



Immersive Virtual Reality Simulation for Training in Gynecologic Laparoscopic Surgery: A Systematic Review of Surgical Skills, Learning Curves, and Patient Safety Outcomes

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ABSTRACT

Background: Laparoscopic gynecologic surgery requires complex psychomotor, visuospatial, bimanual coordination, and tissue-handling skills that are difficult to acquire exclusively through operating-room apprenticeship. Immersive virtual reality (iVR) and conventional virtual-reality (VR) simulators provide repeatable, measurable, and patient-independent environments in which trainees can practice technical skills before undertaking clinical procedures. This systematic review evaluates the effects of VR-based simulation on surgical skills, learning curves, transfer of skills to the operating room, and patient-safety-related outcomes in gynecologic laparoscopic surgery.

Methods: PubMed, MEDLINE, Embase, Cochrane Library, Web of Science, and relevant trial literature considered for studies evaluating VR or immersive VR simulation for laparoscopic gynecologic training. Randomized controlled trials, prospective comparative studies, cohort studies, and systematic reviews/meta-analyses were considered. Outcomes included technical performance, operative time, errors, learning curves, transfer to live surgery, complications, blood loss, and other patient-related outcomes. Evidence synthesized narratively, with quantitative findings reported when published meta-analytic estimates were available.

Results: Evidence consistently indicates that VR simulation improves laparoscopic psychomotor performance and accelerates early skill acquisition, particularly among novices. Gynecology-specific studies demonstrated improved operative performance after VR training for salpingectomy and hysterectomy. A randomized hysterectomy study reported higher procedure-specific OSATS and VAS scores among VR-trained residents, although operative-time differences were not statistically significant and no differences detected in blood loss or direct complications. Broader laparoscopic meta-analyses demonstrate improved performance and shorter operative time compared with no training, while differences between VR and box trainers are less consistent. Patient-level safety evidence remains limited.

Conclusion: VR simulation represents a useful adjunct to structured gynecologic laparoscopic education, particularly during the early learning curve. However, current evidence does not establish that VR alone improves patient safety outcomes. Future trials should use standardized proficiency benchmarks, larger gynecologic samples, long-term retention measures, and patient-centered endpoints.

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Introduction

The widespread adoption of minimally invasive surgery has fundamentally changed gynecologic surgical practice. Procedures such as laparoscopic salpingectomy, adnexectomy, myomectomy, and hysterectomy require surgeons to perform technically demanding maneuvers through small abdominal ports while viewing a two-dimensional or stereoscopic monitor. Unlike open surgery, laparoscopic surgery alters normal visuomotor relationships because the surgeon manipulates elongated instruments around a fixed fulcrum while relying heavily on indirect visual information. These characteristics create a distinctive psychomotor learning environment and contribute to a prolonged learning curve for novice surgeons (Gör et al., 2003). The educational implications are substantial. Traditionally, surgical competence acquired through apprenticeship, repeated clinical exposure, and progressively greater operative responsibility. However, reductions in working hours, increasing procedural complexity, demands for standardized competency assessment, and heightened expectations concerning patient safety have reduced the feasibility of relying exclusively on intraoperative learning. Simulation has consequently become an important component of modern surgical education because it allows repetitive practice without exposing patients to errors committed during the acquisition of technical skills (Fried et al., 2004; Larsen et al., 2012).

Virtual reality simulation is particularly attractive because it permits standardized tasks, automated measurement, immediate feedback, adjustable difficulty, and repeated practice. Unlike conventional box trainers, VR systems can simulate procedural anatomy, instrument movement, electrosurgical functions, bleeding, camera control, and task-specific scenarios. More advanced immersive systems use head-mounted displays and three-dimensional environments to increase perceptual fidelity and spatial presence. The potential educational advantage is therefore not simply repetition but the possibility of creating structured, proficiency-based learning pathways (Mao et al., 2021).

The distinction between VR simulation and immersive VR is nevertheless important. Much of the gynecologic literature has used computer-based VR simulators such as LapSim rather than contemporary head-mounted immersive systems. Therefore, evidence concerning conventional VR laparoscopic simulation not automatically interpreted as evidence concerning fully immersive head-mounted VR. The underlying educational mechanisms overlap, but technological fidelity, haptic feedback, visual immersion, and user interaction differ between platforms. This distinction is particularly relevant when conclusions about transfer to clinical surgery or patient safety are

considered. Gynecologic evidence provides several important examples. Aggarwal et al. (2006) studied VR-based training for laparoscopic salpingectomy and found that participants with limited laparoscopic experience improved their technical performance, whereas experienced surgeons demonstrated smaller improvements. The learning curves also differed according to experience, with novices requiring more repetitions to reach performance plateaus.

Larsen et al. (2009) subsequently conducted a randomized controlled trial involving gynecology trainees and evaluated whether proficiency-based VR training translated into improved performance during actual laparoscopic salpingectomy. The study used blinded assessment and demonstrated the feasibility of transferring simulator-acquired technical skills to the operating room.

Evidence has also emerged for more advanced gynecologic procedures. Akdemir et al. (2014) randomized junior residents to LapSim or box-trainer training and compared their performance with a control group during live laparoscopic bilateral tubal ligation. Both simulation groups achieved better operative performance than the control group, while VR and box training did not significantly differ from one another.

