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Virtual reality training compared with apprenticeship training in laparoscopic surgery: a meta-analysis

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ABSTRACT

INTRODUCTION Since its inception, laparoscopic surgery has evolved and new techniques have been developed due to technological advances. This requires a different and more complex skill set in comparison with open surgery. Reduced working hours, less training time and patient safety factors demand that such skills need to be achieved outside the operating theatre environment. Several studies have been published and have determined the effectiveness of virtual reality training.

We aimed to compare virtual reality training with the traditional apprenticeship method of training and determine whether it can supplement or replace the traditional apprenticeship model. We also aimed to perform a meta-analysis of the literature and develop conclusions with respect to the benefits achieved by adding virtual reality training on a regular basis to surgical training programmes.

METHODS A literature search was carried out on PubMed, MEDLINE, EMBASE and Google Scholar academic search engines using the MESH terms 'randomised controlled trials', 'virtual reality', 'laparoscopy', 'surgical education' and 'surgical training'. All randomised controlled trials published to January 2018 comparing virtual reality training to apprenticeship training were included. Data were collected on improved dexterity, operative performance and operating times. Each outcome was calculated with 95% confidence intervals and with intention-to-treat analysis; 24 randomised controlled trials were analysed.

FINDINGS Meta-analytical data were extracted for time, path length, instrument handling, tissue handling, error scores and objective structure assessment of technical skills scoring. There was significant improvement in individual trainee skill in all meta-analyses ($p < 0.0002$).

CONCLUSION This meta-analysis shows that virtual reality not only improves efficiency in the trainee's surgical practice but also improves quality with reduced error rates and improved tissue handling.

KEYWORDS

Laparoscopy – Virtual reality – Randomised controlled trials – Patient safety – Apprenticeship training

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Introduction

Laparoscopic surgery and the advent of robotic surgery has modernised surgical care, encouraging hospital and health authorities to shift toward a minimally invasive system of performing surgical procedures.[1] Thus, surgical trainees must acquire the skills and level of proficiency in laparoscopic surgery.[2] Setbacks and health policies safeguarding patient safety threaten and limit the exposure of surgical trainees to laparoscopic surgery.[3–7] To tackle this problem, surgical training centres provide opportunities through simulation and virtual reality.[1,4]

In contrast to the Halstedian mantra, simulation and technology safeguard patient safety and provide trainee feedback during their performance.[1] Unfortunately, there is no recent literature comparing virtual reality with apprenticeship training.[4,7] However, several randomised controlled trials (RCTs) have shown a positive attitude towards the implementation of simulation in surgical training programmes. Current literature reports a general agreement regarding the superiority in the proficiency of virtual reality to the apprenticeship model among trainees.[1,3,8,9]

The typical virtual reality setup is an enclosed device attached to a monitor with ports for insertion of instruments connected to a software-based system.[4,10,11,29] Different devices use different systems, some using tracking of motion for simulation.[7,11] Others use items directed at training individual skills (eg knotting).[7,9]

This meta-analysis had two aims: comparing virtual reality training with apprenticeship training to determine whether it replaces or supplements the latter, and providing data to develop conclusions about the benefits achieved by adding virtual reality training routinely for surgical trainees.

Methods

We carried out a literature search of PubMed, MEDLINE, EMBASE, Cochrane Library and Google Scholar academic search engines using the 'Advanced Search' setting and the medical subject headings 'randomised controlled trial', 'virtual reality', 'laparoscopy', 'surgical education' and 'surgical training'. To obtain specific studies, Boolean characters 'OR' and 'AND' were used, with wildcards such as '+', '"' and '?'. All RCTs published to January 2018 comparing virtual reality training to apprenticeship training were included. Unfortunately, the literature search did not provide any randomised controlled studies between 2015 and 2019.

Additional inclusion criteria were the use of validated virtual reality simulators and studies with objective scoring methods. We excluded RCTs using endoscopic techniques other than laparoscopy. Studies that fitted the inclusion criteria allocated their participants into a virtual reality training group (case) and an apprenticeship training group (control).

Three groups of participants were enrolled:

- naïve – participants with no exposure to laparoscopic surgery including medical students
- novice – surgical residents with some experience in laparoscopic surgery (ie still training)
- expert – laparoscopic surgeons who finished training programme.

The initial literature search yielded 32 RCTs fitting the inclusion criteria and provided sufficient data for the meta-analysis. Studies were analysed to ensure random sequence generator and blinding of participants; assessors and benchmark measurements were used to eliminate performance bias and eliminate selection bias, respectively. Using these criteria, eight studies were excluded, leaving 24 RCTs included in this meta-analysis. Data were collected on six parameters: operative time, path length, instrument handling, tissue handling, error scores and objective structured assessment of technical skills (OSATS) scoring.

The meta-analysis was performed following the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis statement and the Cochrane Collaboration statement (Fig 1).

The data were tabulated using Microsoft Excel and the analysis was done using Reference Manager 5.3 and SPSS 24.0. For each outcome, the mean difference was calculated with 95% confidence interval and with intention-to-treat analysis. Study heterogeneity was assessed by the I-square (I^2) and Chi-square (χ^2) tests.

Findings

The objectives were finalised by six meta-analyses for each of the six data sets mentioned above. For each of the six meta-analyses we used the data available depending on the six parameters we set out to analyse. For example, if four papers studied and compared the operative time in virtual reality training compared with apprenticeship training these were included (Tables 1 and 2).

