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Telementoring of Surgeons: A Systematic Review

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Abstract

Background. Telementoring is a technique that has shown potential as a surgical training aid. Previous studies have suggested that telementoring is a safe training modality. This review aimed to review both the technological capabilities of reported telementoring systems as well as its potential benefits as a mentoring modality. *Methods*. A systematic review of the literature, up to July 2017, was carried out in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Study quality was assessed using the Oxford Levels of Evidence proforma. Data were extracted regarding technical capabilities, bandwidth, latency, and costs. Additionally, the primary aim and key results were extracted from each study and analyzed. *Results*. A total of 66 studies were identified for inclusion. In all, 48% of studies were conducted in general surgery; 22 (33%), 24 (36%), and 20 (30%) of studies reported telementoring that occurred within the same hospital, outside the hospital, and outside the country, respectively. Sixty-four (98%) of studies employed video and audio and 38 (58%) used telestration. Twelve separate studies directly compared telementoring against on-site mentoring. Seven (58%) showed no difference in outcomes between telementoring and on-site mentoring. No study found telementoring to result in poorer postoperative outcomes. *Conclusions*. The results of this review suggest that telementoring has a similar safety and efficacy profile as on-site mentoring. Future analysis to determine the potential benefits and pitfalls to surgical education through telementoring are required to determine the exact role it shall play in the future. Technological advances to improve remote connectivity would also aid the uptake of telementoring on a larger scale.

Keywords

telemedicine, telementoring, technology, training, education

Introduction

Surgery in the 21st century is facing a number of new pressures. There is an increasing clinical burden facing the global surgical community. As a result of shifting patterns of disease and an increase in global population, surgery is likely to play an increasing role in treating both acute and chronic diseases.[1] Low- and low-middle income countries have largely shouldered the rising clinical burden, with restricted access for their populations to safe, timely, and affordable surgical care.[1] However, issues regarding access to healthcare are not limited to low-income countries. In high-income countries, centralization of care has been shown to improve outcomes across a number of conditions.[2] Centralization typically concentrates specialist surgery in metropolitan hubs and an unintended consequence of this is the restriction of access to surgery in rural areas.[3]

The application of telemedicine is one modality that has the potential to help face these challenges. Telemedicine has previously been defined as "the use of medical information exchanged from one site to another via electronic communications to improve a patient's clinical health status."[4]

Telementoring in particular provides a unique solution, to increase both quality and access to surgical care. Telementoring is "a relationship, facilitated by telecommunication technology, in which an expert (Mentor) provides guidance to a less experienced learner (Mentee) from a remote location."[4] Previous studies have demonstrated that telementoring can be used effectively and reliably in a variety of settings.[5] The studies describing these have a large amount of heterogeneity in the technology used, as well as setting, and outcomes described.

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Previous systematic reviews have been conducted into telementoring.[5,6] These were not able to comprehensively review the topic and either focused primarily on the technical details of telementoring or its effectiveness. Additionally, since their search was conducted, further original studies have been published detailing experience with telementoring. Therefore, the aim of this systematic review was to comprehensively review both the technological capabilities of specific telementoring set-ups and also evaluate clinical outcomes and educational benefits.

Methods

Search Strategy

A literature search was conducted in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. A free text search was carried out of the EMBASE and MEDLINE databases up to July 2017. The search terms used were "telementoring," "telemedicine," "teleconferencing," "telemonitoring," "telepresence," "interoperability," "teleconsultation," "telestration," and "surgery." Boolean operators of AND and OR were used to extend the search. In addition, a manual search was conducted of the bibliographies of included studies and previous systematic reviews on the topic. Two researchers (SE and DKTY) carried out the literature search and data extraction independently. Any discrepancies were resolved by consensus.

Selection Criteria and Evidence Quality

Peer-reviewed, original studies in English were selected for inclusion if they used telementoring, as defined by the SAGES (Society of American Gastrointestinal and Endoscopic Surgeons) telementoring initiative,[4] and delivered in real-time. Additionally, studies were selected that demonstrated an aim that was clinical (the effect of telementoring on outcomes); educational (the effect of telementoring on surgical training); or a telementoring feasibility pilot. Studies were excluded if telementoring lacked bidirectional communication between trainee and mentor. Duplication analysis of the same cohort was avoided by selecting the latest publication from a study group. Evidence quality was assessed using the "Oxford Centre for Evidence-based Medicine: Levels of Evidence" proforma.