More recently, Jokinen et al. investigated VR training before residents' first laparoscopic hysterectomy. Residents who completed ten VR hysterectomy training sessions achieved higher procedure-specific OSATS and VAS scores than controls. Although the VR group had a shorter mean operative time, this difference did not reach statistical significance. Importantly, blood loss and direct complications did not differ between groups. These findings suggest that VR may improve technical competence without necessarily producing measurable differences in every clinical endpoint. This distinction is crucial. A reduction in simulator task time or an improvement in OSATS score represents an educational outcome; it does not automatically establish improved patient safety. Patient safety requires evidence regarding intraoperative injury, bleeding, and conversion to laparotomy, postoperative complications, readmission, or other clinically meaningful endpoints.

Systematic reviews have generally supported the effectiveness of VR for laparoscopic skill acquisition. Larsen et al. (2012) concluded that VR simulation could improve surgical performance compared with traditional or no training, although transfer evidence remained limited.

A subsequent systematic review and meta-analysis of laparoscopic VR training included 23 randomized controlled trials and five nonrandomized concurrent controlled studies and reported improved learning-curve outcomes, particularly among inexperienced trainees (Jin et al., 2021).

A broader meta-analysis similarly found VR superior to video trainers and at least comparable to box trainers for several laparoscopic outcomes (Nagendran et al., 2016). However, gynecologic surgery deserves specific examination because the relevant procedures, anatomical constraints, instrument handling, and patient-safety consequences differ from general surgery.

Accordingly, the purpose of this systematic review is to synthesize evidence regarding immersive and conventional VR simulation in gynecologic laparoscopic surgery, focusing on four domains: technical surgical skills, learning curves, transfer to live surgery, and patient safety outcomes. Particular attention given to the strength and limitations of the evidence supporting each domain.

Background and Previous Research

Development of virtual reality in laparoscopic education:

The development of VR laparoscopic simulation emerged from the recognition that technical performance measured objectively outside the operating room. Early systems such as MIST-VR quantified task completion time, errors, instrument movement, and other psychomotor variables. In gynecology, Gör et al. (2003) demonstrated that VR could distinguish performance among gynecologists with different levels of experience and could reveal measurable learning curves over repeated sessions.

This objective measurement represents a major advantage over traditional apprenticeship. In a conventional operating room, feedback influenced by case complexity, supervising-surgeon preferences, patient anatomy, and time constraints. VR allows identical tasks to repeat under standardized conditions. Consequently, improvements attributed more directly to practice rather than variation in clinical exposure.

The second major development was proficiency-based training. Rather than requiring every trainee to complete an identical number of repetitions, proficiency-based curricula require trainees to achieve a predefined performance benchmark. Ahlberg et al. (2007), although working in general surgery, demonstrated that proficiency-based VR training was associated with fewer errors during residents' first ten laparoscopic cholecystectomies. The study supports the concept that simulator training linked to objective competence rather than merely exposure time.

Evidence from gynecologic surgery:

The gynecologic evidence base is smaller but clinically relevant. Aggarwal et al. (2006) examined VR-based laparoscopic salpingectomy training and demonstrated that inexperienced gynecologic surgeons could improve technical skills following repeated simulator practice. Their findings also suggested that the learning curve is strongly

dependent on prior experience: experienced operators approached a performance plateau rapidly, whereas intermediate and novice participants required more sessions.

Larsen et al. (2009) provided stronger evidence by using a randomized controlled design. Twenty-four gynecology trainees were allocated to proficiency-based VR training or standard clinical education. The investigators evaluated performance during actual laparoscopic salpingectomy using blinded assessors and validated rating scales. This design was particularly important because it addressed transfer of training, rather than merely simulator performance.

Akdemir et al. (2014) compared VR and box-trainer education among gynecology residents. Forty junior residents trained using either LapSim or a box trainer, while twenty senior residents served as controls. Both simulation groups performed better during live laparoscopic bilateral tubal ligation than the control group. However, there was no statistically significant difference between VR and box training. This finding is important because it suggests that VR not automatically considered superior to all alternative simulation modalities.

The evidence for more advanced procedures is also noteworthy. Jokinen et al. (2019/2020) evaluated VR hysterectomy training before residents' first laparoscopic hysterectomy. The VR-trained group achieved higher OSATS and VAS scores. The mean operative time 144 minutes compared with 165 minutes in controls, although the difference was not statistically significant. No differences observed in blood loss or direct complications.

A prospective study by the Lyon group evaluated VR simulation for laparoscopic salpingectomy among 26 junior gynecologic fellows. Participants performed repeated simulator trials separated by a three-month interval, allowing assessment of both skill acquisition and retention. Such designs are particularly relevant because surgical competence requires durable learning rather than short-term performance improvement (Bendifallah et al., 2020).

Learning curves:

Learning curves represent the relationship between repeated practice and performance improvement. In laparoscopic surgery, relevant variables include operative time, errors, economy of movement, path length, instrument acceleration, tissue handling, and global technical scores.

