Review Article

Virtual reality simulation training in laparoscopic suturing and knot-tying: a narrative review

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Background and Objective: The evolving domain of surgical training, particularly in laparoscopic suturing, relies on technological advancements. This review explores the complex landscape of virtual reality (VR) simulators, focusing on their role in laparoscopic suturing training. The primary objective is to assess challenges and advancements within laparoscopic suturing methodologies, emphasizing the need for evidence-based approaches in VR surgical education.

Methods: A comprehensive literature search on 5 independent databases provided studies and reviews from the last decade. Recent advancements in laparoscopic suturing training were a key focus, with specific attention to haptic feedback challenges in VR simulations, technology integration in education, and evidence-based curriculum for skills development. The review aimed to offer a comprehensive overview of challenges, advancements and gaps in VR laparoscopic suturing training.

Key Content and Findings: VR simulation training emerges as pivotal for laparoscopic suturing skill development. While box trainers have limitations, VR provides immersive experiences, enhancing psychomotor abilities. The importance of trainee involvement, early exposure, and customized training durations is emphasized for effective skill development. This review explores heterogeneity in VR educational tools for laparoscopic suturing, emphasizing the significance of haptic feedback. Some studies show conflicting evidence on the effectiveness of haptic-enhanced VR, demanding further research and cost-benefit analyses. Examples provided highlight the need for evidence-based curriculum in laparoscopic suturing training.

Conclusions: Laparoscopic suturing skills demand innovative training tools. VR simulators prove transformative in simplifying complex information and engaging trainees effectively. While promising, achieving VR's full potential requires ongoing efforts to refine haptic feedback realism, develop evidence-based curriculum, and comprehensively evaluate effectiveness. The review calls for wider delivery of relevant VR training programs. Ultimately, the goal is safer, more proficient, and patient-friendly minimally invasive surgical procedures through advanced training methodologies.

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Keywords: Laparoscopic suturing; virtual reality (VR); simulation; intracorporeal knot-tying; surgical training

Received: 15 January 2024; Accepted: 14 May 2024; Published online: 16 July 2024.
doi: 10.21037/ales-24-4
View this article at: https://dx.doi.org/10.21037/ales-24-4

Introduction

Background

Surgical training is a demanding task with complex and multifaceted goals, covering technical skills, clinical knowledge, communication, decision making, and patient safety. Surgical training has undergone substantial transformations since its inception.

Rationale and knowledge gap

The traditional medical model of "see one, do one, teach one" is no longer sufficient for training surgeons, as many skills cannot be effectively acquired by simply observing an expert (1).

Objective

The primary objective of this article is to explore how emerging technologies such as virtual simulation can be deployed to enhance and update the training methods in laparoscopic suturing and knot-tying. According to Schenarts *et al.* (2) and the cognitive overload theory (3), the complexity of surgical training setting can lead to cognitive overload among trainees. Several strategies can be used by educators to diminish this overload. Reducing intrinsic load is possible by simplifying information and offering training prior to the task. To reduce extraneous load, distractions should be minimized, and new information should be presented in a structured way. Active engagement in the learning process is also very important to sustain focus and facilitate knowledge acquisition and retention. Finally, feedback has been shown to shorten the learning process and assist trainees in reaching their objectives (4).

Apart from the traditional apprenticeship model, some of the current techniques for surgical training include video games, wet lab models, robotics, telemedicine, virtual reality (VR) simulation, online learning portals, videos, social media outlets and podcasts (5). E-learning, which refers to the use of digital and online educational resources (6), plays a significant role in surgical training. This approach harnesses the power of technology to overcome obstacles related to surgical education by offering enhanced accessibility to learning material, standardization of content, personalized teaching, ease in updating and editing content, as well as effortless distribution (7). In this way, basic surgical skills can be acquired outside the operating room (OR), in a laboratory setting or even at home. In a study that compared video games and laparoscopy simulators for the development of laparoscopic skills among surgical trainees, those who were assigned to use the Xbox 360 (Microsoft Corp, Redmond, WA, USA) seemed to dedicate more time each week to gaming. This group and especially those who reported a history of playing video games showed the most substantial improvement in the tested peg transfer time (8). Regarding other kinds of techniques in surgical training, telesurgery permits remote mentoring. Telementoring permits the performance of laparoscopic procedures by less experienced surgeons under the supervision and guidance of expert surgeons (5).