Data Extraction

Full-text analysis was carried out on selected studies. Data were extracted detailing the specialty, specific operations, whether the procedures were carried out on simulated models, animals, cadavers or live patients. Technical capabilities of the technologies used were also extracted, including bandwidth, video latency, and costs (Supplementary Material 1, available in the online version of the article). Data were securely stored, with password protection using Excel (Microsoft Corporation, Redmond, WA), allowing for descriptive statistics to be used in analyzing the extracted data. The aims and key results of each study were initially extracted independently by two researchers (SE and DKTY). Any discrepancies (n = 1) were resolved by consensus after revisiting the articles.

Results

The original database search identified 5153 articles, whilst the free-hand search of reference lists identified 8 additional studies. After removal of duplicates and screening of titles and abstracts, 157 full-text articles were assessed. A total of 66 studies were subsequently assessed as being suitable for inclusion[7-72] (Figure 1).

The majority of studies were of level IV evidence (n = 49; 74%), as they were either case series or poor-quality case-control or cohort studies. These studies covered a number of different specialties, but most notably focused on general surgery (n = 32, 48%) and urology (n = 15; 23%) (Table 1).

A summary of the key findings from each study is shown in Table 2. Six studies had a clinical aim; 3 had an educational aim; 44 had both a clinical and educational aim; and 13 aimed to show telementoring feasibility.

The individual capabilities of the telementoring systems used across the studies are outlined in Table 3. Ninety-seven percent of studies used combination audio-video (AV) systems to transmit data between trainee and mentor. Fifty-eight percent of these studies implemented screen notation, which would either involve telestration (annotation on live image), or the overlaying of images on top of the trainee visual field. Other capabilities described included: mentor control of the camera (n = 8; 12%), mentor robotic assistance (n = 4; 6%), mentor control of energy device (n = 2; 3%), and extracorporeal annotation (n = 1; 2%).

Technical Reporting of Telementoring

Technical features of telementoring were poorly reported. Bandwidth was reported showing 2 studies (3%) conducted at speeds of ≤150 kbps, while 10 studies (15%) reported speeds of >512 kbps. Latency ≤100 ms was achieved when the mentor was in the same building or operating theatre as the trainee.[12,50,66] The longest latency was reported as 1.0 to 1.5 seconds, where the mentors and mentees were located between 2 US states.[70]

