotic	RAPN	OT, WIT	OT: 150 WIT: 30

Table 1 (continued)

Study	No. of patients	No. of surgeons	Previous surgical experience	Operation	Outcomes	No. of cases needed to observe an improvement and a plateau phase in the outcomes measured
Larcher et al. [49]	457		Robotic	RAPN	WIT, complications, PSM	WIT: 150 Complications: significant improvement, plateau not reached PSM: no significant improvement, plateau not reached
Paulucci et al. [40]	960	4	Laparoscopic, open, robotic	RAPN	WIT, BL, BT, LOS, trifecta	300: significant improvement for all the outcomes, plateau not reached
Collins et al. [14]	67	2	Robotic	RARC + intracorporal neobladder	OT, LOS, LNY	OT:10 LOS: no significant improvement LNY: no significant improvement
Richards et al. [41]	60	1	Robotic	RARC	OT, BL, LOS, LNY, complication	OT, BL, LOS, complication: 20–40 LNY: plateau not reached
Hayn et al. [27]	496	21	–	RARC + extracorporeal urinary diversion	OT, LNY, PSM, BL, LOS,	OT: 21 LNY, BL: 30 LOS: plateau not reached PSM: 30 (not significant)

OT operative time, *BL* blood loss, *PSM* positive surgical margins, *EC* early continence, *BT* blood transfusion, *LOS* length of stay, *VUAT* vesicourethral anastomosis time, *SF* sexual function, *SB* sexual bother, *UR* urinary continence, *UB* urinary bother, *WIT* warm ischemia time, *LNY* lymph-node yield, *MIC* margin–ischemia–complications

[a] Plateau phase of the learning curve

non-linear relationship between outcomes and experience progression. Therefore, these results should be interpreted with caution.

Several studies on RARP learning curve are also limited by the fact that they exclusively focused on technical aspects without assessing the learning process on cancer control, that is mandatory considering the reason for which the patients undergo surgery. On this direction, few reports assessed the impact of surgeon experience on oncologic efficacy of RARP [13, 28, 32, 33]. It merits mention the study by Bravi et al. [12, 32] that relied on a large cohort of prostate cancer (PCa) patients ($n = 2231$) treated with RARP at a single tertiary care referral centre by nine surgeons. The authors observed a significant, non-linear relationship between surgeon experience and PSMs, with a steep reduction after 200th procedure. However, the authors failed to observe a relationship between surgical experience and biochemical recurrence (BCR). Contrarily to what commonly believed, these data could suggest that the high dexterity of robotic surgery might guarantee optimal cancer removal also in less experienced hands. Moreover, it is of note that previous experience in open surgery was not associated with the risk of PSMs during RARP [32], emphasizing that there is a learning curve in RARP also for expert open surgeons. In the same direction, Thompson et al. [13, 33] analysed whether high-volume experienced open surgeons can improve their functional and oncological outcomes with RARP. Specifically, for a single surgeon who performed more than 3000 open RP, they reported that the risk of PSMs for RARP relative to open RP became lower after 382 cases, plateauing after 484 cases. The authors [13, 33] reported for the first time that the improved PSMs rate for RARP resulted in improved biochemical control. The risk of BCR of RARP vs. open RP rapidly decreased with the increasing number of procedures performed, and became lower after 191 cases, plateauing after 226 cases. Similar findings were observed when functional outcomes were investigated. Mean RARP sexual function and sexual bother scores surpassed open RP scores after approximately 160 procedures. Moreover, after almost 140 procedures, the adoption of robotic technology resulted into a better early urinary function and incontinence domains. More than 400 procedures were needed to allow that RARP yielded a superior performance than open RP for late urinary function and incontinence scores [13, 33]. All these findings indirectly suggest that to improve the learning process of RARP, a structured robotic training is mandatory also in skilled open surgeons. Indeed, evidence confirms that fellowship-trained robotic surgeons outperform earlier experienced open RP surgeons incorporating RARP into practice with regards to perioperative morbidity and oncological outcomes [34].

