The American Journal of Surgery 224 (2022) 1126–1134

Contents lists available at ScienceDirect

The American Journal of Surgery

journal homepage: www.elsevier.com/locate/amjsurg

Review Article

Use of procedure specific preoperative warm-up during surgical priming improves operative outcomes: A systematic review

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ARTICLE INFO

Keywords:
Warm-up
Simulation
Surgical outcomes
Performance
Priming

ABSTRACT

Background: Preoperative warm-up in preparation for surgery is a technique used in recognition of similarities between surgeons and performance based professionals. The aim of this review was to evaluate the use of simulation-based preoperative warm-up on surgical performance in the operating room and its impact on both clinical and patient outcomes.

Materials and methods: A systematic review of the literature was carried out in accordance with PRISMA guidelines between August–September 2021. In total 15 studies were retrieved.

Results: Seven studies across general surgery, urology, and vascular surgery used a procedure specific warm-up, with significant improvement in operative performance, rate of errors, radiological and patient-based outcomes. Variables including level of experience and specialty appeared to have no impact on the merits of preoperative warm-up demonstrated.

Conclusions: While heterogeneity in the benefit of generic warm-up procedures was noted, procedure specific warm-up methods consistently resulted in significantly better operative outcomes.

1. Introduction

Surgeons are oft compared to performance based careers including musicians, dancers, and athletes.[1] Willaert et al.[2] noted the use of warm-up techniques is common in performance driven careers to promote both physical, psychological dexterity, instil confidence and suitably "prime" performers for the task ahead, however this has yet be widely adapted in everyday surgical practice. The introduction of surgical simulation on a virtually based platform has led to a recent surge in the use of simulation-based learning in surgical training to promote surgical skill acquisition,[3–5] with a recent focus on its use in the perioperative period.[1,6,7]

Several studies have highlighted the use of simulation based training to evaluate the efficacy of the virtual platform in the preoperative period to promote surgical performance.[8–10] While its use has been demonstrated to improve measured outcomes, significant limitations to the use of simulation derived metrics without in vivo assessment exist. Learning bias is a recognised limitation to assessment tools using machine automated scores,[11] with participants demonstrating improved performances and outcomes due to familiarity with the equipment.

It is incumbent on clinicians to ensure adequate validation of novel educational or simulation based equipment is completed prior to implementation into clinical practice.[12] The step from the virtual platform to the operating room is the most significant to ensure that time and training given to simulation based tools is reflected in improved operative performance.[13] The aim of this review was to evaluate the use of simulation-based preoperative priming defined as simulation in the preoperative period on technical surgical performance carried out in the operating room and its impact on clinical and patient outcomes.

2. Materials and methods

2.1. Search strategy

A comprehensive search strategy was performed of electronic databases including PubMed, Ovid Medline, EMBASE, Google Scholar, with study selection identification from August 2021–September 2021. Broad search terms to ensure adequate capture were used; with a combination of "warm*", "prim*", "performance", "surg*", "outcomes", using Boolean characters "AND" and "OR". The search was carried out in

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https://doi.org/10.1016/j.amjsurg.2022.05.031
Received 5 April 2022; Received in revised form 5 May 2022; Accepted 24 May 2022
Available online 27 May 2022

accordance with PRISMA guidelines. Two independent reviewers performed a literature search in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[14] and reviewed the search results, with a senior author arbitrating in the event of a disagreement, based on a protocol agreed on by all authors. Use of Assessing the Methodological Quality of Systematic Reviews (AMSTAR) was applied to retrieved studies to evaluate quality of articles retrieved. This review was registered with PROSPERO under registration number CRD42021285522.

2.2. Eligibility criteria

The inclusion criteria consisted of (i) in-vivo studies (ii) use of simulation as a warm-up method pre-operatively (iii) English or full translation freely available. The exclusion criteria included (i) case reports (ii) use of simulation-based assessment to analysis effect of pre-operative warm-up (iii) warm-up techniques not involving simulation-based practice.

2.3. Outcomes analysed and statistical analysis

Ad-hoc tables were designed to summarize data from the included studies. Study design, surgical specialty and level of participant experience were collected. Comparison groups if used were also noted, in addition to the warm-up regimen employed by each study. Evidence of any change in surgical performance by participants following priming were recorded in addition to subjective or objective tools used. and any differences in study outcomes recorded. Risk of bias was assessed using the ROB (Risk of Bias) and ROBINS-I (Risk of Bias in Non randomised Studies) tools. No deviations from protocol were noted during data collection and collation.

2.4. Objectives and aims

The objective is to review and collectively compare the impact of virtual reality simulation in the preoperative period on technical surgical performance in the operating room.

3. Results

In total 15 study fulfilling outlined criteria were included for analysis (Fig. 1).

3.1. Risk of bias assessment

Risk of Bias using ROB2 and ROBINs-I tools was calculated. Risk of bias arising due to randomisation where applicable, deviation from intended intervention, missing data, outcome measurements, and selection of reported results was assessed for each study. No studies were identified as containing a high risk of bias. A moderate risk of bias was identified due to bias in measurement of outcomes,[15] and risk due to confounding factors[16] each in a single domain in two studies.

3.2. Study design

Six studies[17–22] included used a randomised crossover design, with intraparticipant scores recorded for comparison (Table 1.). Two studies randomised patients to warm-up and control groups, with surgical teams undergoing warm-up according to the grouping status of the patient.[23,24] Paschold et al.[16] used an observational pre-post study design, with Mucksavage et al.[15] evaluating outcomes via a retrospective review. Five studies used a randomised control study design.[25–29]

3.3. Specialty

General surgery was the specialty most frequently analysing outcomes following surgical priming,[16,18–20,22,25–27,29] followed by Obstetrics + Gynaecology,[21,24] Urology,[15,17] with one study evaluating surgical Ophthalmology,[28] and Vascular surgery[23] procedures included.