It should be mentioned that simulation, VR, robotics, telemedicine, and gaming are not just emerging trends in surgical education. They now define the established benchmark for the development and assessment of surgical competence. According to Schmidt *et al.*, the future of surgical training lays not only on technical management of procedural events but also on surgeons' communication skills and their ability to educate their patients properly (9). Finally, hands-on and interactive educational experiences as well as simulation programs are crucial for the acquisition of procedural and decision-making skills. The ultimate goal is to create a training and assessment system that is both effective and adaptive, and this can best be achieved by incorporating intelligent technologies. This system should not only be tailored to learner's current skill level but also to adjust itself based on user's performance and identified shortcomings, as well as the rate of learner's progress (10). We present this article in accordance with the Narrative Review reporting checklist (available at https://ales.amegroups.com/article/view/10.21037/ales-24-4/rc).

Methods

A review of studies concerning laparoscopic suturing

Table 1 The search strategy summary

Items	Specification
Date of search	Dec 09 2023
Databases and other sources searched	NLM (PubMed), Scopus, Web of Science, LISTA (EBSCO), Library of Congress
Search terms used	"Laparoscopic suturing" or "Laparoscopic knot-tying" in title/abstract
Timeframe	No time restrictions
Inclusion criteria	Original studies, English language
Selection process	Conducted by E.T. and E.D. independently. Where consensus was not obtained P.M.L. resolved disagreement

training and VR simulation in surgical education was conducted. The authors independently performed the literature search, study selection, and data extraction. Databases that were accessed were NLM (PubMed), Scopus, Web of Science, LISTA (EBSCO) and the Library of Congress. Last search was performed on December 09 2023. Our search was limited to articles written in English that used the key terms "Laparoscopic suturing" or "Laparoscopic knot-tying" in the title or in the abstract of the publication. *Table 1* summarizes the search strategy.

VR simulation training

VR refers to a set of technologies that enable individuals to engage seamlessly with three-dimensional computerized databases in real-time, utilizing their innate senses and abilities (11). There are several forms of simulation used in surgical training. The least expensive comprises of mechanical simulators, or box trainers in which props such as 3D printed organs are positioned and manipulated using surgical instruments (12). This kind of simulation is ideal for the initial development of fundamental skills. On the other hand, computer-based simulators allow practicing on a spectrum starting from basic surgical skills and extending to more complex operations, requiring learners to make intraprocedural decisions through exposure to rarely encountered conditions (13). VR helps trainees develop psychomotor abilities and technical skills, and improve their proficiency in a wide range of procedures. It has been utilized in several fields including general surgery (14), orthopedic surgery (15), ear-nose-throat (ENT) surgery (16), neurosurgery (17), gynecology (18), urology (19), thoracic surgery (20) and plastic surgery (21).

VR simulation in surgical training offers a wide range of benefits, both for aspiring surgeons and experienced professionals. High-quality VR simulation can accurately replicate human anatomy. It enables multiple viewpoints including ones that are unattainable through the dissection of cadavers, enhancing understanding of spatial connections between anatomical structures (22). VR can also replicate a complete, fully equipped OR, encompassing personnel and equipment. It can even replicate stressful and immersive situations that can impact user's performance (23). In this way, it facilitates the transfer of both technical and non-technical skills, like management of anxiety and team coordination, from the virtual environment to the actual OR. According to a single-center prospective randomized controlled study, a structured and short-term curriculum using VR simulator improved the visuospatial ability (VSA) of novice medical trainees when compared to those who had not undergone any training (24). In the aforementioned study, it was demonstrated that individuals who initially had lower VSA levels were able to notably enhance their surgical skills and VSA scores following a structured 9-day VR training program. VSA is correlated positively with training progress and surgical performance, particularly for complex surgical tasks (24). Finally, the strong engagement and active participation fostered by VR, appear to enhance retention of the gained knowledge (22).