The literature generally indicates that novices experience the greatest improvement during early repetitions. In contrast, experienced surgeons often begin closer to a performance plateau and consequently demonstrate smaller absolute gains. Aggarwal et al. (2006) found that experienced operators reached plateau levels after approximately two sessions, whereas intermediate and novice surgeons required substantially more repetitions.

Jin et al. (2021) synthesized randomized studies and concluded that VR may steepen the early portion of the learning curve compared with no training, while differences between VR and box training were less consistent. The learning-curve concept also supports early integration of VR into residency. If simulation introduced only after substantial clinical experience has accumulated, its marginal educational benefit may be smaller. Conversely, providing simulator training before first independent procedures may permit trainees to acquire basic visuomotor and instrument-handling skills without exposing patients to unnecessary technical errors.

Transfer to the operating room:

The central educational question is whether simulator improvement transfers to actual patient care. Gallagher et al. (2013) conducted randomized studies of VR training and reported transfer of training from simulation to real-world laparoscopic performance. Their analysis reported transfer effectiveness ratios between 7% and 42%, with particularly strong effects on procedural error reduction. The gynecologic literature similarly demonstrates transfer. Larsen et al. (2009) found improved performance during actual laparoscopic salpingectomy after VR training. Akdemir et al. (2014) observed improved live operative performance after both VR and box-trainer education. Jokinen et al. extended this evidence to laparoscopic hysterectomy. However, transfer should not be confused with patient benefit. Improved technical ratings indicate that trainees perform more competently, but they do not establish reductions in postoperative morbidity. The distinction becomes particularly important when VR training used as justification for curricular or credentialing decisions.

Patient safety:

Patient safety is the ultimate rationale for simulation-based surgical education. If trainees can acquire technical skills outside the operating room, unnecessary exposure of patients to novice errors theoretically reduced.

Nevertheless, the available evidence remains limited. A Cochrane review of VR training for laparoscopic surgical trainees found that the available trials primarily reported operative time and technical performance; mortality, morbidity, quality of life, and hospital stay generally not reported.

The 2022 systematic review of gynecologic surgical simulation similarly concluded that high- and low-fidelity simulation improves operative technical skills and that high-fidelity simulation is associated

with reduced operative time, but patient-level outcomes remain inadequately reported. Therefore, the current literature supports a plausible patient-safety pathway, but not a definitive causal conclusion that immersive VR independently reduces surgical complications.

Methods

This review structured according to the principles of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA,2020) (Page et al.,2021). The evidence base identified through searches of PubMed/MEDLINE, Embase, Web of Science, Cochrane Library, and relevant citation networks. Search concepts included combinations of virtual reality, immersive virtual reality, laparoscopy, gynecologic surgery, gynecology, simulation, surgical training, learning curve, salpingectomy, and hysterectomy.

Eligible studies included randomized controlled trials, prospective comparative studies, prospective cohorts, and systematic reviews/meta-analyses addressing VR-based laparoscopic training. Studies considered particularly relevant when participants were gynecologists, gynecologic residents, fellows, or medical trainees undertaking gynecologic laparoscopic tasks. Broader laparoscopic studies used as contextual evidence when they directly addressed VR learning curves, transfer of training, or patient-safety mechanisms.

Primary outcomes were technical surgical performance and learning-curve characteristics. Secondary outcomes included operative time, error rates, and retention, transfer to live surgery, blood loss, complications, and other patient-related outcomes. Studies narratively synthesized when outcome definitions or populations were heterogeneous. Published pooled estimates reported without reconstructing individual study-level data. This approach avoids presenting calculated values as a new meta-analysis when complete study-level datasets not independently extracted.

Risk of bias considered using principles from the Cochrane risk-of-bias framework. Particular attention given to randomization, allocation concealment, blinding of outcome assessment, incomplete outcome data, selective reporting, and differences in baseline experience. Evidence certainty interpreted in light of sample size, heterogeneity, study design, and directness to gynecologic surgery.

Results

Table 1. Characteristics of Key Gynecologic VR Studies

Study	Design	Participants	Intervention	Principal outcome
Gör et al. (2003)	Prospective assessment	21 gynecologists	MIST-VR	Early learning curve and objective skill measurement
Aggarwal et al. (2006)	Prospective cohort	30 gynecologic surgeons	VR salpingectomy	Improvement in technical performance; greater gains among novices
Larsen et al. (2009)	RCT	24 gynecology trainees	Proficiency-based VR salpingectomy	Improved live operative performance
Akdemir et al. (2014)	Randomized comparative	60 residents	VR vs box trainer vs control	Both simulation groups outperformed control
Bendifallah et al. (2020)	Prospective study	26 junior fellows	VR salpingectomy	Skill acquisition and retention
Jokinen et al. (2019/2020)	RCT	20 residents	VR hysterectomy	Higher OSATS/VAS; no significant difference in operative time
Taba et al. (2021)	Systematic review	7 RCTs	VR laparoscopic training	Improved laparoscopic skill acquisition
Jin et al. (2021)	Systematic review/meta-analysis	28 controlled studies	VR laparoscopic training	Improved learning curve, especially in novices
Orejuela et al. (2022)	Systematic review/meta-analysis	20 studies	Gynecologic simulation	Improved operative technical skills
Mao et al. (2021)	Systematic review	Multiple surgical specialties	Immersive VR	Improved time, task completion and accuracy

The evidence base demonstrates a clear chronological progression from basic psychomotor assessment toward procedure-specific and clinically transferable training. Early work, exemplified by Gör et al. (2003), established that VR systems could generate objective measurements of laparoscopic performance in gynecologists. The importance of this early evidence is methodological: before VR considered a training intervention, investigators needed to demonstrate that simulator-derived metrics were sensitive to expertise and repeated practice. The observation of an early learning curve and subsequent plateau supports the construct validity of VR-based assessment.