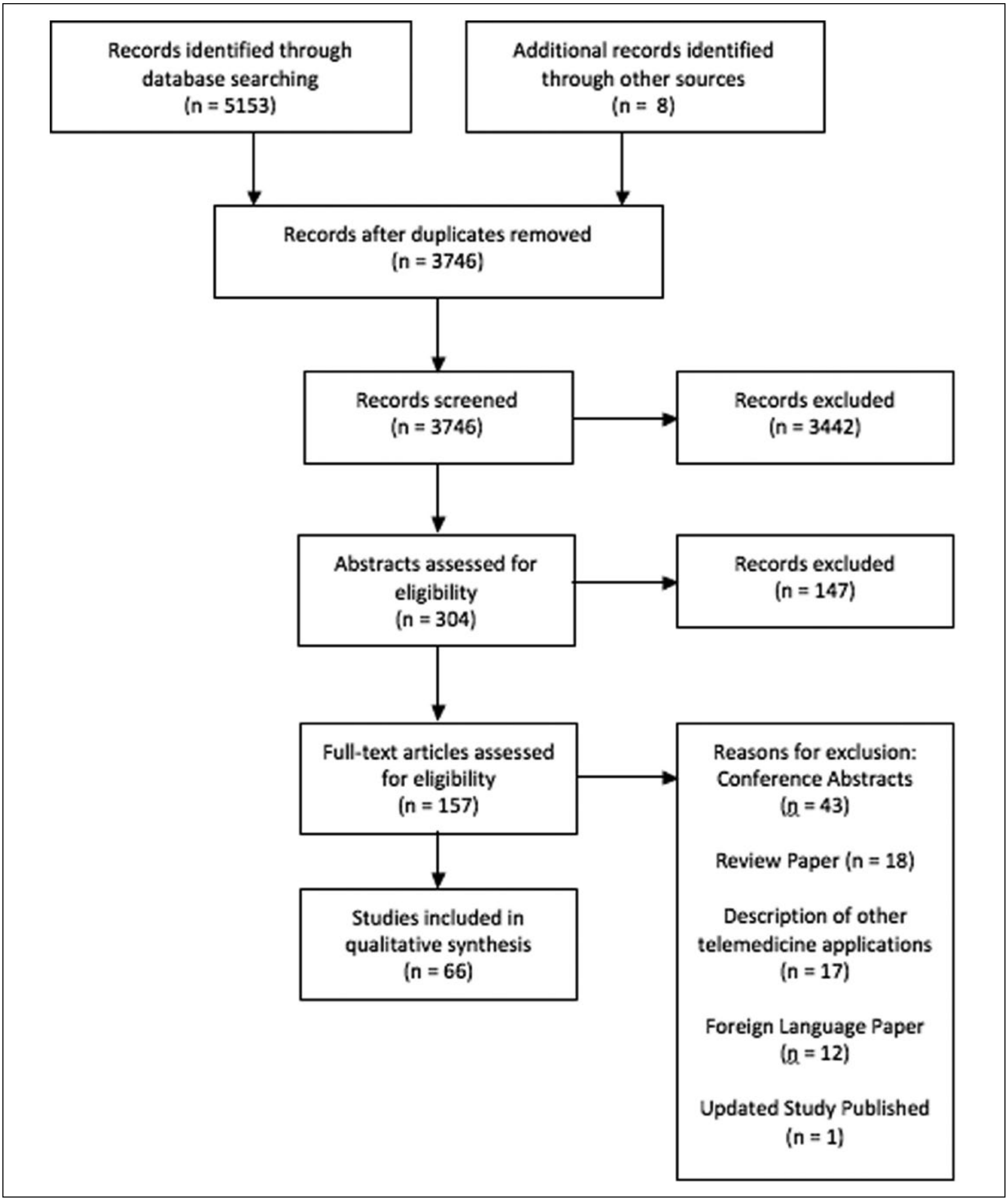

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart.

The distance between the telementor and trainee varied between each study. In 25 cases (38%), the mentor was within the same hospital or institution. In 3 studies (5%), these surgeons were within the same room as the trainees. 30 percent of studies reported data of telementoring between institutions in different countries (Table 4).

Table 1. Study Characteristics.

Year	Lead Author	Country	Specialty	Operation	Study Quality[a]
2017	Jarc	USA	Urology	Dissection and suturing tasks	IV
2016	Andersen	USA	General Surgery	Abdominal incision	IIB
2016	Brewer	USA	General/Thoracic Surgery	Needle placement	IIB
2016	Bruns	USA and France	Pediatric Surgery	Laparoscopic appendicectomy, thoracoscopic thymectomy	IV
2016	Davis	USA and Vietnam	Neurosurgery	Endoscopic third ventriculostomy/ choroid plexus cauterization, Biopsies	IV
2016	Singh	India	General Surgery	NR	IV
2016	Snyderman	USA and Slovenia	Neurosurgery/ENT	Endoscopic base of skull approach for tumor resection	IV
2015	Budrionis	Norway	General Surgery	Laparoscopic surgery	IB
2015	Budrionis	Norway	General Surgery	Laparoscopic surgery	IB
2015	Datta	Germany, Brazil, USA, and Paraguay	General Surgery	Hernia repair	IV
2015	Forgione	Italy and Russia	General Surgery	Laparoscopic colorectal surgery	IV
2015	Fuertes-Guiró	Spain	General Surgery	Bariatric procedures	IV
2015	Hashimoto	USA	General Surgery	Open cholecystectomy	IIIB
2015	Kirkpatrick	Canada	Trauma Surgery	Laparotomy and liver packing	IB
2015	Safir	USA	Urology	Cystoscopy, ureteral stent placement, cystolitholapaxy, ureteroscopy with laser lithotripsy, transurethral resection of bladder tumor, transurethral resection of prostate	IV
2015	Shin	USA	Urology	Prostatectomy, renal procedures	IIB
2015	Ye	USA and China	Ophthalmology	NR	IV
2014	Hinata	Japan	Urology	Radical prostatectomy	IIB
2014	Ponce	USA	Orthopedics	Arthroscopy of the shoulder	IV
2014	Ponce	USA	Orthopedics	Total shoulder replacement	IV
2014	Ponsky	USA	Pediatric Surgery	Left lower lobe resection of the lung, insertion of a gastric stimulator, laparoscopic inguinal hernia repair	IIB
2014	Shenai	USA	Neurosurgery	Dissection of the pineal region	IV
2014	Vera	USA	General Surgery	Laparoscopic suturing	IB
2013	Påhlsson	Sweden	General Surgery	ERCP	IV
2013	Treter	USA	General Surgery	Adrenalectomy	IV
2012	Marttos	USA	General Surgery	Trauma and nontrauma	IV
2012	Miller	Australia	General Surgery	Adrenalectomy	IV
2011	Shenai	USA	Neurosurgery	Carotid endartectomy and pterional craniotomy	IV
2010	Okrainec	Canada and Botswana	General Surgery	FLS tasks	IV
2010	Parker	USA	General Surgery	Laparoscopic cholecystectomy	IV
2010	Schlachta	Canada	General Surgery	Laparoscopic colorectal surgery	IV
2008	Ali	USA	General Surgery	Robotic arm tasks	IIB
2008	Gambadauro	UK	Obstetrics and Gynecology	Endoscopic, laparoscopic, per vaginal procedures	IV
2008	Rothenberg	USA	Pediatric Surgery	Laparoscopic exploration, hiatus hernia repair, duodenal atresia repair	IV
2007	Agarwal	USA	Urology	Nephrectomy, cystectomy	IV
2007	Latifi	USA	General Surgery	Trauma	IV
2007	Sereno	USA and France	General Surgery	Small bowel resection	IIB
2006	Pradeep	India	General Surgery/ENT	Thyroidectomy	IV