Operative time

Operative time is the time taken to complete the assessment task planned on the individual RCTs. A total of 15 RCTs were included in the meta-analysis involving 433 participants: 250 in the virtual reality training group compared with 183 in the control traditional training group. The meta-analysis for the outcome operative time fell in favour of virtual reality training (Fig 2). The mean difference of operative time for virtual reality compared with traditional training was 0.84 minutes with 95% confidence intervals (CI) of –1.05 and –0.64 The results were statistically significant since CI did not include zero. The heterogeneity value was $\chi^2 = 10.15$ ($p < 0.00001$) $I^2 = 0\%$.[3,10–23]

Path length

Path length is the score performed for the recording of the economy of movement. Four randomised controlled trials were chosen involving a total of 112 participants: 57 (virtual reality training) compared with 55 (control traditional training). The meta-analysis for the path length outcome fell in favour of virtual reality training (Fig 3). The mean difference of path length for virtual reality compared with traditional training was 0.78 metres with confidence intervals of –1.17 and –0.39. The results were statistically significant since the confidence intervals did not include zero. The heterogeneity value was $\chi^2 = 1.23$ ($p < 0.0001$) $I^2 = 0\%$.[10,15,21,22]

Instrument handling

Instrument handling is the score obtained from blinded assessors for manipulation of instruments. Six RCTs were chosen, with a total of 131 participants (66 in the virtual reality training group vs 65 in the control traditional training group). The meta-analysis for instrument handling outcome was in favour of virtual reality training (Fig 4). The mean difference of the instrument handling score for virtual reality compared with traditional training was 1.34 (95% CI –1.73 and –0.95). The results were statistically significant since the confidence intervals did not include zero. The heterogeneity value was $\chi^2 = 3.38$ ($p < 0.00001$) $I^2 = 0\%$.[12,13,22,24–26]

Tissue handling

Tissue handling is the score obtained from blinded assessors for handling of tissues during the test. Six RCTs were chosen including a total of 200 participants (116 in the virtual reality training group vs 84 in the control group). The meta-analysis for the tissue handling outcome fell in favour of virtual reality training (Fig 5). The mean difference of tissue handling score for virtual reality compared with traditional training was 0.58 (95% CI –0.88 and –0.28). The results were statistically significant since the confidence intervals did not include zero. The heterogeneity value was $\chi^2 = 6.36$ ($p < 0.0001$) $I^2 = 21\%$.[6,24–28]

Error score

The error score is the score obtained from blinded assessors for errors for each test RCT or total number of errors recorded in the assessment process. Five RCTs were chosen consisting of a total of 75 participants (38 in the virtual reality training group vs 37 in the control group). The meta-analysis for the error scores outcome fell in favour of virtual reality training (Fig 6). The mean difference of error scores for virtual reality compared with traditional