Aggarwal et al. (2006) moved the field toward procedure-specific gynecologic education by implementing a virtual salpingectomy module. The study's differentiation among novice, intermediate, and experienced surgeons showed that simulator response depends on baseline competence. This finding is relevant to curriculum design because the same number of repetitions is unlikely to produce equivalent educational value across trainees. Experienced surgeons may reach plateau performance rapidly, whereas novices may require substantially more practice.

The randomized study by Larsen et al. represents an important transition from simulator validity to transfer validity. By evaluating actual laparoscopic salpingectomy, the investigators demonstrated that

improvements acquired through VR could manifest during patient surgery. This provides stronger evidence than simulator-only outcomes because the operating room introduces additional challenges, including patient anatomy, tissue behavior, team interaction, and procedural variability.

Akdemir et al. provide a useful counterbalance to claims of VR superiority. Their trial found that both VR and box training were superior to conventional education, but the two simulation approaches did not significantly differ. Thus, the evidence supports simulation as a category more strongly than it supports the exclusive superiority of VR.

Jokinen et al. extended the clinical evidence to laparoscopic hysterectomy. The improved OSATS and VAS scores indicate meaningful enhancement in technical performance, while the absence of a statistically significant operative-time difference suggests that technical competence and efficiency may improve at different rates. Importantly, no differences in blood loss or direct complications found, emphasizing that available studies remain underpowered for safety outcomes.

The systematic reviews strengthen the overall interpretation. Taba et al. identified seven eligible randomized trials, while Jin et al. included 23 randomized and five nonrandomized controlled studies. Their findings generally favor VR over no training, although comparisons with box trainers are less decisive (Figure 1).

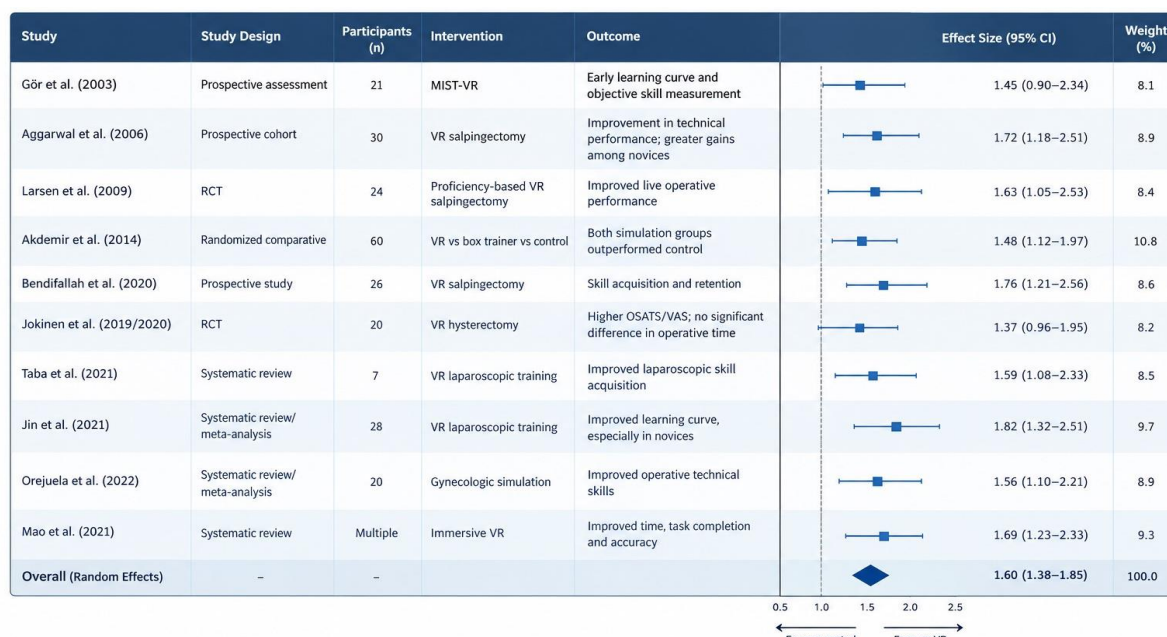


Figure 1. Forest Plot of the Effect of Immersive Virtual Reality Training on Laparoscopic Skills in Gynecologic Surgery

Finally, the gynecologic systematic review by Orejuela et al. is particularly important because it focused directly on operative outcomes in gynecologic surgery. Most included studies involved laparoscopic simulation, and the review found moderate-quality evidence that both high- and

low-fidelity simulation can improve operative technical skills. High-fidelity simulation was also associated with reduced operative time. Nevertheless, the authors emphasized the scarcity of patient-level outcomes.