(continued)

Table 1. (continued)

Year	Lead Author	Country	Specialty	Operation	Study Quality[a]
2006	Sebajang	Canada	General Surgery	Laparoscopic colorectal surgery	IV
2005	Bruschi	Italy	General Surgery	Laparoscopic adrenalectomy	IV
2005	Challacombe	USA and UK	Urology	Live-donor nephrectomy	IV
2005	Di Valentino	Switzerland	Vascular	Endovascular aortic repair	IV
2005	Mendez	Canada	Neurosurgery	Craniotomy	IV
2005	Panait	Romania	General Surgery	Laparoscopic skills: grasping, cutting, clip-applying, suturing	IB
2005	Schneider	Germany	Laparoscopic	NR	IV
2005	Sebajang	Canada	General Surgery	Bowel resection, Nissen fundoplication, splenectomy, Hartmann's reversal and ventral hernia repair	IV
2005	Smith	USA	General Surgery	Abdominal dissection	IV
2004	Rafiq	USA	General Surgery	Unilateral thyroidectomy	IV
2003	Bove	USA and Italy	Urology	Spermatic vein ligation, retroperitoneal renal biopsy, percutaneous approach, nephrectomy, pyeloplasty	IV
2003	Netto	USA and Brazil	Urology	Laparoscopic bilateral baricocelectomy and percutaneous nephrolithotomy	IV
2002	Burgess	USA	ENT	Endoscopic sinus surgery	IB
2002	Klapan	Croatia	ENT	Sinus surgery	IV
2002	Rodas	USA and Ecuador	General Surgery	Open inguinal hernia repair	IV
2001	Rogers	USA	General Surgery	Trauma surgery	IV
2000	Bauer	USA, Austria, Thailand, Italy, and Singapore	Urology	Varicocelectomy, adrenalectomy, nephrectomy	IV
2000	Byrne	UK	General Surgery	Laparoscopic cholecystectomy	IV
2000	Lee	USA and China	Urology	Laparoscopic varicocelectomy, adrenalectomy, nephrectomy	IV
2000	Micali	USA and Italy	Urology	Laparoscopic spermatic vein ligation, retroperitoneal renal biopsy, laparoscopic nephrectomy, percutaneous access to the kidney	IV
2000	Sawyer	USA	General Surgery	Laparoscopic cholecystectomy	IIB
1999	Cubano	USA	General Surgery	Inguinal hernia repair	IV
1999	Deaton	USA	Vascular	Endovascular aortic grafts	IV
1998	Lee	USA, Austria, and Thailand	Urology	Nephrectomy, adrenalectomy	IV
1997	Docimo	USA	Urology	Pelvic lymph node dissection, ureterolysis, orchidopexy, (partial) nephrectomy, bladder neck suspension, renal biopsy orchidectomy, varicocelectomy, pyeloplasty	IIIB
1997	Rosser	USA	General Surgery	Laparoscopic colectomy	IIB
1997	Schulam	USA	Urology	Orchidopexy, varix ligation, vasectomy, renal biopsy, nephrectomy	IV
1996	Moore	USA	Urology	Pelvic lymphadenectomy, diagnostic laparoscopy	IV

Abbreviation: ENT, ear, nose, and throat; ERCP, endoscopic retrograde cholangiopancreatography; FLS, fundamentals of laparoscopic skills; NR, not recorded.
[a]Study quality rated using the "Oxford Centre for Evidence-based Medicine—Levels of Evidence Proforma."