Regarding the robot-assisted partial nephrectomy (RAPN) setting, the majority of the studies that assess the learning process of this minimally invasive procedure are limited by their sample size (Table 1) [35–38]. This limits the ability to accurately assess the learning curve. Larcher et al. [39], however, reported the learning curve for RAPN based on a multi-institutional cohort of 457 consecutive patients diagnosed with cT1–cT2 renal mass. In this study, a significant, non-linear relationship between surgical experience and optimal warm ischemia time was observed after accounting for different confounders, yielding a plateau after 150 procedures. A significant relationship was also identified between surgeon experience and Clavien–Dindo ≥ 2 complications-free course, suggesting that surgical expertise is mandatory to reduce the risk of postoperative complications in RAPN setting. As this relationship is linear [39], it suggests that the learning process with respect to postoperative complications is continuously evolving and is longer than expected. In this context, the study by Paulucci et al. [40] should also be mentioned. This study underlined that perioperative outcomes (i.e., warm ischemia, estimated blood loss, blood transfusion, length of stay, and trifecta achievement) continue to improve up to 300 procedures, despite an increase over time in patient morbidity and tumour size. These RAPN-related findings overwhelmingly underline that the learning curve for RAPN is long and complex and skilled surgeons are needed to safely perform this procedure.

Regarding robot-assisted radical cystectomy (RARC), only few studies assessed the relationship between surgeon experience and patient outcomes after RARC (Table 1) [14, 27, 41]. For example, Hayn et al. [27] reported the largest series ($n=496$) evaluating the learning curve for RARC with the majority of patients undergoing extracorporeal urinary diversion by 21 surgeons, with different previous experience in robotic surgery (7 surgeons performed less than 50 RARP, 5 performed between 50 and 100 RARPs, 3 performed between 101 and 150 RARP, and 6 performed more than 150 RARPs). The authors reported a relatively low number of minimum required procedures for a stabilization of the defined outcomes. Specifically, they observed an optimal operative time of 390 min after reaching a plateau at 21 cases. Moreover, 30 cases were needed to obtain a count of 20 lymph nodes removed and to have a 5% overall PSMs rate [27]. To date, only one study assessed the learning curve for RARC with intracorporeal neobladder in 67 patients treated by two surgeons [14]. An early decrease of operative time, overall complications, and length of stay was observed. Conversely, blood loss, lymph-node yield, and PSMs rate could not be related to the experience of the surgeon [14]. Unfortunately, none of these analyses used appropriate statistical adjustment methods that accounted for the impact of inter-surgeon variability and previous robotic/open experience [16]. Therefore, the likely short RARC learning curve provided by the aforementioned studies may be related to the different surgical experience developed before RARC learning process was started. Moreover, the aforementioned studies were also limited by their historical nature [14, 27, 41] and small sample sizes [14, 41]. Thus, further analyses using clustering methodology at surgeon level in contemporary RARC series are urgently needed.

To summarize, robotic surgery continues to be challenging and not devoid of complications. To improve patient safety and outcomes, surgical expertise is mandatory especially for stronger outcomes [13, 33, 42]. This calls for structured training programs that represent the ideal starting point for surgeons to reduce the length of their learning process [31].

Robotic surgical training

Robot-assisted surgery harbours unique characteristics when compared to laparoscopic or open surgery [5, 7–9]. As the robotic technology advances, a surgeon training has to be focused on machinery type, as well as on new surgical techniques. Uniquely, from a clinical standpoint, surgical training programs have to accommodate for innovations robot-assisted surgery (e.g., clinical availability of different robot-assisted surgical platforms) to guarantee virtually the same clinical outcomes among different centres. This added complexity underlines the fundamental need to design standardized and validated training programs [8].

To achieve this goal, the European Association of Urology Robotic Urology Section (ERUS) developed the first structured and validated curriculum in urology that specifically focuses on RARP (Table 2) [43]. After its initial publication in 2015 [43], the curriculum was recently updated by doubling the training periods from 3 to 6 months to allow naïve surgeons to participate with a time suitable for adequate preparation [44]. Overall, the ERUS training program is proposed in a modular fashion, following precise and well-defined steps [43]. The first phase of the curriculum training course foresees a theoretical deepening (i.e., e-Learning). It can be accessed using web links and it