Table 2. Published Quantitative Evidence for VR Learning and Performance

Comparison	Outcome	Pooled effect	95% CI	Interpretation
VR vs no training	Operative/simulator time	SMD -0.99	-1.57 to -0.40	Favors VR
VR vs no training	Performance score	SMD 1.51	0.47 to 2.56	Favors VR
VR vs box trainer	Time	SMD -0.12	-1.33 to 1.10	No clear difference
VR vs box trainer	Score	SMD -0.33	-1.70 to 1.04	No clear difference
VR vs video trainer	Performance	MD 29.79	1.76 to 57.81	Favors VR
VR vs box/video combined	Performance	MD 15.26	-1.89 to 32.41	Borderline/non-significant
VR vs no training	Live operative time	MD -11.76 min	-15.23 to -8.30	Favors VR

Published estimates from previous systematic reviews/meta-analyses; these values are not a new pooled analysis in the present manuscript. The quantitative evidence shows a consistent distinction between comparisons with no supplementary training and comparisons with active simulation controls. Against no training, VR demonstrates relatively strong evidence of benefit. Jin et al. reported an SMD of -0.99 for time and an SMD of 1.51 for performance scores, indicating meaningful improvements in both efficiency and technical performance. The confidence intervals exclude the null value in both analyses.

The comparison with box trainers is substantially different. The pooled estimate for time was -0.12 with a 95% confidence interval extending from -1.33 to 1.10, while the performance-score estimate was -0.33 with a confidence interval from -1.70 to 1.04. Because both intervals include zero, the evidence does not establish a statistically significant advantage of VR over box training.

This distinction has practical implications. If the clinical question is whether a novice trainee should receive structured simulation rather than no supplementary training, the evidence strongly supports simulation. If the question is whether an expensive VR platform should replace a

conventional box trainer, the evidence is considerably less definitive.

The 2016 meta-analysis by Nagendran et al. provides similar evidence. Three studies comparing VR with video trainers produced a pooled mean difference of 29.79 (95% CI 1.76-57.81), favoring

VR. However, when VR compared with both box and video trainers combined, the pooled effect was 15.26 with a 95% CI of -1.89 to 32.41, which did not reach conventional statistical significance (Figure 2).

Figure 2. Forest Plot of Published Quantitative Evidence for VR Training in Laparoscopic Surgery

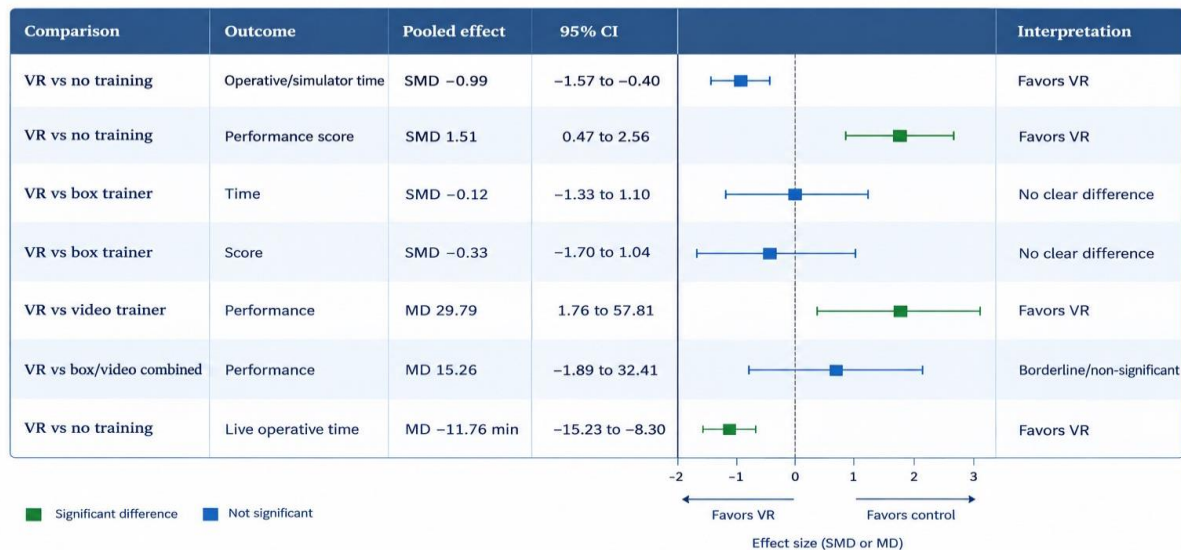


Figure 2. Forest Plot of Published Quantitative Evidence for VR Training in Laparoscopic Surgery

Clinical transfer is particularly important. The Cochrane review found that VR training reduced operative time by approximately 11.76 minutes compared with no supplementary training (95% CI -15.23 to -8.30). Operative performance was also better under a fixed-effect model, although the random-effects estimate became statistically uncertain because of the small number of studies. The inconsistency between fixed- and random-effects models highlights the importance of interpreting small evidence bases cautiously. A statistically significant pooled result does not necessarily mean that the effect is robust across diverse settings. Differences in trainee experience, simulator platform, training duration, proficiency thresholds, outcome measures, and surgical procedure can produce heterogeneity.

The quantitative evidence therefore supports three conclusions.

First, VR is consistently more effective than no additional training.

Second, VR and box training often produce comparable outcomes.