Table 2. Summary of Study Results.

Lead Author	Outcome Objective	Aim	Key Results
Brewer	Clinical	To assess a wearable visualization system that increases the instructors' field of view.	Use of Google Glass technology to visualize the trainees' field of view improved accuracy of needle placement ($P < .05$). It also significantly reduced time to task completion ($P < .001$).
Hinata	Clinical	To assess a web-based telementoring system for robot-assisted radical prostatectomy (RARP).	There were no significant differences between telementoring and direct mentoring in operative time, blood loss, complication rate or whether a negative surgical margin was obtained.
Ponsky	Clinical	To compare readily available equipment against a proprietary telementoring robot for telementoring.	Readily available equipment was less costly, but lacked telestration capability and was held over an unsecure network. Both methods allowed procedures to be completed successfully, without complications or loss of transmission.
Pradeep	Clinical	To describe a case report of telementoring to aid thyroidectomy following 2 failed attempts.	With the help of telemedicine technology, the same surgeon was successful in locating and removing the tumor.
Rogers	Clinical	To outline the benefits of telementoring between trauma surgeons and surgeons in the community.	Out of 26 cases, 7% of consultations were deemed to be lifesaving. 83% of community providers agreed or strongly agreed that the consultations improved patient care. Only 25% agreed the consultation could have been similarly carried out with a telephone.
Schneider	Clinical	To evaluate a digital telepresence system in an operating theatre.	The system was evaluated in 238 cases. In 12% of cases the link could not be established. In only 18% of cases was the fully capability of telementoring used.
Andersen	Clinical and Educational	To compare System for Telementoring with Augmented Reality (STAR) against a conventional telestration system.	Participants using STAR completed surgical tasks with less placement error ($P < .001$) and fewer focus shifts ($P < .0001$).
Bauer	Clinical and Educational	To determine the clinical utility of subspecialty telementoring.	Each procedure was carried out without complication with similar estimated blood loss and operative times to nonmentored cases previously reported.
Bove	Clinical and Educational	To report experience with intercontinental telementoring in urology.	It was impossible to establish connection in 5 (29%) of cases. All cases were completed without intraoperative complications. Time delay of 700 ms did not interfere with telementoring capabilities.
Bruns	Clinical and Educational	To report 2 cases of intercontinental telementoring.	Both cases were completed successfully. The use of telestration was used to help facilitate the case. Issues with trans-Atlantic mentoring were identified with technical issues with equipment and connectivity, and difference in time zones.
Bruschi	Clinical and Educational	To report preliminary experience with telementoring.	All the procedures were successfully performed. The mean operative times, blood loss, and postoperative morbidity results were comparable to those reported in the literature.
Budrionis	Clinical and Educational	To demonstrate feasibility telementoring on small touch screen devices (tablet or smartphone) and to identify factors of the platform that influence the mentoring process.	PC use was associated with an increased ability to identify anatomical structures ($P > .05$). The participants preferred stationary computer (50%) over tablet (42%) and smartphone (8%) as the preferred device for telementoring.

(continued)

Table 2. (continued)