Table 2 Urological and basic training robotic surgery curricula

Name	Study	Year	Validation	Field
ERUS robotic surgery training curriculum	Volpe et al. [43, 44]	2014	VALIDATED	Urology
British Association of Urological Surgeons (BAUS) Robotic Surgery curriculum	Not published [58]	2015	NOT VALIDATED	Urology
The ERUS curriculum for robot-assisted Partial Nephrectomy	Larcher et al. [56]	2019	VALIDATED	Urology
The ERUS curriculum for robot-assisted radical cystectomy	Dell'Oglio et al. [57]	2019	NOT VALIDATED	Urology
Fundamental skills of robotic surgery (FSRS)	Stegemann et al. [59]	2013	VALIDATED	Basic training
Proficiency-based robotic curriculum	Dulan et al. [60]	2012	VALIDATED	Basic training
University of Toronto basic skills training curriculum (BSTC)	Foell et al. [61]	2013	VALIDATED	Basic training
Fundamentals of robotic surgery: Orlando group	Macgregor et al. [64]	2012	NOT VALIDATED	Basic training
Texas Association of Surgical Skills Laboratories (TASSL) training collaborative	Lyons et al. [65]	2013	NOT VALIDATED	Basic training
Roswell Park Cancer Institute Robot Assisted Surgical Training (RAST) program	Attalla et al. [63]	2013	NOT VALIDATED	Basic training
Fundamentals of robotic surgery (FRS)	Smith et al. [66]	2014	NOT VALIDATED	Basic training
Fellowship of International College of Robotic Surgeons (FICRS)	Not published [62, 64]	NA	NOT VALIDATED	Basic training

involves three different teaching modules: transmission of theoretical knowledge, teaching on surgical techniques, and instructions on virtual patients. Such an approach allows for a first acquaintance with important information for robot-assisted surgery, and it is characterized by flexibility, ease of access, and ease of updating [45]. After the e-Learning module, the initial phase of hands-on training in robot-assisted surgery starts from the basic characteristics that distinguish this approach from laparoscopic or open surgery, such as the EndoWrist manipulation, camera movements and clutching, use of energy and dissection, and needle driving [46]. From an ethical point of view, it is best to learn these technical characteristics through the use of virtual simulators [5, 8, 47, 48] that allow to replicate steps of different urologic procedures. Recent evidences suggest that this preclinical simulation-based phase significantly improves surgical performance as measured using objective metrics [49]. Subsequently, the RARP curriculum program proceeds with wet laboratory training, where surgical techniques are performed on deceased animals (canine model) and live animals (porcine model). These models allow surgeons to distinguish the consistency of tissues and to perform surgical procedures on models that closely replicate real case surgery. Moreover, live animals also allow to simulate emergencies, such as vascular or organ injuries, to prepare surgeons for such complexities. Following a 1-week intensive course module on animal models, the surgeons transition to patients to perform a 6-month clinical modular training under expert surgeon supervision. This module involves progressive, proficiency-based [50, 51] training through surgical steps with increasing levels of complexity [43, 44]. At the end of the clinical training, the surgeon must perform and record a complete procedure that will be blindly evaluated by an external committee using a validated score that is assigned through recognized assessment tools, like the GEARS (Global Evaluative Assessment of Robotic Skills) [52]. In summary, the goal of the ERUS RARP curriculum is to provide an objective evaluation of the surgical skills acquired during the training course. This helps to certify the fellow as a robotic surgeon who successfully completed a structured and validated training program [3, 6, 10, 11]. Recent studies reported the effect of structured RARP training on outcomes [53–55]. Schiavina et al. [54] demonstrated that optimal perioperative and functional outcomes may be attained in an early phase of the learning curve after an intensive structured modular training, with less than 100 consecutive procedures needed to achieve optimal urinary continence and erectile function recovery. Similarly, Bedir et al. [55] showed that an RARP curriculum trained surgeon may achieve high outcome rates in his initial learning phase that are comparable to those of experienced surgeons from high-volume referral centres.

Recently, a new training program on RAPN was presented by the ERUS with the aim of helping surgeons willing to start robotic renal cancer surgery [56] (Table 2). Similar to the RARP curriculum course, this RAPN-specific pathway guides the trainee from theoretical knowledge to preclinical learning, passing through virtual reality simulators, dry and wet laboratory training, up to clinical-based modules practice. After the initial e-Learning phase, the RAPN course starts with an intensive week of preclinical simulation-based training that closely replicates that of RARP curriculum course. Subsequently, the course proceeds with a clinical modular training that is based on the partition of a complete RAPN case in ten fundamental steps, to divide the procedure into replicable modules to be learned [56]. Specifically, five modules including ten specific steps were proposed and ordered according to increasing level of step complexity after a Delphi consensus process. In the pilot phase of RAPN curriculum course clinical validation, no evidence of any detriment with respect to patient clinical outcomes was recorded and the program allowed for a safe transition from the beginning of surgical experience through increasing responsibility to the independent completion of a full case [56].