The question of whether practice on a simulator is translated to real-life surgical skills is crucial. A review of 34 studies found evidence that trainees who achieved proficiency through simulation-based training exhibited improved and quicker performance in patient-based assessment tasks when compared to those who did not undergo such training (25). These findings are in line with a meta-analysis conducted by Schmidt *et al.* (9) which demonstrated that performance on robotic simulators could be indicative of one's current technical abilities in the OR. However, skill transfer to OR is complex given several parameters related to patient-specific characteristics. The transferability of surgical skills from VR to the real OR involves several crucial variables, including the realism and accuracy of the VR simulation, the extent of pre-training, the diversity of covered tasks, as well as the quality of assessment tools and feedback provided during VR training. Optimizing these variables can enhance the transferability of skills to the real OR, ultimately benefiting patient outcomes and safety.

Laparoscopic suturing training

Laparoscopic surgery has proven to be a more patient-friendly alternative to open procedures as it offers benefits such as quicker recovery, shorter hospital stays and increased patient satisfaction (26). However, the complexity of laparoscopic suturing has impended its broader adoption. The challenging nature of laparoscopic suturing, due to factors like altered depth perception and counterintuitive movements, necessitates specialized training (26,27). Therefore, laparoscopic suturing training stands as a critical focal point in the evolution and widespread acceptance of minimally invasive surgery (MIS) (26). It is important to highlight that the lack of endoscopic suturing skills is responsible for long operation times in laparoscopic surgery as mentioned by Gabriel *et al.* (28). Extended surgical durations associated with suturing have been linked to negative outcomes such as a longer duration of anesthesia, postoperative nausea and vomiting, more thromboembolic events and postoperative infections, thus emphasizing the need of efficient laparoscopic suturing techniques (26). Hence, proficiency in laparoscopic suturing is essential to mitigate prolonged surgical duration, complications and errors, and therefore to enhance patient outcomes while simultaneously reducing healthcare costs (26).

Interestingly, prior experience in laparoscopic surgery does not appear to significantly impact the acquisition of laparoscopic suturing skills (29-31). All three studies, which reach this conclusion, utilized box trainers for their simulations (29-31). One study was carried on a box trainer with a porcine model, with vessels taken from the slaughterhouse (29), while the others utilized synthetic models, including a sponge foam with marked lines and a round white soft pad with black and red dots, both within box trainers (30,31). These studies have shown that surgeons with previous exposure to laparoscopic surgery and surgeons with very limited or no previous experience benefited at an equal level from training in laparoscopic suturing skills (29-31). A prospective study by Bansal *et al.* examined the impact of a short-term curriculum on the development of laparoscopic suturing skills, specifically following practicing on gastrojejunostomy on an animal model (29). The study examined the impact of previous exposure in laparoscopic surgery on the pace of development of suturing skills. According to reported results, during the first steps of the study, surgeons with experience in laparoscopic surgery demonstrated a faster learning pace. However, along progression of the curriculum, this difference of average duration of the procedure was attenuated. Therefore, laparoscopy-naïve surgeons seem to catch up with the suturing skills of laparoscopy-exposed surgeons, and the acquisition of basic laparoscopic skills is not necessarily a prerequisite for training in intracorporeal suturing (29,30).

There is an evident skill gap in laparoscopic suturing among surgical residents that emphasizes the need for training in order to shape proficient surgical skills and to ensure optimal patient care (30). A recent survey of Fellowship Council (FC) program directors in the United States found that up to 56% of graduating surgical trainees were not able to perform laparoscopic suturing (32). Additionally, a national survey conducted in the USA by Nepomnayshy *et al.*, pinpointed laparoscopic suturing as the most deficient skill among trainees at the end of residency training (33). Interestingly, these trainees identified laparoscopic suturing skills as the most crucial to master before completing fellowship training (33). This skill gap of laparoscopic suturing is due to visual and mechanical constraints of laparoscopic suturing training, the lack of a universal system for laparoscopic skills assessment and the debatable time needed for acquisition of this skill (30,34). Therefore, although laparoscopic suturing is a demanding task in the field of MIS, and training opportunities are usually reserved for experienced trainees, research studies highlight the need for wider delivery of relevant training programs (30).