Laparoscopic Cholecystectomies were the most commonly used procedure to assess the impact of preoperative preparation,[16,18–20,25,27,29] with Laparoscopic appendicectomies,[16,20,27] Laparoscopic colonic resection,[20,26] tubal surgery,[21,24] partial and radical nephrectomies[15,17] also used. Bariatric surgery procedures, laparoscopic hernia repair,[20] laparoscopic hysterectomy,[24] endovascular aortic repair (EVAR),[23] and vitrectomy[28] were each used in a single study.

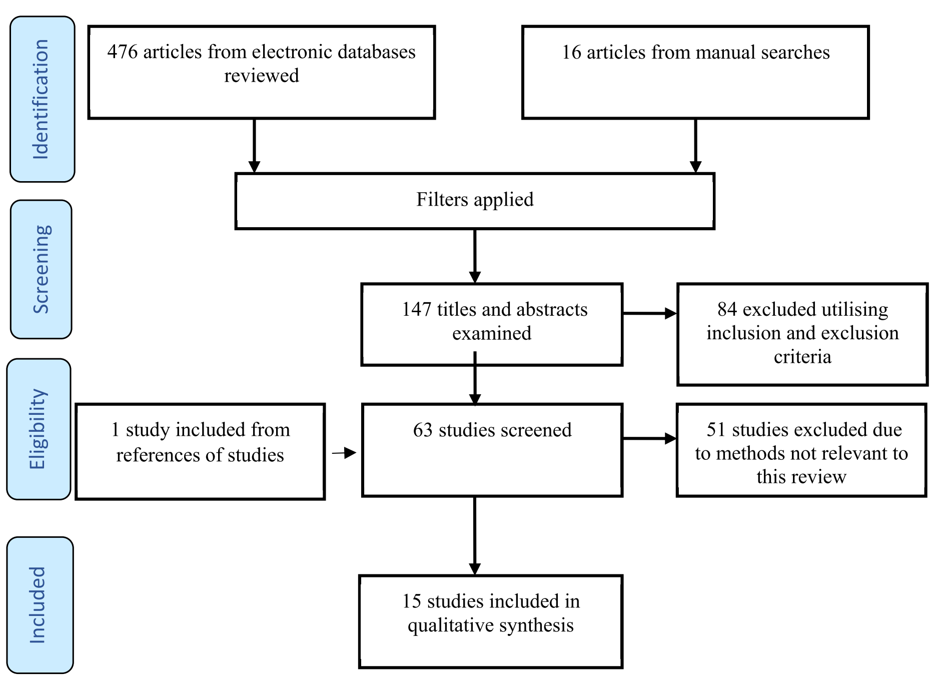

Fig. 1. Prisma flowchart.

Table 1
Studies included for analysis.

Authors	Study Design Population	Specialty Grade	Methods	Operation	Assessment	Comparison	Outcome	Simulator
Lee et al. (2012)[14]	Crossover interventional study n:7	Urology Senior residents	Subjects completed two laparoscopic renal surgery cases having completed electrocautery simulation task on LapMentor and laparoscopic suturing on a box trainer on one occasion	Renal surgical cases including nephrectomy (radical and partial), pyeloplasty, renal cyst decortication	EEG monitoring, pupillary eye-tracking, operative assessment tool (not validated)	Trainees acted as own control	Greater hand smoothness ($p < 0.03$), tool smoothness ($p < 0.05$), posture ($p < 0.05$), attention (EEG) (<0.02), mental workload scores ($p < 0.001$)	LAPMentor (Simbionix Ltd) + pelvic box trainer
Chen et al. (2013)[15]	RCT N: 184	O + G[a] Residents	Procedures were randomised to be carried out by a participant who had warmed-up on a simulator using "bead transfer", "rubber band placement", "run the rope" or one who had not completed a warm-up.	Major: Supercervical and total hysterectomies Minor: adnexal and tubal surgery	Global Rating Scale- OSATs (Objective Structured Assessment of Technical Skills)	Procedures were randomised to warm-up or no warm-up	Improved resident performance intraoperatively following warm-up compared to control group ($p \leq 0.001$)	TASKIT laparoscopic trainer (Ethicon Endo-Surgery)
Moran-Atkin et al. (2014)[16]	Crossover RCT N: 40	General Surgery Residents	Participants were randomised to undergo warm up on simulator using one of 4 tasks: peg transfer, pattern cutting, endoloop, intracorporal suturing before 1st case of the day over 5 days or perform the operation without simulated warm up. Participants than crossed over to the other arm.	Major: Colon resections, laparoscopic inguinal hernia repair, laparoscopic bariatric surgery Minor: laparoscopic appendicectomies, laparoscopic cholecystectomies	Global rating scale OSATs (Objective Structured Assessment of Technical Skills), and Global Rating Scale of LSC operative performance	Trainees acted as own control	Improved depth perception ($p = 0.02$), bimanual dexterity ($p = 0.01$), efficient movement ($p = 0.03$)	Fundamentals of Laparoscopic Surgery training box
Troncoso-Bacelis et al. (2017)[17]	Single-blinded CT n:16	General Surgery Specialist	Participants recruited to undergo 2 laparoscopic cholecystectomies, one of which carried out with standard preoperative preparation, and one with a simulated warm-up on a simulator consisting of 5 tasks: Transference, cuts, endoloop, Extracorporeal and intracorporal knots.	Laparoscopic Cholecystectomy	Operative time, blood loss, perforation, drainage, postoperative pain, haematoma formation	No VR warm-up	Less bleeding ($p = 0.01$), reduced operative time ($p = 0.019$)	LAPA-PRO
Paschold et al. (2014)[18]	Observational pre-post design	General Surgery Residents	Participants underwent virtual laparoscopic tasks consisting of fine dissection, Cholecystectomy II, Peg transfer before and after each operation. Scores from each attempt were compared to evaluate comparative improvement in surgical skills after laparoscopic surgery	Laparoscopic appendicectomy Laparoscopic cholecystectomy	Virtual reality derived scores from Preparation task, virtual procedural task, instrument coordination task, and operative time	None	Significant improvement demonstrated in performances completed postoperatively, with a greater effect seen in more experienced surgeons ($p = 0.03$)	LapSim