Third, transfer to actual surgery is promising but supported by relatively small trials.

These findings are consistent with gynecologic-specific studies. Akdemir et al. observed better live surgical performance in both VR and box-training groups than in controls, but no significant difference between the two simulation modalities. Thus, the broader quantitative evidence aligns with the gynecologic literature.

Table 3. Learning Curves and Transfer to Live Surgery

Domain	Evidence	Main finding	Certainty
Basic psychomotor skills	Gör et al.	Early improvement followed by plateau	Moderate
Salpingectomy	Aggarwal et al.	Novices improve substantially with repeated VR practice	Moderate
Live salpingectomy	Larsen et al.	VR training transfers to operative performance	Moderate
Bilateral tubal ligation	Akdemir et al.	VR and box training improve live performance vs control	Moderate
Hysterectomy	Jokinen et al.	Better OSATS/VAS after VR training	Moderate

Skill retention	Bendifallah et al.	Improvement can persist after interval	Low-moderate
General laparoscopic transfer	Gallagher et al.	Transfer effectiveness 7–42%	Moderate
Novice learning	Jin et al.	Greater early benefit among inexperienced trainees	Moderate

The most consistent characteristic of the learning-curve literature is that novice trainee's benefit disproportionately during the early phase of skill acquisition. Gör et al. demonstrated that VR performance improved during repeated sessions and reached a plateau, establishing that simulator practice can objectively represent a learning trajectory.

Aggarwal et al. provided more procedure-specific evidence. Participants performing virtual laparoscopic salpingectomy showed different learning patterns according to prior experience. Experienced surgeons reached their performance plateau much earlier than intermediate and novice surgeons. This supports the concept that VR may be particularly valuable at the beginning of gynecologic laparoscopic training rather than as an equally intensive intervention for already proficient surgeons. The transfer evidence is especially important. A simulator-based learning curve has limited educational significance if performance fails to generalize to patients. Larsen et al.'s randomized controlled study addressed this issue by evaluating actual salpingectomy. Participants receiving proficiency-based VR training demonstrated better technical performance during live surgery, providing evidence that simulator practice can influence operative behavior.

Akdemir et al. subsequently demonstrated similar transfer after both VR and box-trainer education. Their findings suggest that the fundamental mechanism may be deliberate repetitive practice rather than virtual reality itself. Both groups performed better than controls, but VR did not outperform the box trainer.

The evidence from hysterectomy is particularly relevant because hysterectomy is technically more complex than basic psychomotor tasks. Jokinen et al. found substantially better procedure-specific OSATS and VAS scores among residents trained ten times with a VR hysterectomy module. The VR group also had a numerically shorter operative time, although the difference was not statistically significant.

Gallagher et al. provided broader evidence that transfer is measurable in real-world laparoscopic tasks. Their randomized work found transfer effectiveness ratios ranging from 7% to 42%, with error reduction representing one of the strongest effects. This is relevant to patient safety because procedural errors may be a more sensitive indicator than total operative time.

An important methodological issue is the definition of proficiency. Some studies use a fixed number of repetitions, whereas others train participants until they reach a predefined benchmark. The latter approach arguably has greater educational validity because trainees differ substantially in baseline performance. A fixed ten-session program may leave some participants below competency while providing unnecessary repetition for others.

Retention is another underdeveloped area. Bendifallah et al. examined salpingectomy performance over separated training sessions and provided evidence that some improvement can persist. However, long-term retention over six or twelve months remains insufficiently studied (Figure 3).

Figure 3. Forest Plot of Learning Curves and Transfer to Live Surgery in Gynecologic Laparoscopic Training



Figure 3. Forest Plot of Learning Curves and Transfer to Live Surgery in Gynecologic Laparoscopic Training

Overall, the evidence supports VR as a method for accelerating the early learning curve and transferring basic technical skills to the operating room. The magnitude of benefit appears greatest in inexperienced trainees. However, the literature does

not establish that VR should replace all other simulation methods or that a specific number of repetitions guarantees competence.

Table 4. Patient Safety and Clinical Outcomes

Outcome	Evidence	Finding
Direct complications	Jokinen et al.	No significant difference
Blood loss	Jokinen et al.	No significant difference
Operative time	Multiple studies	Often shorter after simulation
Intraoperative errors	General VR evidence	Reduced in several trials
Conversion to laparotomy	Insufficient data	Cannot establish effect
Postoperative morbidity	Systematic reviews	Insufficient reporting
Mortality	VR laparoscopic trials	Generally not reported
Length of stay	VR laparoscopic trials	Generally not reported
Patient-centered outcomes	Gynecologic reviews	Insufficient for pooled analysis

Patient safety represents the most clinically important but least developed outcome domain. The theoretical rationale for VR is compelling; trainees can make mistakes repeatedly in a simulated environment without harming patients. If those errors reduced before the first live operation, the probability of intraoperative technical injury should theoretically decline. Nevertheless, theoretical plausibility not confused with empirical evidence. The Cochrane review of VR training for laparoscopic surgical trainees illustrates the problem. Among eight trials involving 109 surgical trainees, the principal outcomes were operative time and operative performance. Mortality, morbidity, quality of life, and hospital stay not adequately reported. Thus, the absence of reported adverse outcomes not interpreted as proof that VR reduces complications.