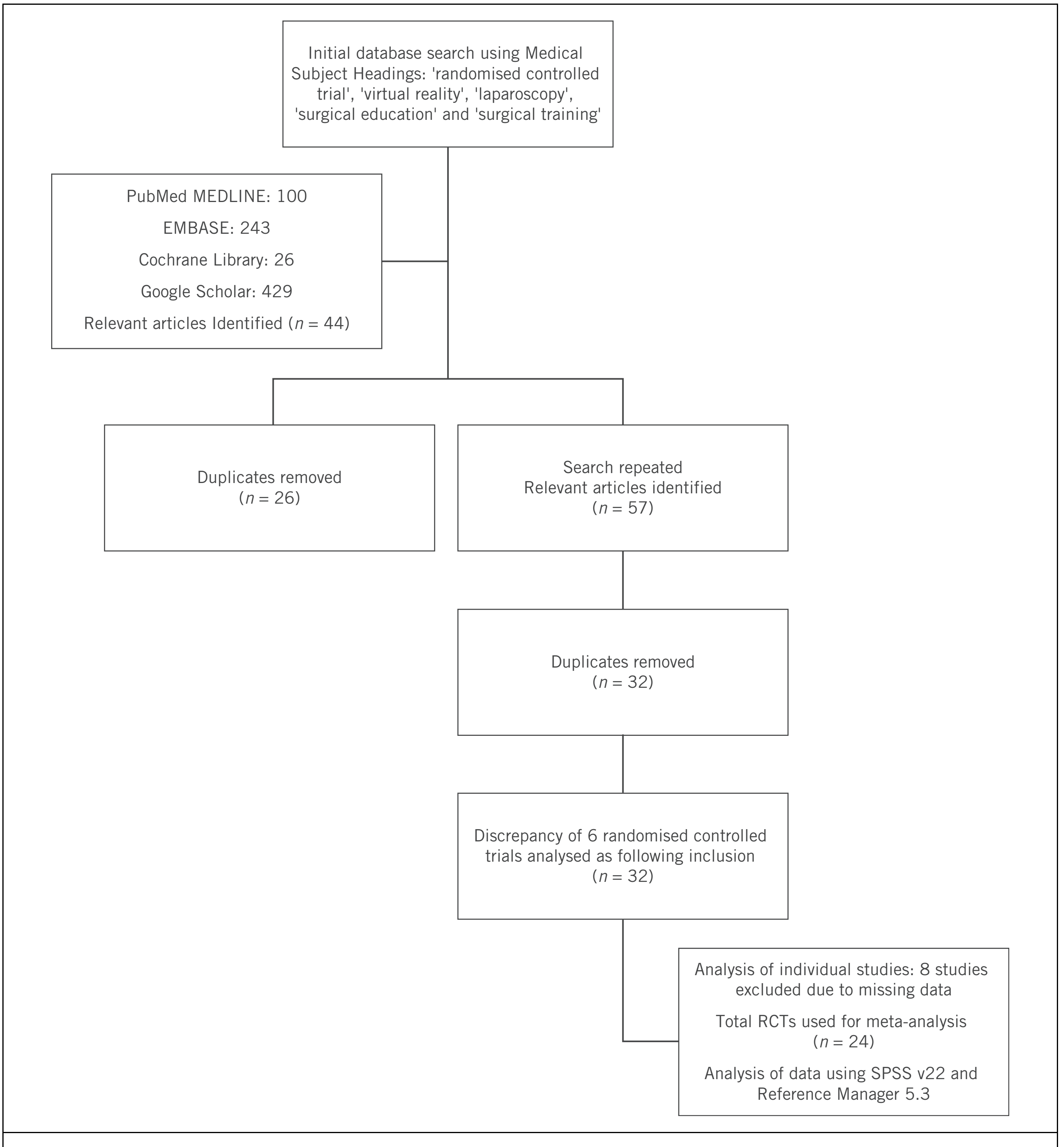

Figure 1 Flow diagram illustrating the studies included

Table 1 Summary of characteristics of included studies

Study	Participants (*n*)	Benchmark measurements	Level of expertise	VR training modality	VR training performed	Control group	Assessment method	Recorded results
Aggarwal *et al* (2007)[10]	19	10 experienced surgeons completed 2 laparoscopic cholecystectomies	Novice	LapSim® (Surgical Sciences Sweden AB)	Proficiency based: Calot's triangle dissection + 3 porcine laparoscopic cholecystectomies	5 cadaveric porcine laparoscopic cholecystectomies	5 porcine laparoscopic cholecystectomies	ROVIMAS; time taken, total path length, total number of movements, video rating scores
Ahlberg *et al* (2007)[39]	13	5 experienced surgeons performed 6 tasks in recorded results	Novice	LapSim	Proficiency based: 6 tasks performed under supervision until expert level attained	No additional training	10 laparoscopic cholecystectomies performed per trainee	Errors in exposure, clipping and tissue division, dissection errors, total errors, surgical time
Ahlborg *et al* (2013)[3]	28	Nil (No benchmark measurement)	Novice	LapSim	2-day practice on simulator	No additional training	3 supervised laparoscopic tubal occlusions	Visuospatial ability, flow scores, time
Ali *et al* (2014)[11]	60	Nil	Novice and expert	LapSim	LapSim group: camera navigation, instrument navigation, coordination, grasping, cutting, lifting, suturing, dissection. Box model group: excise a drawn circle, move pegs, cut the outer balloon, grasp and throw beans, peel an orange, suture and tie a knot, introduce an epidural catheter into an intravenous infusion tube.	No additional training	Supervised laparoscopic tubal occlusions	OSA-LS; operation time, total score, economy of movements, movements/instrument handling, economy of time, respect of tissue
Andreatta *et al* (2006)[12]	19	Nil	Novice	Lap Mentor™ (3D Systems)	Proficiency based: camera navigation, eye-hand coordination, clipping and grasping, cutting, electrocautery and translocation of objects	No additional training	Laparoscopic skills exercises on anaesthetised male pigs	Camera navigation, eye–hand coordination, time, efficiency of motion, instrument handling, perceptual ability, safe electrocautery, safe clipping
Calatayud *et al* (2010)[13]	10	Nil	Novice and expert	LapSim	Preoperative VR training termed as 'warm-up'	No additional training	Supervised laparoscopic cholecystectomy	OSATS; respect for tissue, time and motion, instrument handling, knowledge of instruments, use of assistants, flow of operation, knowledge

Cosman *et al* (2007)[14]	10	10 experienced surgeons performed clipping task on the simulator	Novice	LapSim	Proficiency based: clipping task + training protocol for a maximum of 1 hour/day	No additional training	Supervised application of clips and divide cystic duct or cystic artery during a laparoscopic cholecystectomy	Errors, global score, time
Hogle *et al* (2009)[27]	33	Nil	Novice and expert	LapSim	Proficiency based: novice – camera navigation, instrument navigation, coordination, grasping, lifting and grasping, cutting and clip applying; expert – training on a laparoscopic simulator for 5 weeks	No additional training	Supervised laparoscopic cholecystectomy	GOALS; Depth perception, bimanual dexterity, efficiency, efficiency, tissue handling, autonomy, operative time
Hung *et al* (2012)[28]	24	Nil	Novice	DaVinci® Skills Simulator (Mimic Technologies Inc.)	17 simulator exercises over 10 weeks	No additional training	Porcine bowel resection, cystotomy and repair and partial nephrectomy using robotic system	GOALS; objects dropped, motion economy, excessive instrument force, instrument collisions, missed targets, time, broken vessels, blood loss
Hyltander *et al* (2002)[5,22]	24	Nil	Naïve	LapSim	4 simulator exercises: camera navigation, instrument navigation, instrument handling, manipulating items for 2 hours/week for 5 weeks	No additional training	Laparoscopic surgery on two anaesthetised pigs	Camera navigation, instrument navigation, combination, extended combination, time
Larsen *et al* (2009)[23]	21	Nil	Novice	LapSim	Oral introduction on simulator + simulator training in lifting and grasping and cutting + completion of a simulated right sided salpingectomy. Training cycles of 45–60 minutes.	No additional training	Supervised laparoscopic salpingectomy	Duration of training, time, score
Lucas *et al* (2008)[25]	32	Nil	Naïve	Lap Mentor	8 simulator exercises: camera manipulation, hand–eye coordination, clipping, grasping, 2-handed manoeuvres, cutting, fulguration and object translocation. 6 unsupervised training sessions of 30 minutes each.	No additional training	Porcine laparoscopic nephrectomy	OSATS; respect for tissue, time and motion, instrument handling, knowledge of instruments, use of assistants, flow of operation, knowledge