(continued on next page)

Table 1 (*continued*)

Authors	Study Design Population	Specialty Grade	Methods	Operation	Assessment	Comparison	Outcome	Simulator
Araujo et al. (2014)[19]	Single-blinded RCT n:14	General Surgery Novices	Participants were randomised to warm-up consisting of a virtual laparoscopic sigmoid resection or no warm up prior to undertaking a laparoscopic sigmoid colectomy on pigs. Performance assessed by colorectal surgeons blinded to the grouping status of participants.	Laparoscopic sigmoid colectomy	Generic laparoscopic technical skills scores, and specific skills related to sigmoid colectomy	No VR warm-up	Warm-up group significantly outperformed control in generic ($p = 0.002$) and specific skills ($p = 0.001$)	LapMentor (Simbionix)
Moldovanu et al. (2011)[20]	Crossover RCT n:1	General Surgery Specialist	A surgical team carried out laparoscopic cholecystectomies having undergone warm-up on a VR or not. Warm-up consisted of camera navigation, coordination, clip application, clipping and grasping, electrocautery, cystic pedicle dissection, clipping and cutting. Blinded reviewers assessed performance using GRS tool	Laparoscopic Cholecystectomy	Modified Global Rating Score	No VR warm-up	Respect for tissues significantly improved in the warm-up group ($p = 0.021$; $p = 0.04$)	LapMentor (Simbionix)
Calatayud et al. (2010)[21]	Crossover RCT n:8	General Surgery Residents	Participants were randomised to complete a laparoscopic cholecystectomy having completed a generic laparoscopic warm-up VR training program consisting of “lifting and grasping”, “clip applying”, “dissection” or without warm-up.	Laparoscopic Cholecystectomy	Generic OSATS Global Rating Scale	Trainees acted as own control	Surgical performance was significantly improved following a VR warm-up ($p = 0.04$)	Lapsim
Kelly et al. (2021)[22]	Crossover RCT n:41	General Surgery/ Urology,/O + G	A combination of modules “Ring and Rail 2”, “Match Board 3”, “Endowrist manipulation 2”, “Suture Sponge 3”, and “Running Suture 2” were used across 5 groups	Not specified	Global Evaluative Assessment of Robotic Skills (GEARS) tool	Subjects acted as own control	No significant difference in performance between scores following warm-up and no warm-up in any measured metric	dVSS
Mucksavage et al. (2012)[23]	Retrospective review n:1	Urology Specialist	Review of outcomes following laparoscopic partial nephrectomies (LPN) and radical nephrectomies (LRN) carried out by a single surgeon were analysed for difference in collected outcomes. Warm-up consisted of pelvic trainer suturing exercises.	Laparoscopic partial nephrectomy (LPN) and laparoscopic radical nephrectomy (LRN)	Total operative time, surgical time, estimated blood loss, warm ischemia time, complications, positive margins, length of stay, Hb fall, creatinine, analgesic requirements	Subject acted as own control	Surgical time post warm-up was significantly faster ($p = 0.03$)	Pelvic trainer
						No warm-up		

(continued on next page)

Table 1 (*continued*)

Authors	Study Design Population	Specialty Grade	Methods	Operation	Assessment	Comparison	Outcome	Simulator
da Cruz et al. (2016)[24]	Single-blinded RCT n:20	General Surgery Medical Students	Participants carried out live porcine laparoscopic cholecystectomy after watching a video explaining the procedure, with half having also undergone a simulated laparoscopic cholecystectomy.	Laparoscopic cholecystectomy	Global Operative Assessment of Laparoscopic Skills (GOALS)		Subjects who underwent warm-up dissect gallbladder pedicle faster ($p = 0.01$), pedicle clipping ($p = 0.004$), blood loss ($p = 0.006$), depth perception ($p = 0.004$), bimanual dexterity ($p = 0.004$), tissue handling ($p = 0.012$), autonomy ($p = 0.02$)	VRSS LapVR (Immersion Medical)
Polterauer et al. (2016)[25]	Crossover RCT n:10	O + G Specialist	Participants performed USO having either undergone warm-up exercises including peg transfer, pattern cutting and fine dissection or performing USO without VR warm-up.	Laparoscopic unilateral salpingo-oopherectomy (USO)	Objective structured assessment of technical skills (OSATS), operative time, Generic Error Rating Tool (GERT)	Subjects acted as own control	No significant difference in GERT scores ($p = 0.5$), OSAT scores ($p = 0.2$), operative time ($p = 0.2$)	LapSim
Weston et al. (2014)[26]	Single-blinded RCT n:75	General Surgery Specialist	Participants were randomised to carry out a game console exercise, perform intracorporal suturing, or no warm-up prior to surgery. Videos of LC and LA were taken and assessed.	Laparoscopic cholecystectomy, laparoscopic appendicectomy	GOALS	Game console practice or No warm-up	No significant difference noted across any metric	PlayStation 2 Box trainer
Deuchler et al. (2016)[27]	Single-blinded RCT n:4	Surgical Ophthalmology Specialist	Participants were randomised to undergo warmup on simulator comprising of a bimanual task, peeling, and retinal detachment surgery 20 min prior or proceed directly to surgery. Operative performance was videoed and assessed by 2 blinded reviewers.	Pars plana vitrectomy	Global rating assessment of skill in intraocular surgery (GRASIS)	No warm-up	Final operative outcome improved post warm-up ($p = 0.03$)	EyeSi
Desender et al. (2016)[28]	Multi-centre RCT n:100	Vascular Patients with AAA ° + Complete operative team	Vascular surgeons carried out operation on patients having carried out a virtual team-based operation using patient-based metrics within 24 h of the procedure, or proceeding without a virtual run-through	Endovascular Aneurysm Repair	Intraoperative errors, 30-day mortality, Imperial College Error Capture (ICECAP), operative time, number of angiograms	Patients randomised to have no virtual run through preoperatively	Intervention group lower error rate ($p = 0.004$; $p = 0.03$), number of angiograms lower in the intervention group ($p = 0.005$; $p = 0.004$)	ANGIO Mentor Express Dual Access Simulation System (Simbionix)

Legend.
[a] Obstetrics + Gynaecology ° Abdominal Aortic Aneurysm.