A highly recommended approach to acquire laparoscopic suturing skills involves training on both inanimate and animate models in skill-laboratories, before attempting them in actual clinical practice (30). Improvements of laparoscopic suturing skills that were reported after a 3-day program of intensive training by Bansal *et al.*, included reduction in mean operative time and increase in the overall quality of anastomosis, based on a score accounting for anastomotic leak, size of anastomosis, suture placement and mucosal approximation (29). Moreover, trainees self-reported facing lower difficulty in laparoscopic gastrojejunostomy at the end of the course (29). As surgeons improve their skills, duration of operations decreases, eventually reaching a minimum level comparable to that of experts (29). Operation time is a significant parameter to assess the laparoscopic skills of a surgeon and therefore a primary goal of laparoscopic suturing training is to decrease the mean time of each exercise's execution after the training session (29,31). For example, in a cohort study by Sleiman *et al.*, it was shown that by using the suturing training and testing (SUTT) model, every surgeon, regardless of their laparoscopic surgery experience, could notably enhance their laparoscopic suturing skills and reduce the number of mistakes and the time needed to complete each exercise (31). Additionally, validated suturing exercises objectively demonstrated the improvement of each trainee in ambidextrous handling, suturing accuracy and knot-tying. Therefore, participants were also able to improve the quality of knot-tying.

One of the most important priorities when designing a skill training activity is optimizing the timing and duration of the activity. As mentioned earlier, according to Tang *et al.*, training in laparoscopic suturing is not commonly a component of core laparoscopic skills courses (30). However, there seemed to be no statistically significant correlation between the level of acquired basic laparoscopic skills and the level of acquired laparoscopic suturing skills. Therefore, it can be argued that laparoscopic suturing skills training should be introduced during the early stages of the specialty (30). This was contradicted by the same study, highlighting the need for an early introduction of laparoscopic suturing skills within surgical training programs (30). Until now, skills courses have primarily relied on the expertise of educator panels without considering input from surgical trainees (30). This lack of trainee involvement might explain why laparoscopic suturing has been excluded from basic skills courses. In the absence of such data, it is crucial to heed the opinions expressed by surgical trainees as highlighted in the study by Tang *et al.* (30). Trainees strongly advocate for earlier exposure to laparoscopic suturing, with 91% of senior trainees and 94% of junior trainees arguing that it should be included in the basic laparoscopic training course. This proves that surgery trainees want to learn and practice laparoscopic suturing earlier in their training and adequate preparation equips them for future opportunities in their field (30).

Regarding the duration of laparoscopic exercises, Tang *et al.* recommend a schedule of two consecutive half-days for optimal skill development. The ideal duration for practical laparoscopic suturing sessions varied between senior trainees, who had prior experience in laparoscopic suturing, and junior trainees, who had not yet practiced this skill. Among senior trainees, 77% preferred two half-days or one full day, while 58% of junior trainees believed that one half-day sufficed (30). Another study by Argay *et al.* compared 3-day *vs.* 1-day laparoscopic suturing courses. Both 3- and 1-day courses were found successful in improving laparoscopic suturing skills regardless of participants' experience. However, they suggested that experienced participants could benefit more from a longer course while the 1-day should be dedicated to pre-surgical competences acquisition. Hence, it was recommended that utilizing a short course can effectively introduce a greater number of less-experienced trainees to the complexities of laparoscopic suturing before they enter the OR. Conversely, the longer 3-day course appears better suited for more experienced surgeons, providing extended practice time that allows for the refinement of accuracy (34). In conclusion, Tang *et al.* recommend two consecutive half days, while Argay *et al.* suggest tailored durations for varying skill levels in laparoscopic suturing training.

There is evidence that laparoscopic suturing skills acquired by simulation training can be transferred to actual laparoscopic surgery (30,31). A survey conducted among urologists affirms the positive impact of hands-on laparoscopy training courses on the expansion of laparoscopic practice. Findings revealed that a majority, about 61% of participants, were able to enhance their clinical practice by incorporating intracorporeal suturing into laparoscopic urological procedures, thanks to the experience gained from these training sessions (30,35). In gynecology, institutions that ran standardized training programs, like the European Society for Gynaecological Endoscopy or the European Academy of Gynaecological Surgery which implements the SUTT model, advocate laparoscopic suturing as an essential part of surgical education, as mentioned in a similar study by Sleiman *et al.* (31). The SUTT model, a program with specific exercises and simulations designed to replicate the challenges of laparoscopic suturing, significantly improved surgeons' laparoscopic suturing ability, regardless of their level of experience in laparoscopic surgery (30,31).