Lucas *et al* (2008)[24]	32	Nil	Naïve	Lap Mentor	8 simulator exercises: camera manipulation, hand–eye coordination, clipping, grasping, 2-handed manoeuvres, cutting, fulguration and object translocation. 6 unsupervised training sessions of 30 minutes each.	No additional training	Supervised simple laparoscopic cholecystectomy	OSATS; respect for tissue, time and motion, instrument handling, knowledge of instruments, use of assistants, flow of operation, knowledge
Madan & Frantzides (2007)[40]	65	Nil	Naïve	MIST-VR	Simulator exercises: acquire and place, transfer and place, transversal, withdraw and insert, diathermy, manipulate and diathermy. 10 sessions of 20 minutes each for both simulator and box-trainer groups.	No additional training	Four tasks assessed in a porcine laboratory	Tissue handling, placing bowel in retrieval bag, liver biopsy, stapling, 'running' the bowel
Maschuw *et al* (2011)[15]	50	Nil	Novice	LapSim	Proficiency based simulator exercises + virtual laparoscopic cholecystectomy for twice a week sessions for 3 months	No additional training	VR simulation assessing predefined criteria	Time, path length, angular path, tissue damage, economy of motion
McClusky *et al* (2004)[6]	12	Experienced surgeons performed laparoscopic cholecystectomy	Novice	MIST-VR	Simulator exercises: manipulation and diathermy	No additional training	Supervised laparoscopic cholecystectomy	OSATS; time, path length, angular path, operative steps, score
Palter *et al* (2012)[21]	25	Nil	Novice	LapSim	Proficiency based: simulator exercises + video instruction for a duration of 5 months	No additional training	Supervised laparoscopic right hemicolectomy	OSATS; respect for tissue, time and motion, instrument handling, knowledge of instruments, use of assistants, flow of operation, knowledge
Palter *et al* (2013)[16]	18	Nil	Novice	LapSim	Theoretical training + case-based learning + simulator training for 6 months	No additional training	5 laparoscopic cholecystectomies in operating theatre, VR assessment and simulated crisis scenario	Time, path length, angular path, number of errors

Sergio *et al* (2014)[26]	14	Nil	Naïve	Lap Mentor	Virtual sigmoid colectomy: 2-hour training on simulator	No additional training	Laparoscopic sigmoid resection on anaesthetised pig	Tissue handling, dexterity, instrument handling, exposure, haemostasis, flow of tasks, technical skills score
Seymour *et al* (2002)[29]	16	4 experienced surgeons performed the 10 trials in recorded results	Novice	MIST-VR	Proficiency based: two trials performed with both hands. Training sessions lasted approx. 1 hour.	No additional training	Supervised laparoscopic cholecystectomy	Number of errors
Tanoue *et al* (2005)[18]	30	Nil	Naïve	MIST-VR	1 simulator exercise - one stitch and two ties including left- and right-hand repetitions for 2 hours/day for 2 days	No additional training	One stitch and two ties including left and right repetitions in a box trainer	Improvement rate
Tanoue *et al* (2008)[17]	35	Nil	Naïve	MIST-VR	3 simulator/box trainer exercises: suturing, knot tying and diathermy including left- and right-hand repetitions for 2 hours/day for 2 days	Watched an educational video for 30 minutes	Stitch needle to place one stitch and two ties between dots printed on a rubber sheet in a box trainer	Time, speed
Verdaasdonk *et al* (2008)[19]	20	Nil	Novice	Simendo®	Proficiency based: knot-tying repeated for 10 times	No additional training	Laparoscopic knot on an anaesthetised porcine model	Instrument handling, needle and suture drops, attempted loops, knot tightening
Youngblood *et al* (2005)[20]	46	Experienced surgeons performed laparoscopic techniques	Naïve	LapSim and tower trainer	3 simulator tasks: grasping and placing gallstones in endo bag, running the bowel, clipping and cutting an artery. 4 supervised, 45-minute training sessions.	No additional training	Laparoscopic assessment in porcine laboratory	Time, accuracy

GOALS, global operative assessment of laparoscopic skills; MIST-VR, minimally invasive surgery trainer – virtual reality; OSA-LS, objective structured assessment – laparoscopic salpingectomy; OSATS, objective structured assessment of technical skills; ROVIMAS, RObotics VIdeo and Motion Assessment Software; VR, virtual reality