Subsequently, the first structured training curriculum for RARC led by ERUS educational board based on simulation activity, clinical training, and non-technical skills aimed at improvement of patient safety and outcomes during RARC learning process, was developed [57] (Table 2). However, clinical implementation of this curriculum is still missing and, in consequence, urgently needed.

The British Association of Urological Surgeons (BAUS) curriculum [58] represents another non-validated training model in urological field. It is largely based on the ERUS curriculum [43, 44], with five recognized stages: online theoretical training/e-learning, observation of procedure, simulation-based training, a mentorship/fellowship period, and sign-off for independent surgery. The modular training approach of the BAUS curriculum is applicable to four urological procedures, namely RARP, RAPN, RARC, and robot-assisted pyeloplasty (RAP). For each procedure, there are suggested numbers of cases and also procedure-specific quality indicators [58].

Expanding research outside the urologic field, several basic robotic surgical curricula have been created. For example, the Fundamental Skills of Robotic Surgery (FSRS) training curriculum is a validated, structured, simulation-based training program, that can improve trainees' basic robotic surgical skills [59]. It represents an integration of the previously validated program Fundamentals of Laparoscopic Surgery (FLS) curriculum in robotic surgery. The curriculum consists of 4 modules (orientation, motor skills, basic, and intermediate surgical skills) with a series of 16 tasks, each task containing 3 difficulty levels, performed on Robotic surgical simulator (RoSS).

Another validated, multidisciplinary, and comprehensive proficiency-based robotic curriculum was created by the University of Texas Southwestern Medical Centre [60]. This validated curriculum is divided in three main components: an online tutorial (created by Intuitive Surgical) on bases of robotic surgery, a half-day interactive session, and hands-on practice with nine inanimate exercises. The exercises are performed on a classic da Vinci system with box trainer and show increasing degrees of complexity to facilitate proficiency-based skill acquisition. The program lasts 2 months and trainees have to self-practice the nine exercises. Finally, they receive an evaluation using FLS metrics.

Moreover, the University of Toronto developed the basic skills' training curriculum (BSTC), a validated 4-week training program [61]. The first part of training is characterized by didactic lectures and self-directed online training modules (including Fundamentals of Robotic Surgery) before starting on the da Vinci robot. Thereafter, trainees start exercising basic skills on the da Vinci Surgical Simulator. The robotic surgical skills of the trainees are evaluated by the built-in assessment tool of the simulator. Wet lab or real-life surgery training is not included in this training curriculum. Finally, other non-validated basic robotic surgical curriculum is reported in Table 2 [62–66].

One of the points of discussion in validated curriculum is the distribution of the training sessions. Indeed, data from other surgical specialty demonstrated that spacing training sessions improves long-term surgical skills retention when compared to intensive practice [67]. However, data specifically focused on the differential effect of distributed training session in urological robotic surgery are missing. As such, this conclusion may not be applicable to our analysis, suggesting that further efforts are needed to validate these findings in robotic setting.

Finally, it is crucial to define whether the proficiency level of a trainee is reached. To achieve this goal, it is fundamental to define proficiency metrics by four stages: (1) task analysis and metric identification; (2) operational definition of metrics; (3) metric definition verification and refinement; (4) metric validation (relying, for example, on the Delphi methodology [10]). Subsequently, after defining these metrics, it is important to progressively verify knowledge acquisition and psychomotor skill acquisition, and, ultimately, to supervise real-world application of the acquired skills [50, 51]. This stepwise process defines the proficiency-based progression (PBP) training module. Indeed, it has been demonstrated in prospective, randomized, and blinded studies that metric-based PBP simulation training derived from and benchmarked on experienced and proficient surgeons produces a superior surgical skill set in comparison to traditional approaches to training [68–73], with an additional potential effect on shortening the learning curve process [74].

Moreover, objective surgical skill assessment has gained interest not only for the evaluation of surgeon proficiency but also for its impact on patient outcomes. For example, Hung et al. [75] used automated performance metrics and deep-learning models to predict continence recovery after RARP. The association of kinematic data with clinical patient features showed the highest accuracy in prediction of continence recovery after RARP compared to clinical features only. Furthermore, the patients operated by surgeons with more efficient automated performance metrics had higher continence rate at 3 and 6 months compared to patients operated by surgeons with less efficient metrics [75].