VR simulation

Laparoscopic suturing training has seen a transformative shift with the emergence of VR simulation (36). VR platforms provide an immersive way to learn surgical procedures, but they have drawbacks. They are expensive and sometimes lack the essential tactile feedback, limiting their widespread accessibility (37). However, studies corroborate their effectiveness, proving them at least as valuable as traditional box trainers, in teaching suturing (38,39). While VR is costly and does not perfectly replicate real surgery, it is an evolving tool meeting the growing demand for learning laparoscopic suturing outside the OR (36).

Especially for laparoscopic suturing skills it is important that trainees experience haptic feedback when performing the task in VR simulation (38). The term 'haptic feedback' refers to the combination of tactile feedback through sensory skin receptors, and kinesthetic feedback through muscle, tendons, and joint sensory receptors (38). Botden *et al.* highlighted the pivotal role of haptic sensations in skill refinement, emphasizing its significance in tissue interaction and suturing material manipulation (38). The absence of realistic haptic feedback in many VR simulators is an important concern, limiting the transferability of skills to clinical settings (38). While high-fidelity simulations promise better training effects, incorporating efficient haptic sensations remains complex and challenging in VR systems (38).

Botden *et al.* emphasized the significance of informative feedback and goal setting in motivating trainees to practice extensively (40). Their study on the ProMIS Augmented Reality (AR) laparoscopic simulator's adapted suturing module (Haptica, Dublin, Ireland) concluded it was a potent tool for acquiring laparoscopic suturing skills (40). The distinction between intrinsic and extrinsic feedback was explained, with extrinsic feedback's role being highlighted in motivating trainees and facilitating goal achievement (40). The AR simulator was able to assess knot strength, offering valuable informative feedback on performance, which was deemed crucial since a well-tied knot is a principal goal in laparoscopic suturing training (40). Additionally, it measured "time spent in the correct area", displaying this information after each attempt, allowing trainees to identify and address problematic areas in achieving an optimal knot (40).

In 2008, Botden *et al.* highlighted the absence of haptic feedback in most VR simulators (38). Notably, recent studies provide insights into the advantages of achieving realistic haptic feedback in VR simulations (41,42). Shen *et al.* and Panait *et al.* highlighted the positive impact of haptic feedback on concentration, skill challenge, precision and overall performance in VR simulations (41,42). Considering the challenges outlined in these studies, it is crucial to explore potential avenues for enhancing haptic feedback in VR simulations. Technological intricacies, as reported by Våpenstad *et al.*, involve achieving mechanical transparency, updating frequencies and calculating virtual forces to simulate realistic haptic feedback (43). Panait *et al.* suggested that superior precision and performance can be achieved with advancements in haptic technology (42).

Future research should focus on enhancing the effectiveness and realism of haptic experiences. A crucial aspect involves refining haptic devices to provide more authentic sensations, addressing concerns about friction and mechanical transparency during movements (43). Additionally, optimizing the frequencies at which haptic feedback is delivered is essential to achieve genuine and stable sensations, contributing to a more immersive VR environment (43). Moreover, investigating the integration of biofeedback approaches could further contribute to the understanding of haptic feedback's role in enhancing skills acquisition and performance in VR environments (41).

The few studies performed on VR simulators with haptics have shown conflicting results regarding usefulness and transferability to the OR (44). Hagelsteen *et al.*'s study revealed a paradox. While laparoscopic VR simulators exhibit restricted fidelity in providing haptic feedback, they remarkably reduce stretch damage, endorsing their subtle yet impactful role in skill enhancement (44). Another study by Fu *et al.*, showed that the Virtual Basic Laparoscopic Skill Trainer Suturing Simulator (VBLaST-SS) is an effective tool for laparoscopic suturing skill development (45). Demonstrating training effectiveness and skill retention after a two-week gap, VBLaST-SS can be a feasible and transferable solution (45). While performance scores on both VBLaST-SS and traditional box trainers remained similar, the study suggested that the VBLaST-SS system holds promise for supporting suturing skill training, offering potential for widespread adoption in laparoscopic training programs (45).