Table 2 Summary of characteristics of excluded studies

Study	Participants (*n*)	Benchmark measurements	Level of expertise	VR Training Modality	VR Training Performed	Control group	Assessment method	Recorded results	Reason for exclusion
Clevin & Grantcharov (2008)[41]	16	Nil	Novice	LapSim® (Surgical Sciences Sweden AB)	Simulator exercises: camera navigation, instrument navigation, coordination, grasping, lifting, cutting and clip applying. Box training exercises: moving pegs, cutting, introducing an epidural catheter in an infusion tube, applying clips, cutting for 5-minute didactic hands-on instruction on simulator followed by 3 hours on a box model trainer.	No additional training	Simulator exercises	Time, misses, drift, path length, angular path	No documentation of specific mean results other than *p*-value
Gallacher *et al* (2013)[42]	225	Nil	Novice and expert	MIST-VR	Simulator exercises: experts and novices: holding items, instrument manipulation	No additional training	Simulator exercises - cutting, grasping, instrument manipulation, object manipulation	Correct incisions, errors	No documentation of specific mean results other than *p* -value
Grantcharov *et al* (2004)[43]	16	Nil	Novice	MIST-VR	6 simulator exercises	No additional training	Simulated laparoscopic cholecystectomy	Errors, economy of movement	No documentation of specific mean results other than *p* -value
Hiemstra *et al* (2011)[8]	50	Nil	Naïve	Simendo®	Simulator exercises	No additional training	Simulator exercises	Time, path length, motion	Evaluation of data showed comparison done between VR, box-trainer and control. data inadequate for the study
Munz *et al* (2004)[44]	24	Nil	Naïve	LapSim	Simulator exercises: instrument navigation, coordination, grasping, cutting, precision, speed for 3 weekly sessions of 30 minutes each	No additional training	Simulator exercises	Distance, time, economy of movement, errors	No documentation of specific mean results other than *p* -value

Pearson *et al* (2002)[9]	43	Nil	Naive	MIST-VR	Simulator exercises: knot tying	No additional training	10 knot-tying trials	Economy of movement, errors, time	No documentation of specific mean results other than *p* -value
Torkington *et al* (2000)[45]	30	Nil	Naive	MIST-VR	6 simulator tasks: minimal-access training tasks performed over a period of one hour	No additional training	Drills performed using the Imperial College Surgical Assessment Device	Distance, movements, speed, time	Data compared values for both right- and left-handed use of laparoscopic tools. No overall data was recorded. Excluded to avoid bias.
Van Bruwaene *et al* (2015)[46]	30	Nil	Novice	Lap Mentor™ (3D Systems)	Proficiency based: simulator exercises and box trainer exercises: laparoscopic cholecystectomy exercises for 5 hours	No additional training	Laparoscopic cholecystectomy on an anaesthetised pig	Time, performance score	No documentation of specific mean results other than *p*-value

MIST-VR, minimally invasive surgery trainer – virtual reality; VR, virtual reality

training was 0.95 (95% CI –1.45 and –0.44). The results were statistically significant since the confidence intervals did not include zero. The heterogeneity value was χ^2 = 6.21 ($p < 0.0002$) I^2 = 36%.[6,14,16,19,29]

OSATS score

The OSATS score is the total of seven parameters including respect for tissue, time and motion, instrument handling, knowledge of instruments, flow of operation, formed planning, and knowledge of the specific procedure. Four RCTs were chosen consisting of a total of 99 participants (50 in the virtual reality training group vs 49 in the control group). The meta-analysis for the OSATS outcome was in favour of virtual reality training (Fig 7). The mean difference of OSATS score for virtual reality compared with traditional training was 0.92 (95% CI –1.33 and –0.50). The results were statistically significant since the confidence intervals did not include zero. The heterogeneity value was χ^2 = 0.52 ($p < 0.0001$).

Discussion

This study aimed to compare virtual reality training with the traditional apprenticeship approach of teaching and to establish whether it can supplement or replace the latter training model.

A thorough literature search highlighted 24 RCTs, which provided the essential numerical data to carry out separate meta-analyses within the six recorded parameters as described in the methodology. For the purpose of this study, a *p*-value of less than 0.5 was considered as being statistically significant and this was applied to each meta-analysis.

The results from each respective meta-analysis suggested a significant concordance towards a positive effect observed from supplementing the laparoscopic trainee with virtual reality simulations. Furthermore, this study emphasised that virtual reality training accentuated aspects crucial to adequate surgical performance. As noted, participants in the virtual reality training model completed the assessment in a shorter time compared with the control group. In addition, the participants scored better overall in the OSATS and showed good technical ability throughout instrument/tissue handling. The economy of movement was better and the participants did not succumb to the same number of mistakes of the control group. An exception was the study by Pater *et al*, which showed a borderline result.[16]

Unfortunately, this meta-analysis could not prevent the existence of systematic bias. Some studies did not specify whether individuals who had the opportunity to pre-train on virtual reality systems were excluded from their study groups. This could have made an unfair comparison when virtual reality training was used as the assessment of the traditional apprenticeship model of training among these participants.