3.4. Level of experience

Medical students were used by da Cruz et al.,[29] surgery naïve surgical trainees by Araujo et al.[26] Residents were used in four studies[16,17,20,24] with the majority of studies using a combination of both residents and specialists.[19,21,25,27] Specialists were used solely in three studies.[15,18,28] Desender et al.[23] used a preparatory team approach, and one study did not specify the level of experience.[22]

3.5. Preoperative surgical warm-up methods used

LapMentor (Simbionix),[17,18,26] and LapSim (SurgicalScience)[16,19,21] were the most commonly used virtual reality simulators. One study each used simulators including "LAPA-PRO",[25] "TASKIT" laparoscopic box trainer (Ethicon Endosurgery),[24] "dVSS",[22] "LapVR",[29] "ANGIO Mentor Express Dual Access (Simbionix)",[23] and "EyeSi".[28] Four studies[15,17,20,27] used low fidelity box trainers, with Weston et al.[27] also including a group exposed to video gaming devices in the preoperative period.

Studies used either a generic or specific warm-up approach. Within studies using a procedure specific warm-up, two main methods were used; the complete procedure was utilised in the virtual environment in four studies,[16,23,26,29] while simulated modules consisting of operative steps specific to the procedure to be performed were included in three studies.[18,19,21]

Generic surgical skill modules were used in six studies either in isolation[17,20–22,24,25] or in conjunction with a simulated module specific to the operation to be carried out.[28] Generic warm-up tasks were predominantly used for laparoscopic skills including: peg/bead transfer/transference,[16,20–22,24,25] cuts/electrocautery,[17,21,25] rubber band placement,[24] endoloop/intracorporal/extracorporeal suturing,[20,22,25] knots,[25] or dedicated bimanual tasks.[28]

Suturing or box tasks were used to warm-up preoperatively in two studies.[15,27] Video games were used as a mode of surgical warm-up in one of the intervention groups utilised by Weston et al.[27]

3.6. Assessment used

Both objective and subjective methods of assessment were used within studies. A variety of subjective laparoscopic global rating scales were used to measure the impact of preoperative warm-up including Objective Structured Assessment of technical skills (OSAT),[19–21,24] modified Global Rating Scale,[18] Global Evaluative Assessment of Robotic Skills (GEARS),[22] Global Operative Assessment of Laparoscopic Skills (GOALS),[15,27] simulation derived scores from virtual reality based modules,[16,28] generic laparoscopic technical skills,[26] and those specific to the procedure.[26] Deuchler et al.[28] used a Global Rating Assessment of Skill in Intraocular Surgery (GRASIS) as the only non-laparoscopic-based procedure in this review. Lee et al.[17] used a modified global rating scale not yet validated in the literature.

Polterauer et al.[21] additionally used a Generic Error Rating Tool (GERT) to evaluate number of mistakes in conjunction with overall performance, with Desender et al.[23] similarly using a measure of intraoperative errors via the Imperial College Error Capture (ICECAP).

Objective assessments used to evaluate preparatory warm-up included participant specific endpoints including electroencephalogram (EEG) monitoring,[17] posture,[17] and pupillary eye trackers.[17] Patient based outcomes were more commonly used, including operative time[15,23,25]; blood loss[15,25]; postoperative laboratory markers including renal function and haemoglobin drop[15]; complications[15,25]; 30-day mortality[23]; pain/analgesic requirements,[15,25] and length of stay.[15] Desender et al.[23] also used number of intraoperative images taken to evaluate efficacy of patient-specific preoperative virtual run-throughs.

3.7. Time dedicated to warm-up

Two main methods were used during the required warm-up time given to participants. Studies included in this review used a predominantly task-based approach to the warm-up procedure, with nine studies allotting time dedicated to the warm-up period based on completion of a required task.[16–18,21–24,28,29] Seven studies provided an allotted time for the warm-up period, with shorter dedicated warm-ups ranging from 5 to 10 min in three studies,[20,25,27] and longer dedicated preoperative warm-up of 15–20 min prescribed in four studies.[15,19,28,17] Aruajo et al.[26] allocated a time of 2 h to complete the set task, although noted all participants completed it within this time frame.

3.8. Time warm-up implemented prior to surgery

A degree of heterogeneity was demonstrated in the use of preoperative priming prior to the operative assessment. While four studies noted the warm-up was completed immediately preoperatively,[16,19,24,28] two reported completion of the tasks within 15[18]-30 min,[27] one study within 1 h.[20] Deuchler et al.[23] reported the longest degradation time with completion of the simulated operation done within 24 h. Six studies did not specify the use of warm-up in relation to the operative list to be completed.[15,17,21,22,25,26,29]

3.9. Outcomes

Improved surgical performance was found in 12 of the 15 studies included for analysis. In three studies[21,22,27] no significant changes were reported in outcomes between the intervention and control groups (Table 2.).

3.9.1. Objective outcomes

Studies evaluating objective metrics demonstrated a significant improvement in radiological, patient, and participant-based endpoints with the exception of one study.[21] Polterauer et al.[21] found no difference in operative time from procedures carried out by specialists having completed a generic preoperative warm-up was found ($p = 0.2$)[21]. This is in contrast with two studies who demonstrated a significantly faster time to completion by trainees ($p = 0.01$)[4] and specialists ($p = 0.03$)[10] who were preoperatively primed using generic exercises. Similarly, da Cruz et al.[29] found intraoperative steps were completed in a shorter duration by novices who had practiced procedure specific manoeuvres as a preoperative warm-up ($p = 0.01$).