The feasibility and transferability of laparoscopic suturing skills through VR simulations with haptic feedback have garnered mixed reviews (36). Rangarajan *et al.*'s study underlines the effectiveness of haptic-enhanced VR, showcasing reduced learning curves and faster skill acquisition among novices (36). However, the high cost of haptic simulators poses a barrier, demanding further cost-benefit analyses (36). On the other hand, VR simulation holds the advantage for solo training sessions without additional manpower (46). Kothari *et al.* compared the

Minimally Invasive Surgery Trainer in Virtual Reality (MIST-VR) with traditional laparoscopic training approaches and argued in favor of the equivalence of MIST-VR in intracorporeal suturing skill improvement (46). The MIST-VR's portability, self-sufficiency and detailed performance analysis underscore its feasibility as a transferable, effective, alternative suturing training simulator (46).

In a recent study by Elessawy *et al.*, the quality of VR simulation training was assessed, attaining high ratings for both realism and training efficacy (47). The study emphasized the positive impact on surgeons' real practice, showcasing improvements in laparoscopic suturing and operative time reduction (47). With participants recognizing the simulator's critical clinical relevance, VR simulation stands as an additive alternative, promising enhanced skills and maintaining enthusiasm in surgical training (47).

The studies mentioned above highlight the heterogeneity in developing educational tools for surgical skill acquisition, particularly in laparoscopic surgery. They reflect diverse approaches and evaluations regarding the effectiveness of training in VR environments for learning surgical skills, such as laparoscopic suturing (36,38,44,45). Most of them emphasize the significance of acquiring haptic feedback for effective training in laparoscopic suturing (36,38,44). Botden *et al.* and Qi *et al.* emphasized the importance of haptic feedback but also noted the complexity in implementing it effectively in VR systems for laparoscopic suturing training (38,48). Rangarajan *et al.* demonstrated the effectiveness of haptic-enhanced VR simulation in skill training, but also the need for further research and cost-benefit analyses due to the complexities and costs associated with haptic simulators (36). Additionally, Hagelsteen *et al.* discussed the limitations in the fidelity of haptic feedback in VR simulators despite showing improved performance with haptics enabled (44). The development of VR simulations with high-quality haptic feedback is deemed crucial but remains challenging due to its complexity in implementation (36,38,44).

The examples provided underscore the necessity for evidence-based curricula in laparoscopic suturing training. Efforts to integrate technology, enhance haptic feedback, and evaluate VR simulator effectiveness are crucial (36,38,44,45). These studies collectively contribute to understanding the challenges and advancements in laparoscopic suturing training methodologies, emphasizing the gaps that exist and the pressing need for evidence-based approaches (36,38,44,45).

Traditional box trainers in laparoscopic suturing training

Despite the advancements in VR training technology, traditional box trainers persist as essential tools in laparoscopic suturing skill development. Box trainers are evidently effective and efficient in developing skills that translate into improved operative performance (49). Due to laparoscopy's long-learning curve and high cost of VR simulation, box trainers are widely available to train laparoscopic skills (49). Lamture *et al.* have proven that short-term, intensive, focused courses using box trainers improved the laparoscopic suturing skills of surgical trainees (49). There was a statistically significant improvement in the mean training score of laparoscopic suturing exercises after 6 months of using box trainers (49). Similar results were observed in studies done by Sihombing *et al.* and Dhariwal *et al.* indicating an improved post-training score when practicing in box trainers (50,51).