It was evident that the virtual reality training model assisted surgical trainees to exercise safer and more efficient tissue/instrument handling techniques with a minimal chance of error. All the meta-analyses performed within their respective subsections/parameters tended towards a more favourable outcome for virtual reality training. In the parameters, subjective scoring was an issue. Thus, we included studies involving multiple expert observers to reduce the risk of observer bias.

Virtual reality training models permit the laparoscopic trainee to acquire the fundamental skills required from

Study or subgroup	VR Mean	VR SD	VR Total	TT Mean	TT SD	TT Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Aggrawal *et al.* 2007[10]	1,365	319.59	9	1,598	319.59	10	4.9%	–0.70 [–1.63, 0.24]
Ahlborg *et al.* 2013[3]	340	373.53	9	760	373.53	19	6.0%	–1.09 [–1.94, –0.24]
Ali *et al.* 2014[11]	340	139.51	40	425	139.51	20	14.4%	–0.60 [–1.15, –0.05]
Andreatta *et al.* 2006[12]	166.1	49.64	10	220.11	49.64	9	4.5%	–1.04 [–2.01, –0.07]
Calatayud *et al.* 2010[13]	180	97.7	5	240	97.7	5	2.6%	–0.55 [–1.83, 0.72]
Cosman *et al.* 2007[14]	94	60.29	5	172	60.29	5	2.2%	–1.17 [–2.57, 0.23]
Hung *et al.* 2011[28]	1,268	454.96	12	1,919	454.96	12	5.2%	–1.38 [–2.29, –0.47]
Hyltander *et al.* 2002[22]	352.6	88.86	12	473	88.86	12	5.4%	–1.37 [–2.20, –0.41]
Larsen *et al.* 2009[23]	720	424.33	11	1,440	424.33	10	4.2%	–1.63 [–2.64, –0.61]
Muschuw *et al.* 2010[15]	141.27	92.82	25	213.93	92.82	25	13.0%	–0.77 [–1.35, –0.19]
Palter *et al.* 2013[16]	2,700	538.57	10	3,360	538.57	8	4.1%	–1.17 [–2.19, –0.14]
Tanoue *et al.* 2005[18]	200.9	172.12	20	343	172.12	10	6.9%	–0.80 [–1.59, –0.01]
Tanoue *et al.* 2008[17]	208.4	135.75	40	304.9	135.75	15	11.6%	–0.70 [–1.31, –0.09]
Verdaasdonk *et al.* 2008[19]	262	105.72	9	374	105.72	10	4.6%	–1.01 [–1.98, –0.04]
Youngblood *et al.* 2005[20]	61.29	157.46	33	105.77	157.46	13	10.4%	–0.28 [–0.92, 0.37]
Total (95% CI)			**250**			**183**	**100.0%**	**–0.84 [–1.05, –0.64]**

Heterogeneity: Chi² = 10.15, df = 14 (p = 0.75); I² = 0%
Test for overall effect: Z = 7.97 (p = 0.00001)

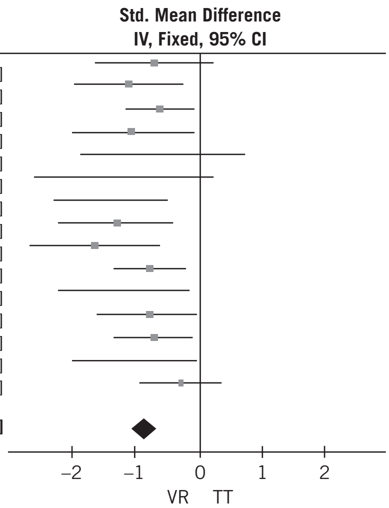

Figure 2 Forrest plot for operative time of virtual reality (VR) compared with traditional training (TT)

Study or subgroup	VR Mean	VR SD	VR Total	TT Mean	TT SD	TT Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Aggrawal *et al.* 2007[10]	5.44	4.08	9	8.6	4.08	10	17.2%	–0.74 [–1.68, 0.20]
Muschuw *et al.* 2010[15]	734.41	584.88	25	1,166.4	584.88	25	45.9%	–0.73 [–1.30, –0.15]
Palter *et al.* 2012[21]	176	152.71	13	272	152.71	12	23.3%	–0.61 [–1.41, 0.20]
Palter *et al.* 2013[16]	2.43	0.65	10	3.33	0.65	8	13.7%	–1.32 [–2.37, –0.27]
Total (95% CI)			**57**			**55**	**100.0%**	**–0.78 [–1.17, –0.39]**

Heterogeneity: Chi² = 1.23, df = 3 (p = 0.75); I² = 0%
Test for overall effect: Z = 3.95 (p < 0.00001)

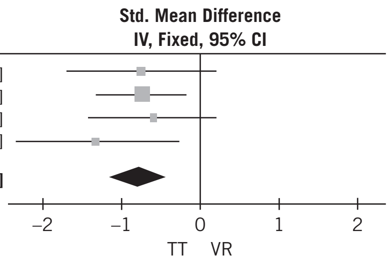

Figure 3 Forrest plot for path length of virtual reality (VR) compared with traditional training (TT)