Both studies evaluating patient-based outcomes demonstrated a significant improvement in estimated blood loss in those who had completed a preoperative warm-up, with both generic ($p = 0.01$)[25] and specific procedure ($p = 0.006$)[29] approaches proving efficacious.

Paschold et al.[16] reported a significant difference in outcomes using simulator based metrics following completion of simulator modules, demonstrated using a simulator following completion of an intraoperative procedure ($p = 0.03$).

3.9.2. Kinemetric-based outcomes

Two studies noted a significant improvement in unexperienced participants' operative performances following completion of a procedure specific warm-up.[26,29] Araujo et al.[26] noted a significant improvement in novices having completed a virtual laparoscopic sigmoid colectomy ($p = 0.001$), and da Cruz et al.[29] found medical students having completed a virtual cholecystectomy performed better than their unprimed counterparts across several metrics including depth perception ($p = 0.004$), bimanual dexterity ($p = 0.004$), tissue handling ($p = 0.01$), and autonomy ($p = 0.02$).

In studies using an operative component specific to the procedure in their warm-up, a significant improvement was noted kinemetric assessments made intraoperatively. Calatayud et al.[19] noted a significant improvement in overall performance using validated assessment tools

Table 2
Outcomes from studies included for analysis.

Improvement post-warm-up	Yes	No
Objective-based outcomes		
Radiological outcomes	Lower number of angiograms ($p = 0.004$)[28]	
Participant based outcomes	Greater posture stability ($p < 0.05$),[14]	
	Greater EEG recorded attention scores ($p < 0.02$)[14]	
	Lower Mental workload scores ($p < 0.001$)[14]	
Patient based outcomes	Decreased blood loss ($p = 0.006$)[24] ($p = 0.01$)[17]	
Time	Gallbladder pedicle dissection faster ($p = 0.01$)[24]	Operative time ($p = 0.2$)[25]
	Operative time ($p = 0.03$)[23] ($p = 0.019$)[17]	
Simulation derived metrics	Overall performance improvement ($p = 0.03$)[18]	
Subjective-based outcomes		
Error rate	Lower error rate ($p = 0.004$)[28]	No difference in GERT scores ($p = 0.5$)[25]
Kinemetric outcomes		
OSAT	Overall improvement ($p = 0.04$)[21] ($p \leq 0.001$)[15]	No improvement noted overall ($p = 0.2$)[25]
GOALS	Depth perception ($p = 0.004$)[24]	No improvement in any measured metric[26]
	Bimanual dexterity ($p = 0.004$)[24]	
	Tissue handling ($p = 0.012$)[24]	
	Autonomy ($p = 0.02$)[24]	
GEARS		No improvement in any metric[22]
Modified GRS	Improved respect for tissue ($p = 0.021$; $p = 0.04$)[20]	
GRASIS	Improved overall performance ($p = 0.03$)[27]	
Generic laparoscopic skills	Overall improvement ($p = 0.002$)[19]	
Specific procedural skills	Overall improvement ($p = 0.001$)[19]	
Psychomotor testing	Greater hand smoothness of movement ($p < 0.03$)[14]	
	Smoothness of instruments ($p < 0.05$)[14]	

within the surgically primed groups ($p = 0.04$). Similarly, Moldovanu et al.[18] found a similar outcome with the preoperatively prepared demonstrating a greater degree of respect for tissue ($p = 0.04$) than those who had not undergone a surgical warm-up using procedure specific components.

Generic warm-ups using basic laparoscopic or other skills resulted in heterogenous outcomes. Three studies found an improvement in kinemetric outcomes in participants having completed a generic warm up.[17,20,24] Simulation based warm up resulted in an improved overall performance (p, ≤ 0.001),[24] box training warm up resulting in improved depth perception ($p = 0.02$), bimanual dexterity ($p = 0.01$), and efficient movement ($p = 0.03$),[20] and a combination of both resulting in greater hand smoothness (<0.03)[17] and use of instruments (<0.05).[17] In contrast, two studies found despite the intervention, no significant difference in observed performance was noted.[21,22]

Suturing to improve dexterity in the preoperative period demonstrated similar heterogenous results. While Mucksavage et al.[15] noted speed was improved intraoperatively ($p = 0.03$), Weston et al.[27] found no significant difference across any kinemetric assessment was noted. Similarly, no significant difference was noted in the group carrying out video games in the preoperative period.[27]

A lower number of recorded errors were noted in the intervention group by Desender et al.[23] reaching a statistically significant degree ($p = 0.004$). In contrast, Polterauer et al.[21] noted no significant change in the rate of errors made by participants following preoperative priming ($p = 0.5$). Desender et al.[23] used patient specific anatomy in the preoperative simulated simulation, which may account for the stark contrast in the findings between these studies.

4. Discussion

The use of virtual reality-based simulation has been discussed in its potential uses to accelerate surgical skill acquisition,[30] and shorten learning curves,[31] through providing a safe learning environment for surgical trainees.[5] This review highlights its potential use in helping promote patient safety through surgically priming primary operators prior to the first case of the day. In studies whereby the preoperative warm-up carried out was specific to the operative case to be completed, a significant improvement across both objective and subjective metrics was demonstrated consistently.

Subjective assessment in surgical performance remains the standard method of evaluation in surgical and simulated surgical performances.[32] Numerous subjective assessment tools exist, with several attempts in recent years to develop a standardised instrument to subjectively assess surgical performance, with functional components within each tool consistent across the studies in which they are applied.[33] Several subjective assessment tools were used in the studies included in this review, with an improved overall performance score noted in four studies.[19,24,26,28] Specific technical skills noted to demonstrate improvement following priming included tissue handling,[18,29] instrument dexterity,[17,29] and depth perception.[29] Three studies however found no significant difference overall performance or measures metrics following priming; this highlights the potential future benefit to be yielded from introduction of a standardised template of subjective assessment of surgical performance,[33] or addition of objective assessment tools in evaluation of surgical skills.[32]

The use of objective assessment tools in surgical skill acquisition are increasing in recognition of an evolving Halstedian surgical training model to a structured training method.[34] A plethora of objective assessment methods were used across in studies included in this review, which consistently demonstrated an improved performance following priming compared to unprimed surgical performance. Simulation derived performance was found to improve globally following preoperative priming by Paschold et al.[16] Similarly, improved performance through participant-based outcomes were identified. Lower mental workload was reported in participants by Lee et al.,[17] also finding participants had greater attention recorded on EEG.