Korndorffer's study suggested that even home box training is effective and led to better laparoscopic suturing skill retention compared to standard simulation center training (52,53). It is also interesting that Sellers' study highlighted the significance of low-cost laparoscopic skill training using DIY box trainers, addressing cost barriers and providing medical students with an affordable means to experience laparoscopy including laparoscopic suturing (54). Therefore, low-cost training box outside the operating theater can improve laparoscopic suturing skills and give trainees the opportunity to practice efficiently the procedures until competency is achieved without exposing the live patient to undue risk (49). Pelvic trainer, another inanimate model similar to box trainers, has demonstrated its effectiveness in enhancing laparoscopic suturing skills (55,56). They offer a cost-effective and robust tool for gynecology residents to develop essential laparoscopic skills (56). Teber's study emphasizes its efficacy of utilizing specially designed tasks for reconstructive laparoscopy, even in the most intricate aspects like intracorporeal suturing. Adept manipulation of needle-holder and optimal needle angle mounting can be effectively acquired through this training method (55). *Table 2* summarizes the key topics and respective current knowledge on laparoscopic simulation training, based on current literature.

Strengths and limitations

This research represents a narrative review. Narrative reviews are well-suited for exploring new and emerging areas—such as virtual simulation in surgical education—where systematic data

Table 2 Central summarizing table: summary of included studies

Topic	Summary/key aspects	Studies/references
VR simulation training	Simulation types: mechanical, computer-based and VR simulations in surgical training	(12-21)
	Advantages: VR simulations offer benefits in surgical training, including accurate replication of human anatomy, providing multiple viewpoints not achievable through cadaver dissection, and simulating a complete operating room environment	(22-25)
Laparoscopic suturing training	Challenges faced in laparoscopic suturing training: altered depth perception, counterintuitive movements	(26-34)
	Impact of prior experience on suturing skills acquisition: both laparoscopy-exposed and laparoscopy-naïve surgeons improved skills, previous exposure to laparoscopic surgery does not necessarily confer an advantage in acquiring suturing skills	(29,30)
	Identification of skill gap among surgical residents and the need for training in laparoscopic suturing	(30,32,33)
	Recommendations for optimal timing and duration of suturing training sessions: evidence suggests that the optimal timing and duration of suturing training sessions vary	(29-31,34)
VR simulation in laparoscopic suturing training	Role and challenges of VR in laparoscopic suturing training regarding haptic feedback realism and skill transferability to real-world settings	(36-39)
	Challenges in achieving realistic haptic feedback in VR simulations for laparoscopic suturing training include addressing mechanical transparency, updating frequencies and calculating virtual forces, highlighting the need for advancements in these areas	(38,40-43)
	While some studies suggest the feasibility and effectiveness of VR training in laparoscopic suturing compared to traditional methods, there exists heterogeneity in the research field, with varying findings and perspectives on its efficacy	(44-47)
Box trainers	The effectiveness of traditional box trainers in laparoscopic suturing training has been evidenced in multiple studies, highlighting their persistent efficacy in skill development	(49-56)

VR, virtual reality.

may be limited, allowing researchers to generate hypotheses and identify gaps in knowledge. Our study provides a comprehensive overview of virtual simulation in laparoscopic suturing and knot-tying training. Simultaneously, it suggests potential training objectives within the curriculum for surgical trainees as summarized in *Figure 1*.

However, narrative reviews are less methodologically structured compared to systematic reviews, as they do not necessitate a search of all literature within a particular field. This could lead to variability in inclusion criteria, search methods, and data extraction, ultimately impacting the reliability of the conclusions. Additionally, narrative reviews are susceptible to the author's subjective interpretation and selection bias, limiting the reproducibility of the study.

Conclusions

Laparoscopic suturing skills necessitate innovative training tools and technological advancements to bridge the skill gap among surgical trainees. Within surgical education, VR simulators stand as a transformative tool, particularly in training for laparoscopic suturing. These simulations simplify complex information, reduce distractions, and actively engage trainees, addressing the cognitive overload which is often present in surgical learning environments. As part of the technological revolution in surgical education, VR offers accessible, personalized and realistic platforms for acquiring laparoscopic suturing skills outside the OR. It is now clear that tailored training durations, early exposure, and trainee involvement significantly improve the effectiveness of laparoscopic suturing training. While demonstrating potential in improving VSA and knowledge retention, VR simulations face challenges in replicating realistic haptic feedback, which is crucial for refining laparoscopic suturing skills. With the view of achieving the promising transformative full potential of VR simulations, the way forward requires efforts to enhance haptic feedback realism, develop evidence-based curricula, and comprehensively evaluate simulator effectiveness. The continued evolution of VR stands to revolutionize