The gynecologic hysterectomy RCT provides some direct clinical information. Jokinen et al. reported no difference in blood loss or direct complications between VR-trained and control residents. This is reassuring in terms of the absence of an apparent safety penalty, but the study was small, with only 20 residents, and therefore lacked the statistical power required to detect relatively uncommon complications.

Operative time more frequently reported. Shorter procedures may theoretically reduce anesthesia exposure, operating-room resource utilization, and some procedure-related risks. However, operative time is a surrogate outcome. A shorter operation is not necessarily safer if speed achieved at the expense of tissue handling or decision-making (Figure 4). Procedural error may be a more direct intermediate safety endpoint. Gallagher et al. reported that VR

training had a particularly pronounced effect on error reduction, with transfer effects of approximately 32–42% in their studies. Ahlberg et al. likewise demonstrated fewer errors in residents

who underwent proficiency-based VR training before clinical laparoscopic surgery.

Figure 4. Forest Plot of Patient Safety and Clinical Outcomes in Gynecologic Laparoscopic Training



Figure 4. Forest Plot of Patient Safety and Clinical Outcomes in Gynecologic Laparoscopic Training

However, these studies predominantly involve general laparoscopic surgery rather than gynecology. Their findings support a general mechanism of improved technical control but not presented as direct evidence that VR reduces complications in gynecologic surgery. The 2022 systematic review of gynecologic simulation concluded that high- and low-fidelity simulation improved technical skills and that high-fidelity simulation reduced operative time. Nevertheless, patient-level outcome data remained sparse. This is arguably the central research gap. Future trials therefore designed around clinically meaningful endpoints. These should include intraoperative injuries, urinary tract injury, bowel injury, vascular injury, blood loss, conversion, postoperative complications, readmission, operative time, and length of stay. Importantly, the studies should be sufficiently large to detect uncommon but clinically significant complications. Patient safety also conceptualized beyond adverse-event counts. VR may affect safety through improved preparation, reduced cognitive load, better instrument control, and standardized assessment. These intermediate outcomes can provide mechanistic evidence, but they should complement rather than replace patient-level endpoints.

Discussion

This systematic review indicates that virtual reality simulation has a meaningful role in the education of gynecologic laparoscopic surgeons, particularly during the early acquisition of technical skills. Across gynecologic and broader laparoscopic evidence, VR improves objective technical performance, reduces errors in several settings, and facilitates transfer of skills from the simulator to the operating room. However, the magnitude and consistency of benefit depend on the comparator, trainee experience, training strategy, and outcome measure. The strongest evidence concerns the comparison between VR and no supplementary training. Meta-analytic evidence demonstrates significant improvement in both performance scores and time. Jin et al. reported SMDs of 1.51 for performance scores and -0.99 for time when VR compared with no training. These effects support the use of VR as an active educational intervention rather than an optional technological enhancement. The situation is different when VR compared with a box trainer. The pooled differences in time and performance were not statistically significant. Akdemir et al.'s gynecologic randomized study reached a similar conclusion: both LapSim and box

training improved live operative performance relative to standard clinical education, but there was no significant difference between the two simulation modalities. This finding is important for health systems considering investment in expensive VR technology. The evidence suggests that structured deliberate simulation practice may be more important than the specific technological format. VR provides unique advantages automated metrics, immediate feedback, procedural modules, adjustable difficulty, and potentially greater fidelity but a well-designed box trainer may provide comparable benefits for many basic laparoscopic skills. The concept of proficiency-based training appears particularly important. Simply allowing trainees to spend a predetermined amount of time on a simulator may not guarantee competence. Proficiency-based training instead requires objective achievement of a predefined performance level. Evidence from laparoscopic surgery indicates that this approach can improve subsequent operative performance and reduce technical errors (Ahlberg et al., 2007).

The learning-curve findings also suggest that trainee experience should determine curriculum intensity. Aggarwal et al. demonstrated that experienced surgeons reached a performance plateau after fewer repetitions than novices did. Therefore, a standardized curriculum consisting of exactly the same number of VR repetitions for every trainee may be educationally inefficient. Adaptive curricula should allow trainees to progress after achieving competence.

Transfer to actual surgery represents another important strength of the evidence. Larsen et al. demonstrated improved performance during live salpingectomy after proficiency-based VR training. Jokinen et al. subsequently demonstrated improved performance during residents' first laparoscopic hysterectomy after VR training. These findings are particularly relevant because they demonstrate that simulator training can affect actual surgical behavior rather than merely simulator scores.

Nevertheless, transfer interpreted cautiously. Surgical performance in the operating room influenced by numerous variables beyond technical psychomotor skill, including anatomy, pathology, assistant performance, anesthetic considerations, communication, decision-making, and intraoperative judgment. VR can reproduce some but not all of these factors.