Time as an objective measurement in performance assessment has demonstrated limitations in the literature.[26] While shorter operative times has beneficial downstream effects on patient outcomes,[35] and help reduce inefficiency commonly experienced on the operative list,[36] its use as a method to evaluate proficiency should be used with caution. In this review, three of the four studies looking at operative times saw preoperative warm-up resulted in shorter surgical times recorded. Mucksavage et al.[15] found a significant decrease in operative time following introduction of a warm-up, however as a retrospective review using a single surgeon with a sequential rather than parallel method used, the impact of a greater degree of surgical experience during the period with which warm-up procedures were used on subsequent clinical and patient outcomes should be considered.[15] Similarly, while the use of radiological imaging has not demonstrated construct validity in the literature,[37] and its use is not reflective of superior operative performance; reduction in radiation exposure for both patient and practitioner should be encouraged to reduce sequelae associated with prolonged or repeat exposure[38] as found by Desender et al.[23]

Studies have previously sought to evaluate the impact of surgical order on operative lists has an effect on surgical outcomes,[39] operative times,[40] and infection risk.[41] To date no significant impact on rates of complications arising from operative list composition has been demonstrated, with rates of orthopaedic postoperative infections thought to be associated with case order, potentially secondary to inadequate cleaning interoperatively.[41] While most studies have found second and subsequent cases have shorter operative times, in comparison to the primary case of the day,[39,42] Makhdom et al.[43] found that second and subsequent cases were significantly slower than the first case of the day. Lavelle et al.[42] found that patient on second and subsequent cases on the operating list had shorter operative times, and hospital lengths of stay. This was reflected in findings from studies included in this review, with significantly lower recorded blood loss following preoperative priming found in two studies.[15,19] This has potential implications on long-term downstream effects on patient outcomes and hospital costs, with additional benefits of a preoperative warm-up to promote work flow in operating lists, with three studies finding preoperative priming yielded significantly shorter operative times.[15,16,19]

Laparoscopic procedures have been reported to transfer well to the virtual platform due to the nature of the 2D feedback received.[44] Similarly, conventional box training provides ample opportunities to obtain adequate exposure to the laparoscopic operative setup to derive significant benefit from its use.[45] In this review the use of operative aids including high-fidelity simulation, box trainers, and simple suturing techniques appear to have an impact on subsequent operative performance. The use of simulation for surgical training in open procedures is sparse in the literature.[37] Only one study in this review used a non-laparoscopic or endovascular surgery to evaluate the impact of preoperative preparation, with positive results.[28] The merits of preoperative surgical priming appear not to be limited by surgical approach, highlighting the generalisability of this practice to all surgical specialities.

Use of virtual reality simulation has been reported to have variable impact on reported efficacy, and improvement in operative performance based on level of experience.[46] While residents and surgeons in training are felt to benefit from simulation to accelerate skill acquisition,[5] this review highlights the potential use of simulation in experienced specialists, with improvement in outcomes demonstrated in both novices and qualified surgeons. While practical limitations of preoperative preparation using surgical simulators were not discussed at length in studies included for review; barriers to the introduction of preoperative priming should be considered, including additional constraints of time on surgical trainees, potential costs of equipment, and the potential limited availability of space near theatre to facilitate surgeon access to preoperative tools.

4.1. Limitations

Significant heterogeneity in study design was noted in this review. While a cross-over RCT method was used in three studies, most studies included used a parallel RCT design, and the impact of inter-surgeon performance variability[22] should be considered in the context of the findings.

5. Conclusion

Procedure specific warm-up methods consistently demonstrated significantly better outcomes in endpoints measured, including operative metrics and surgical performance, and in reported rates of intraoperative errors recorded. Heterogeneity in the benefit of generic warm-up procedures is apparent, however their use yielded mixed-positive results on both low and high-fidelity simulation-based equipment across all levels of experience. The use of procedure specific warm-ups should be considered to improve intraoperative performance and operative metrics including operative time and patient blood loss.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Financial disclosure

No grants or financial support was received for this work.

Conflict of interest

This is a letter pertaining to the submission of the manuscript “Use of procedure specific preoperative warm-up during surgical priming improves operative outcomes: a systematic review”.

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

Acknowledgements

None.