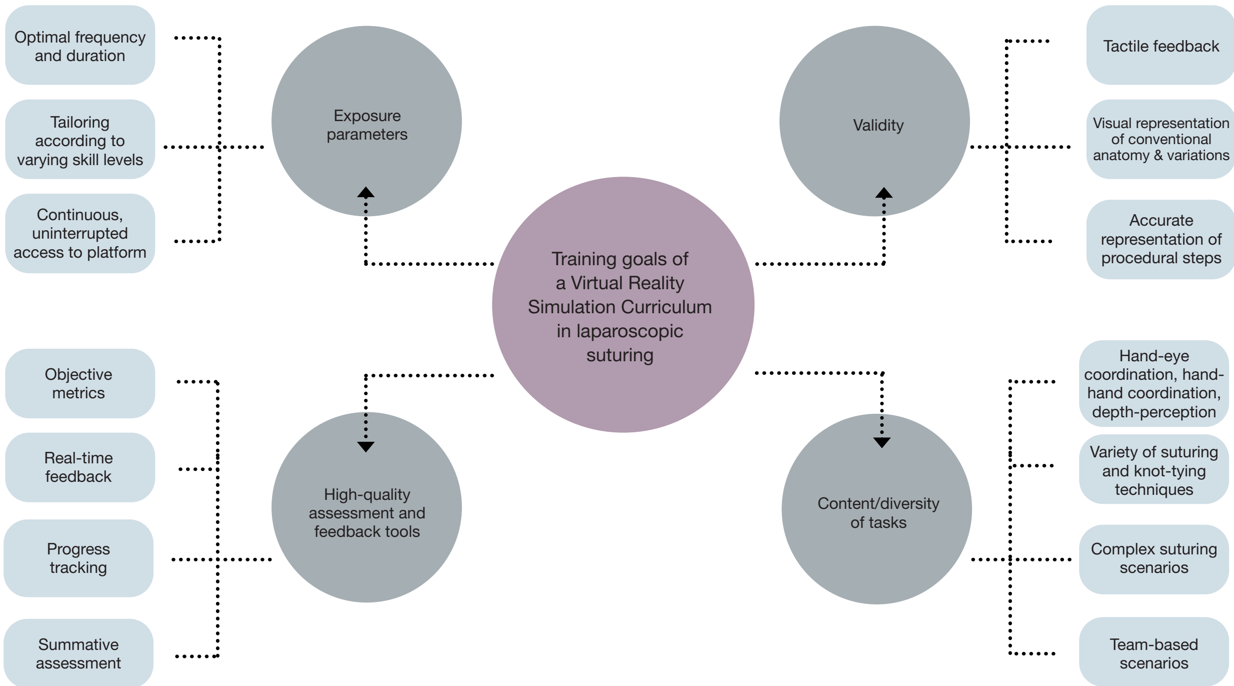

Figure 1 Graphic presentation of key domains and specific areas of a virtual reality simulation curriculum in laparoscopic suturing.

laparoscopic suturing training, potentially ensuring safer, more proficient, and patient-friendly minimally invasive surgical procedures in the future.

Acknowledgments

Funding: None.

Footnote

Reporting Checklist: The authors have completed the Narrative Review reporting checklist. Available at https://ales.amegroups.com/article/view/10.21037/ales-24-4/rc

Peer Review File: Available at https://ales.amegroups.com/article/view/10.21037/ales-24-4/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://ales.amegroups.com/article/view/10.21037/ales-24-4/coif). P.M.L. serves as an unpaid editorial board member of *Annals of Laparoscopic and Endoscopic Surgery* from November 2023 to October 2025, and reports that he received grants from the ScholarRx, lecture payment by MSD, educational event payment by Johnson & Johnson, and support by Medtronic for attending training workshop. The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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doi: 10.21037/ales-24-4
Cite this article as: Akritidou E, Lykoudis PM, Nastos C, Dellaportas D, Pararas N, Papaconstantinou D, Theofilogiannakou E, Davoutis E, Giannou AD, Pikoulis E. Virtual reality simulation training in laparoscopic suturing and knot-tying: a narrative review. Ann Laparosc Endosc Surg 2024.