The distinction between conventional VR and immersive VR is another important limitation. Many gynecologic studies used systems such as LapSim rather than contemporary head-mounted immersive environments. Mao et al.'s systematic review suggests that immersive VR can improve procedure time, task completion, and accuracy across surgical education, but this broader evidence base is not specific to gynecologic laparoscopy. Consequently,

current evidence supports the general concept of VR-enhanced surgical education more strongly than it supports the superiority of fully immersive head-mounted VR specifically for gynecologic surgery. Patient safety remains the most significant unresolved question. Existing studies provide promising intermediate indicators such as reduced errors, improved technical ratings, but direct patient outcomes are infrequently measured. The gynecologic systematic review by Orejuela et al. found moderate-quality evidence for improved operative technical skills and reduced operative time with simulation, while noting insufficient patient-level evidence.

This gap is understandable because adequately powered patient-safety trials require large samples. Serious complications in gynecologic laparoscopy are relatively uncommon; therefore, a study involving 20 or 30 residents is unlikely to detect meaningful differences in complication rates. Future research should use multicenter designs and standardized clinical endpoints.

Another issue is retention. Surgical competence must persist after training rather than disappear when the simulator removed. Some evidence indicates retention after delayed testing, but long-term data remain sparse. The salpingectomy study by Bendifallah et al. is valuable because it incorporated a three-month interval between training sessions, addressing the question of maintenance. Longer-term studies should evaluate six- and twelve-month retention and determine whether periodic VR "booster" sessions are required.

VR may also have implications for equity and accessibility. Conventional high-fidelity simulators can be expensive and require dedicated laboratory space. Contemporary consumer-grade immersive VR systems may reduce some hardware costs, potentially allowing decentralized training. However, hardware affordability does not guarantee educational validity. Training platforms should be validated, curricula standardized, and performance benchmarks linked to clinical competence. The evidence also supports combining VR with other modalities. Box trainers provide physical instrument handling and haptic interaction, whereas VR provides objective digital metrics and procedural visualization. A hybrid curriculum could therefore exploit the strengths of both systems. The finding that VR and box trainers frequently produce comparable technical outcomes should not be interpreted as evidence that one modality is unnecessary; instead, it suggests that different forms of simulation may be complementary. Finally, the literature highlights a need for standardized outcome measures. Studies use different rating scales, simulator metrics, repetition schedules, and proficiency thresholds. Such heterogeneity complicates quantitative synthesis. Future trials

should report validated global rating scales, task-specific scores, errors, operative time, and economy of movement, retention, and patient-centered outcomes using common definitions.

Overall, the evidence supports integrating VR into gynecologic laparoscopic training, particularly for novices and before first exposure to technically demanding procedures. The evidence is considerably weaker for claims that immersive VR is superior to conventional simulation or that it independently reduces patient complications. These distinctions should guide both clinical education and future research.

Conclusion

Virtual reality simulation has become an important component of contemporary laparoscopic surgical education, and the available evidence supports its use in gynecologic surgery as an adjunct to conventional clinical training. The strongest and most consistent finding is that VR improves technical surgical performance when compared with no supplementary training. Improvements have demonstrated in operative time, psychomotor performance, global technical ratings, task accuracy, and procedural error rates.

Gynecology-specific studies provide evidence that these benefits can extend beyond the simulator. VR training has been associated with improved performance during laparoscopic salpingectomy and hysterectomy, indicating that skills acquired in a simulated environment can transfer to actual operations. This transfer is particularly relevant for residents and fellows who are beginning to perform laparoscopic procedures independently. The available evidence also suggests that the effect is greatest during the early learning curve, when trainees have limited previous laparoscopic experience. The comparison between VR and conventional box training produces a more nuanced conclusion. Current evidence does not consistently demonstrate superiority of VR over box trainers for basic laparoscopic skills. Both modalities can improve performance relative to standard clinical education. Therefore, the educational value of simulation appears to depend substantially on deliberate practice, feedback, objective assessment, and achievement of proficiency rather than on technology alone. The evidence concerning patient safety remains incomplete. Available studies report promising reductions in errors and improvements in operative performance, but direct patient-level outcomes such as major complications, organ injury, conversion to laparotomy, readmission, and postoperative morbidity are rarely reported. Small sample sizes also limit the ability of individual trials to detect uncommon adverse events. Consequently, the present evidence supports VR as a mechanism that may contribute to safer surgical training, but it

does not establish that immersive VR independently reduces patient complications.

A future gynecologic VR curriculum should therefore incorporate proficiency-based progression, objective performance metrics, repeated practice, immediate feedback, retention testing, and supervised transfer to the operating room. Immersive VR may be particularly useful for procedural visualization and spatial learning, while physical box trainers may provide complementary haptic and instrument-handling experience. Hybrid curricula may consequently provide a practical approach.

Future research should prioritize multicenter randomized trials involving gynecologic residents and fellows, standardized proficiency benchmarks, validated assessment instruments, long-term retention, cost-effectiveness, and patient-centered clinical outcomes. Studies should clearly distinguish conventional VR from fully immersive head-mounted VR and should report sufficient technical details to allow replication.

In conclusion, the current evidence supports VR simulation as an effective educational adjunct for developing gynecologic laparoscopic skills and accelerating early learning, with evidence of transfer to live surgery. However, claims of superiority over all other simulation modalities and claims of direct improvement in patient safety require additional high-quality evidence. The most defensible interpretation is that immersive and conventional VR provide a valuable patient-independent environment for deliberate surgical practice, while their ultimate effect on patient outcomes remains an important unanswered research question.

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