References

1. Kroft J, Ordon M, Arthur R, Pittini R. Does surgical "warming up" improve laparoscopic simulator performance? *Simulat Healthc J Soc Med Simulat*. 2012;7(6): 339–342. https://doi.org/10.1097/SIH.0b013e31826230d4. Dec.
2. Willaert WI, Aggarwal R, Daruwalla F, et al. Simulated procedure rehearsal is more effective than a preoperative generic warm-up for endovascular procedures. *Ann Surg*. 2012;255(6):1184–1189. https://doi.org/10.1097/SLA.0b013e31824f9dbf. Jun.
3. Lakhani S, Selim OA, Saeed MZ. Arthroscopic simulation: the future of surgical training: a systematic review. *JBJS Rev*. 2021;9(3). https://doi.org/10.2106/JBJS.RVW.20.00076. Mar 22.
4. Pietersen PI, Bjerrum F, Tolsgaard MG, Konge L, Andersen SAW. Standard setting in simulation-based training of surgical procedures: a systematic review. *Ann Surg*. 2021. https://doi.org/10.1097/SLA.0000000000005209. Sep. 13.
5. Huffman EM, Choi JN, Martin JR, et al. A competency-based laparoscopic cholecystectomy curriculum significantly improves general surgery residents' operative performance and decreases skill variability: cohort study. *Ann Surg*. 2021. https://doi.org/10.1097/SLA.0000000000004853. Mar 3.
6. Samuelson ST, Burnett G, Sim AJ, et al. Simulation as a set-up for technical proficiency: can a virtual warm-up improve live fibre-optic intubation? *Br J Anaesth*. 2016;116(3):398–404. https://doi.org/10.1093/bja/aev436. Mar.
7. Lendvay TS, Brand TC, White L, et al. Virtual reality robotic surgery warm-up improves task performance in a dry laboratory environment: a prospective randomized controlled study. *J Am Coll Surg*. 2013;216(6):1181–1192. https://doi.org/10.1016/j.jamcollsurg.2013.02.012. Jun.
8. Plerhoples TA, Zak Y, Hernandez-Boussard T, Lau J. Another use of the mobile device: warm-up for laparoscopic surgery. *J Surg Res*. 2011;170(2):185–188. https://doi.org/10.1016/j.jss.2011.03.015. Oct.
9. Rosser Jr JC, Gentile DA, Hanigan K, Danner OK. The effect of video game "warm-up" on performance of laparoscopic surgery tasks. *J Soc Laparoendosc Surg*. 2012;16 (1):3–9. https://doi.org/10.4293/108680812X13291597715664. Jan-Mar.
10. Kahol K, Satava RM, Ferrara J, Smith ML. Effect of short-term pretrial practice on surgical proficiency in simulated environments: a randomized trial of the "preoperative warm-up" effect. *J Am Coll Surg*. 2009;208(2):255–268. https://doi.org/10.1016/j.jamcollsurg.2008.09.029. Feb.
11. Simmatis LER, Early S, Moore KD, Appaqaq S, Scott SH. Statistical measures of motor, sensory and cognitive performance across repeated robot-based testing. *J NeuroEng Rehabil*. 2020;17(1):86. https://doi.org/10.1186/s12984-020-00713-2. Jul 2.
12. Cook DA, Hatala R. Validation of educational assessments: a primer for simulation and beyond. *Adv Simul (Lond)*. 2016;1:31. https://doi.org/10.1186/s41077-016-0033-y.
13. Stunt J, Wulms P, Kerkhoffs G, Dankelman J, van Dijk C, Tuijthof G. How valid are commercially available medical simulators? *Adv Med Educ Pract*. 2014;5:385–395. https://doi.org/10.2147/AMEP.S63435.

14. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Int J Surg*. 2021;88, 105906. https://doi.org/10.1016/j.ijsu.2021.105906. Apr.
15. Mucksavage P, Lee J, Kerbl DC, Clayman RV, McDougall EM. Preoperative warming up exercises improve laparoscopic operative times in an experienced laparoscopic surgeon. *J Endourol*. 2012;26(7):765–768. https://doi.org/10.1089/end.2011.0134. Jul.
16. Paschold M, Huber T, Kauff DW, Buchheim K, Lang H, Kneist W. Preconditioning in laparoscopic surgery–results of a virtual reality pilot study. *Langenbeck's Arch Surg*. 2014;399(7):889–895. https://doi.org/10.1007/s00423-014-1224-4. Oct.
17. Lee JY, Mucksavage P, Kerbl DC, et al. Laparoscopic warm-up exercises improve performance of senior-level trainees during laparoscopic renal surgery. *J Endourol*. 2012;26(5):545–550. https://doi.org/10.1089/end.2011.0418. May.
18. Moldovanu R, Târcoveanu E, Dimofte G, Lupaşcu C, Bradea C. Preoperative warm-up using a virtual reality simulator. *J Soc Laparoendosc Surg*. 2011;15(4):533–538. https://doi.org/10.4293/108680811X13176785204409. Oct-Dec 2011.
19. Calatayud D, Arora S, Aggarwal R, et al. Warm-up in a virtual reality environment improves performance in the operating room. *Ann Surg*. 2010;251(6):1181–1185. https://doi.org/10.1097/SLA.0b013e3181deb630. Jun.
20. Moran-Atkin E, Abdalla G, Chen G, et al. Preoperative warm-up the key to improved resident technique: a randomized study. *Surg Endosc*. 2015;29(5):1057–1063. https://doi.org/10.1007/s00464-014-3778-1. May.
21. Polterauer S, Husslein H, Kranawetter M, et al. Effect of preoperative warm-up exercise before laparoscopic gynecological surgery: a randomized trial. *J Surg Educ*. 2016;73(3):429–432. https://doi.org/10.1016/j.jsurg.2015.11.017. May-Jun.
22. Kelly JD, Kowalewski TM, Brand T, et al. Virtual reality warm-up before robot-assisted surgery: a randomized controlled trial. *J Surg Res*. 2021;264:107–116. https://doi.org/10.1016/j.jss.2021.01.037. Aug.
23. Desender LM, Van Herzeele I, Lachat ML, et al. Patient-specific rehearsal before EVAR: influence on technical and nontechnical operative performance. A randomized controlled trial. *Ann Surg*. 2016;264(5):703–709. https://doi.org/10.1097/SLA.0000000000001871. Nov.
24. Chen CC, Green IC, Colbert-Getz JM, et al. Warm-up on a simulator improves residents' performance in laparoscopic surgery: a randomized trial. *Int Urogynecol J*. 2013;24(10):1615–1622. https://doi.org/10.1007/s00192-013-2066-2. Oct.
25. Troncoso-Bacelis A, Soto-Amaro J, Ramirez-Velazquez C. [Warming up with endotrainer prior to laparoscopic cholecystectomy]. Jul - Aug *Cir Cir*. 2017;85(4): 299–305. https://doi.org/10.1016/j.circir.2016.10.023. Calentamiento en endotrainer previo a colecistectomia laparoscopica.
26. Araujo SE, Delaney CP, Seid VE, et al. Short-duration virtual reality simulation training positively impacts performance during laparoscopic colectomy in animal model: results of a single-blinded randomized trial : VR warm-up for laparoscopic colectomy. *Surg Endosc*. 2014;28(9):2547–2554. https://doi.org/10.1007/s00464-014-3500-3. Sep.
27. Weston MK, Stephens JH, Schafer A, Hewett PJ. Warm-up before laparoscopic surgery is not essential. *ANZ J Surg*. 2014;84(3):143–147. https://doi.org/10.1111/j.1445-2197.2012.06321.x. Mar.
28. Deuchler S, Wagner C, Singh P, et al. Clinical efficacy of simulated vitreoretinal surgery to prepare surgeons for the upcoming intervention in the operating room. *PLoS One*. 2016;11(3), e0150690. https://doi.org/10.1371/journal.pone.0150690.
29. da Cruz JAS, Dos Reis ST, Cunha Frati RM, et al. Does warm-up training in a virtual reality simulator improve surgical performance? A prospective randomized analysis. *J Surg Educ*. 2016;73(6):974–978. https://doi.org/10.1016/j.jsurg.2016.04.020. Nov - Dec.
30. Fried MP, Sadoughi B, Gibber MJ, et al. From virtual reality to the operating room: the endoscopic sinus surgery simulator experiment. *Otolaryngol Head Neck Surg*. 2010;142(2):202–207. https://doi.org/10.1016/j.otohns.2009.11.023. Feb.
31. Atesok K, Satava RM, Van Heest A, et al. Retention of skills after simulation-based training in orthopaedic surgery. *J Am Acad Orthop Surg*. 2016;24(8):505–514. https://doi.org/10.5435/JAAOS-D-15-00440. Aug.
32. van Empel PJ, van Rijssen LB, Commandeur JP, et al. *Objective versus Subjective Assessment of Laparoscopic Skill. ISRN Minimally Invasive Surgery*. 2013, 686494. https://doi.org/10.1155/2013/686494, 2013/07/02 2013.
33. Seagull FJ, Rooney DM. Filling a void: developing a standard subjective assessment tool for surgical simulation through focused review of current practices. *Surgery*. 2014;156(3):718–722. https://doi.org/10.1016/j.surg.2014.04.048. Sep.
34. Oropesa I, Sanchez-Gonzalez P, Lamata P, et al. Methods and tools for objective assessment of psychomotor skills in laparoscopic surgery. *J Surg Res*. 2011;171(1): e81–95. https://doi.org/10.1016/j.jss.2011.06.034. Nov.
35. Zettervall SL, Haskins IN, Deery SE, Amdur RL, Lin PP, Vaziri K. Open colectomies of shorter operative time do not result in improved outcomes compared with prolonged laparoscopic operations. *Surg Laparosc Endosc Percutaneous Tech*. 2017;27(5): 361–365. https://doi.org/10.1097/SLE.0000000000000443. Oct.
36. Travis E, Woodhouse S, Tan R, Patel S, Donovan J, Brogan K. Operating theatre time, where does it all go? A prospective observational study. *BMJ*. 2014;349:g7182. https://doi.org/10.1136/bmj.g7182. Dec 15.
37. Feeley A, Feeley I, Merghani K, Sheehan E. A pilot study to evaluate the face & construct validity of an orthopaedic virtual reality simulator. *Injury*. 2021;52(7): 1715–1720. https://doi.org/10.1016/j.injury.2021.04.045. Jul.
38. Narain AS, Hijji FY, Yom KH, Kudaravalli KT, Haws BE, Singh K. Radiation exposure and reduction in the operating room: perspectives and future directions in spine surgery. *World J Orthoped*. 2017;8(7):524–530. https://doi.org/10.5312/wjo.v8.i7.524. Jul 18.
39. Thomas AA, Kim B, Derboghossians A, et al. Impact of surgical case order on perioperative outcomes for robotic-assisted radical prostatectomy. *Urol Ann*. 2014;6 (2):142–146. https://doi.org/10.4103/0974-7796.130645. Apr.
40. Pike TW, Mushtaq F, Mann RP, et al. Operating list composition and surgical performance. *Br J Surg*. 2018;105(8):1061–1069. https://doi.org/10.1002/bjs.10804. Jul.
41. Li X, Zhang Q, Dong J, Zhang G, Chai W, Chen J. Impact of surgical case order on peri-operative outcomes for total joint arthroplasty. *Int Orthop*. 2018;42(10): 2289–2294. https://doi.org/10.1007/s00264-018-3835-9. Oct.
42. Lavelle ES, Turner LC, Shepherd JP. Impact of case order on laparoscopic sacrocolpopexy: do surgeons need a warm-up? *Female Pelvic Med Reconstr Surg*. 2017;23(4):272–275. https://doi.org/10.1097/SPV.0000000000000388. Jul/Aug.
43. Makhdom AM, Almaawi A, Tanzer D, Tanzer M. Does warming up improve surgical outcome in total hip arthroplasty? *Eur J Orthop Surg Traumatol*. 2015;25(8): 1265–1269. https://doi.org/10.1007/s00590-015-1679-1. Dec.
44. Feeley A, Feeley I, Merghani K, Sheehan E. Use of virtual reality simulation in surgical training: a systematic review on predictive validity and current use in surgical curricula. *J Surg Simulat*. 2021;8:1–13. https://doi.org/10.1102/2051-7726.2021.0001.
45. Hoopes S, Pham T, Lindo FM, Antosh DD. Home surgical skill training resources for Obstetrics and gynecology trainees during a pandemic. *Obstet Gynecol*. 2020;136(1): 56–64. https://doi.org/10.1097/AOG.0000000000003931, 07.
46. Lohre R, Bois AJ, Athwal GS, Goel DP, (CSES) CSaES. Improved complex skill acquisition by immersive virtual reality training: a randomized controlled trial. *J Bone Joint Surg Am*. 2020;102(6), e26. https://doi.org/10.2106/JBJS.19.00982, 03.