Study or subgroup	TT Mean	TT SD	TT Total	VR Mean	VR SD	VR Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Andreatta *et al.* 2006[10]	2.06	0.83	9	3.58	0.83	10	12.7%	–1.75 [–2.85, –0.65]
Calatayud *et al.* 2010[13]	3	0.78	5	4	0.78	5	7.8%	–1.16 [–2.56, 0.24]
Hyltander *et al.* 2002[22]	15.6	4.79	12	24.3	4.79	12	16.3%	–1.75 [–2.72, –0.79]
Lucas *et al.* 2008[24]	2.03	1.74	16	3.72	1.74	16	28.2%	–0.95 [–1.68, –0.21]
Lucas *et al.* 2008[25]	1.7	1	16	2.9	1	16	26.6%	–1.17 [–1.93, –0.41]
Sergio *et al.* 2014[26]	2.3	0.24	7	2.8	0.24	7	8.4%	–1.95 [–3.30, –0.60]
Total (95% CI)			**65**			**66**	**100.0%**	**–1.34 [–1.73, –0.95]**

Heterogeneity: Chi² = 3.38, df = 5 (p = 0.64); I² = 0%
Test for overall effect: Z = 6.72 (p < 0.00001)

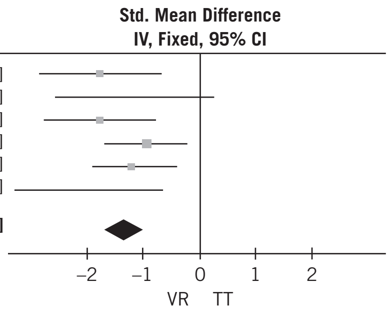

Figure 4 Forrest plot for instrument handling of virtual reality (VR) compared with traditional training (TT)

surgeons such as camera navigation, grasping, cutting and suturing. Different virtual reality systems provide different levels of difficulty, permitting staggered training possibilities. Similarly, to a virtual reality setup, box trainers offer the trainee the possibility to develop basic laparoscopic skills.[30] Newer virtual reality systems also provide statistical data, such as time and path length and provide the trainee with a baseline to evaluate improvement.[1]

However, the virtual reality training model also has some limitations and issues which need to be addressed to ensure an effective training programme for surgical trainees. In comparison with the traditional approach of training, the virtual reality training setup fails to produce haptic feedback to the trainee. This feedback would allow for a proper understanding of the force required to avoid tissue damage and would provide real time correction of the errors if

	TT			VR				
Study or subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**Std. Mean Difference IV, Fixed, 95% CI**
Hogle *et al.* 2009[27]	2.55	0.6	17	2.8	0.6	16	18.8%	–0.41 [–1.10, 0.28]
Hung *et al.* 2011[28]	72	9.2	12	74	9.2	12	13.9%	–0.21 [–1.01, 0.59]
Lucas *et al.* 2008[24]	2.13	1.24	16	3.34	1.24	16	16.6%	–0.95 [–1.69, –0.21]
Lucas *et al.* 2008[25]	2.6	1.34	16	3.1	1.34	16	18.4%	–0.36 [–1.06, 0.34]
Madan *et al.* 2007[41]	62.8	28.33	16	79.1	28.33	49	27.3%	–0.57 [–1.14, 0.00]
Sergio *et al.* 2014[26]	2.3	0.24	7	2.8	0.24	7	4.9%	–1.95 [–3.30, –0.60]
Total (95% CI)			**84**			**116**	**100.0%**	**–0.58 [–0.88, –0.28]**

Heterogeneity: $Chi^2 = 6.36$, df = 5 ($p = 0.27$); $I^2 = 21\%$
Test for overall effect: Z = 3.80 ($p = 0.00001$)

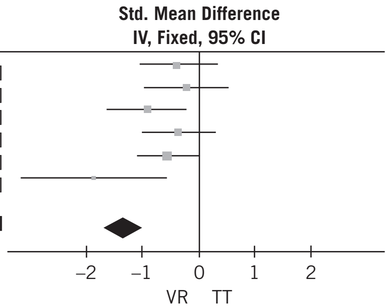

Figure 5 Forrest plot for tissue handling of virtual reality (VR) compared with traditional training (TT)

	VR			TT				
Study or subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**Std. Mean Difference IV, Fixed, 95% CI**
Cosman *et al.* 2007[14]	10	5.49	5	18	5.49	5	12.1%	–1.32 [–2.76, 0.13]
McClusky *et al.* 2004[6]	11.7	4.37	6	19.7	4.37	6	12.9%	–1.69 [–3.09, –0.29]
Palter *et al.* 2013[16]	2	72.91	10	3	72.91	8	29.3%	–0.01 [–0.94, 0.92]
Seymour *et al.* 2002[29]	1.19	3.83	8	7.38	3.83	8	19.0%	–1.53 [–2.68,–0.37]
Verdaasdonk *et al.* 2008[19]	24	11.03	9	36	11.3	10	26.8%	–1.03 [–2.00, –0.05]
Total (95% CI)			**38**			**37**	**100.0%**	**–0.95 [–1.45, –0.44]**

Heterogeneity: $Chi^2 = 6.21$, df = 4 ($p = 0.18$); $I^2 = 36\%$
Test for overall effect: Z = 3.69 ($p = 0.00002$)

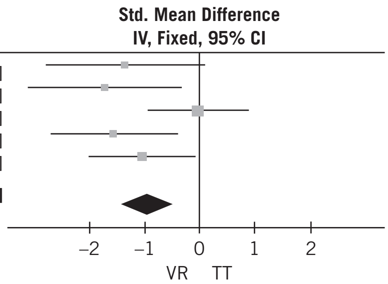

Figure 6 Forrest plot for error scores of virtual reality (VR) compared with traditional training (TT)