It is also of note that the standardization process of training should not only record metrics of trainees' performances, but it should also be focused on trainers' outcomes to guarantee high-level training models. In this context, it has been recently proposed, in a Delphi process-derived consensus of expert opinions, to define the key elements of the "train-the-trainer" program with the intent of providing a structured methodology also for trainers [10]. As such, the standardization process of training has still to be considered as "ongoing". Taken together, these results provide further evidence of the importance of structured training programs for technical skills improvement and, a consequence, patient's safety assurance.

Non-technical skills

What also define experienced surgeons are their non-technical skills that are categorized into cognitive and social skills [76]. The greater technical complexity of robotic surgical procedures requires adequate development of cognitive abilities (situational awareness, decision-making, and planning) and social skills that include communication, teamwork, and leadership skills [76]. The importance of non-technical skills is increasingly growing [10], especially in minimally invasive surgery considering the fact that surgeons sit behind the console, isolated from the patient and operating room staff. These aforementioned non-technical skills may be objectively evaluated using several validated tools [77], such as the Non-Technical Skills for Surgeons (NOTSS) [78] and the Observational Teamwork Assessment for Surgery (OTAS) [79]. However, it is important to remark that these tools were not developed on robotic surgery and, in consequence, they may not perfectly apply to robot-assisted surgery. In consequence, further research focusing on structured validation of these tools for robotic surgery or de novo development of new robotic-specific assessment tools is required. To date, the Interpersonal and Cognitive Assessment for Robotic Surgery (ICARS) is the only objective non-technical skill assessment tool specifically designed for robotic surgery [80]. Relying on Delphi consensus-based panel of experts, it identifies 28 key non-technical skills that should characterize a robotic surgeon. Overall, the validation analysis demonstrated that the ICARS is able to accurately differentiate between novice, intermediate and expert participants, showing high level of agreement with the NOTSS. Amongst the identified key non-technical skills, the communicative skills are included in one of the major domains of the ICARS. Specifically, effective verbal communication whilst at the console, appropriate communication with bed-side assistant, anaesthetist, and theatre staff and ability to engage in confirmatory feedback with theatre staff are critical abilities for maintaining adequate and safe robotic surgical performance [80].

Indeed, evidence exists that communication failure between hospital staff is one of the leading cause of errors and inadvertent patient harms [5, 44, 81–85]. For instance, patients had increased odds of complications or death when the following behaviours were exhibited less frequently: information sharing during intraoperative phases, briefing during handoff phases, and information sharing during handoff phases [86]. On the other, a surgeon with well-trained non-surgical skills is able to recognize and manage those situations, such as active venous/arterial bleeding or bowel perforations, which are dangerous for patient's health [87]. In consequence, these tools are mandatory to develop, especially in minimally invasive surgery, and must be an integral part of robotic training curricula, with the possibility to learn through a simulation training that can replicate common and emergency scenarios in robotic surgery [76, 83, 84].

Specific training programs have been developed to provide a standardized model for non-technical skill development [83]. The two main methods used are the classroom lessons and the simulation centres. Classroom lessons can provide an insight to the key components of these skills. Moreover, videos can be analysed and commented on how to change attitudes and lead to self-reflection [88]. Conversely, the simulations allow using models that closely replicate the real-life setting. In this context, bench or virtual reality models are positioned within a simulated or real operating environment and the whole team can participate [89]. By creating a realistic environment, it is possible to develop technical and non-technical skills that allow a complete training and an effective way of debriefing [77, 90]. It is useful that an expert surgeon also participates to these simulations to create an open discussion and to encourage self-reflection of the trainee. In addition, the entire operatory room team must be trained in non-technical skills to improve patient safety [91]. Thus, considering the general environment of the operating room, specific training courses should be supported for all team members present during a robot-assisted surgery. Future studies are needed to assess the effect of these training modules on non-technical skill improvement.

Conclusion

Robotic surgery allows surgeons to perform complex procedures with improved precision, visualization, and enhanced dexterity relative to conventional open and laparoscopic surgery. That said robotic surgery is challenging and requires technical and non-technical expertise to improve patient safety and outcomes. To be sure that a baseline expertise level is met, it is becoming increasingly important to develop standardized and validated training programs that assist the surgeons during their learning process. To date, only few structured validated curricula exist for standardized training and further efforts are needed in this direction.

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