	TT			VR				
Study or subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**Std. Mean Difference IV, Fixed, 95% CI**
Calatayud *et al.* 2010[13]	19.25	6.05	5	28.5	6.05	5	8.2%	–1.38 [–2.84, 0.08]
Lucas *et al.* 2008[24]	17.25	13.27	16	27.94	13.27	16	33.7%	–0.79 [–1.51, –0.06]
Lucas *et al.* 2008[25]	15.7	5.45	16	21	5.45	16	32.5%	–0.95 [–1.68, –0.21]
Palter *et al.* 2012[21]	8	8.64	12	16	8.64	13	25.6%	–1.90 [–1.73, –0.07]
Total (95% CI)			**49**			**50**	**100.0%**	**–0.92 [–1.33, –0.50]**

Heterogeneity: $Chi^2 = 0.52$, df = 3 ($p = 0.91$); $I^2 = 0\%$
Test for overall effect: Z = 4.28 ($p < 0.00001$)

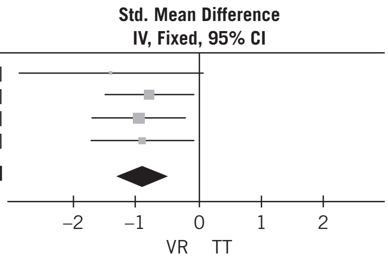

Figure 7 Forrest plot for objective structured assessment of technical skills score of virtual reality (VR) compared with traditional training (TT)

they were to happen.[8] Thus, it was noted that simulation training should be accompanied with feedback, evaluation and formal assessment via methods (eg global operative assessment of laparoscopic skills and OSATS). Literature reviews confirm that both tests are valid in providing formal feedback, but, to date, no study has been identified to compare both scoring systems.[13,21,24,25,27,28,31]

Despite many RCTs being performed and published, no quantitative meta-analytical study has highlighted the benefit of virtual reality training.[30,31] The virtual reality system requires a relatively high-tech setup requiring expensive maintenance and level of functioning. Fortunately, alternatives have been identified, such as box trainers.[32] This necessitates meta-analytical data to enable hospitals to properly evaluate such investment decisions.[30]

This study did not explore the cost–benefit of the two training models, and many variables have been identified that could affect the economic burden of the healthcare sector. Virtual reality simulation equipment is more expensive than box trainer equipment.[10,32,33] Although the price of simulators may vary depending upon the techniques, equipment and learning outcomes, apprenticeship training is not without costs. Bridges and Diamond observed that the operating time increased significantly among surgical trainees in comparison with more senior peers.[33] In fact, this increased operating time amounted to US$12,000/year for every surgical trainee.[33–35]

Moreover, in addition to operating times, complication rates were noted to be higher in junior surgeons.[10,34–36] This negatively impacts the length of stay of patients, and thus ultimately increases the economic burden on medical institutions. Studies suggest that the cost of virtual reality training systems needs to be balanced against the cost of the longer operating time and complication rates through traditional surgical training.[33,36]

Despite the new technology incorporated within the virtual reality setup, instruments need to be tested for face and construct validity. This should encourage more software developers to invest in equipment that would provide the trainee with statistical data of their performance in the virtual reality training programme, allowing an overall improvement in psychomotor skills.

Policies implemented in European and American institutions, such as reduced working hours (time constraints), and the importance of safeguarding patient safety are a detriment to the quality of teaching in the operating theatre environment.[3,4,7,22,23] Thus, virtual reality training offers an alternative to the teaching opportunities within the operating theatre and ensures appropriate levels of safety.[1,26]

In contrast to the apprenticeship model of training, virtual reality training cannot fully prepare the surgical trainee for any anatomical variations they might encounter in real-life surgery. These variations are common within the human body and thus skills acquired on this single computer simulation program may not be applicable in practice.[35–37]

In summary, this meta-analysis has further confirmed that virtual reality training improves efficiency and quality of tissue handling, with reduced error rates, when used in conjunction with the laparoscopic surgeon's individual ability and knowledge.

Conclusion

Although the 24 studied RCTs did not demonstrate actual evidence of improved patient safety and improved cost–benefit when comparing the virtual reality training model to the apprenticeship model, the participants using virtual reality simulations produced significant results in most parameters. Reduced operation time, better instrument and tissue handling technique and minimal errors were observed throughout the results. If such parameters were to be translated into practice, we believe that the virtual reality training model would allow for a reduced economic burden, improved patient safety system and a decrease in operation time and the incidence of surgical complications within the operating theatre.

We suggest that a separate study should focus on performing a cost–benefit analysis. This would quantify the impact of virtual reality training on patient outcomes, hospital stay and, ultimately, on the medical institutions themselves. Furthermore, it would also be possible to provide an average cost per trainee undergoing such a training programme.

Finally, virtual reality training should not replace the experience of a surgical trainee acquired in the theatre setting. Therefore, it should be used as a supplement throughout the surgical training programme. To improve the validity of virtual reality training tools, one should make use of other formal assessment methods which allow adequate feedback to provide the trainee with an individual baseline for further development.

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