Lead Author	Outcome Objective	Aim	Key Results
Budrionis	Clinical and Educational	To measure the impact of telestration in comparison to telementoring without telestration.	Retained knowledge of localisation was greater in the nontelestration cohort ($P = .0055$). Telestration helped reduce the length of time spent telementoring ($P = .0011$). Telestration reduced student misunderstanding, need for clarification, and need for further mentoring after starting incision.
Burgess	Clinical and Educational	To evaluate the safety and feasibility of telementoring compared with conventional mentoring.	Telementored cases took 16% longer for completion ($P < .024$). There was no difference in perioperative morbidity or mortality between telementored and conventional mentoring cases.
Byrne	Clinical and Educational	To assess telementoring as an adjunct to training and assessment in laparoscopic cholecystectomy.	Out of 34 cases: 2.9% were converted to open procedures, 2.9% suffered postoperative bile collection, in 5.9% of cases the trainer scrubbed. There were higher rates of interaction in cases with higher difficulty. Trainer perception outlined benefits including improved assessment of technique and judgement and improved efficiency of trainer's time.
Challacombe	Clinical and Educational	To evaluate telementoring as a modality for training in live laparoscopic living donor nephrectomy.	All procedures were completed laparoscopically without operative complication. There was no significant difference between locally mentored or telementored cases in warm ischemia time, operative time, or estimated blood loss between
Cubano	Clinical and Educational	To present cases of intercontinental telementoring and aboard a naval ship.	The telementoring system enabled timely expertise to be delivered to a naval vessel which otherwise would have required a shore visit.
Davis	Clinical and Educational	To evaluate the feasibility of implementing the VIPAR telementoring platform for global surgery education.	On questioning of clinical utility using a 5-point Likert-type scale, surgeons agreed that VIPAR was useful, resulted in a more effective procedure, and resulted in a safer procedure. It did not increase surgeon fatigue.
Deaton	Clinical and Educational	To evaluate the capability of telementoring to support the introduction of an endovascular surgery program.	There was no difference between local ($n = 11$) or telementored ($n = 7$) cases with regard to clinical course, intraoperative complications or mean length of stay.
Di Valentino	Clinical and Educational	To explore the use of telementoring for distant teaching.	There was no significant difference between telementoring from within or outside the hospital in length of procedure or length of ICU stay.
Docimo	Clinical and Educational	To report an experience with telementoring for adult and paediatric laparoscopic cases.	One of 24 cases (4%) required on-site assistance. Compared with nontelementored cases, operative times were equivalent, apart from nephrectomies, which took longer during telementoring ($P = .02$). There were no significant differences in postoperative pain management, time to recovery, or hospital stay.
Forgione	Clinical and Educational	To demonstrate effectiveness of a training program in laparoscopic colon resection using telementoring as an adjunct.	The trainee surgeon conducted 2 surgeries with telementoring. There was no postoperative morbidity or mortality. This was maintained on 25 subsequent cases without telementoring.
Fuertes-Guiró	Clinical and Educational	To evaluate a telementoring programme in laparoscopic bariatric surgery.	In comparison to no mentoring, telementoring helped reduce operative times ($P < .01$) and hospital stay ($P < .01$). Those cases where telementoring was used there were fewer conversions ($P < .01$) or fewer postoperative complications ($P < .01$).

(continued)

Table 2. (continued)

Lead Author	Outcome Objective	Aim	Key Results
Kirkpatrick	Clinical and Educational	To assess telementoring for first responders who perform damage control laparotomies and abdominal packing.	There was no significant difference in fluid loss between those who received remote telementoring by a trauma surgeon or no mentoring. The only statistically significant improvement with telementoring was operator confidence.
Klapan	Clinical and Educational	To report cases of 3D modeling assisted telementoring.	3D modeling gave additional capability to both the operating surgeon and mentor by helping to identify anatomical markers that were missing from the operative field using computed tomography and magnetic resonance imaging sections.
Latifi	Clinical and Educational	To evaluate telementoring in trauma care in the community.	Out of 21 cases, 5 had life-saving procedures conducted with telementoring and 5 others were managed without the need for transfer to a specialist care hospital.
Lee	Clinical and Educational	To report on international telementoring experiences.	Telementoring was successfully conducted over a distance of 5000 to 10 000 miles.
Marttos	Clinical and Educational	To identify the strengths and weaknesses in the implementation of telementoring.	Remote physicians (94%) and local physicians (74%) felt comfortable communicating via a telepresence system. Both remote and local physicians (90%) strongly agreed that a telepresence system for consultations is more effective than a telephone conversation.
Mendez	Clinical and Educational	To test the feasibility of long-distance telementoring in neurosurgery.	There were no surgical complications, with no perioperative morbidity or mortality with telementored cases. The surgeons believed that input from the mentors was useful in every case.
Micali	Clinical and Educational	To report transcontinental telementoring in urological procedures.	All operations were carried out successfully with telementoring. No comparison was reported.
Miller	Clinical and Educational	To report individual program experience with telementoring to introduce new surgical techniques.	In 3 telementoring cases, there were no complications, with short hospital stays following. The operative team proceeded to conduct 22 further cases without complications.
Moore	Clinical and Educational	To assess the feasibility of telementoring.	96% of urology cases were conducted successfully with telementoring. There was 1 failure in telementoring due to improper position of a robotic arm perioperatively. There was no significant difference in perioperative morbidity between telementored cases and those carried out with conventional mentoring.
Netto	Clinical and Educational	To assess the feasibility of transcontinental telementoring.	Two telementored cases were conducted without morbidity or mortality between the United States and Brazil.
Påhlsson	Clinical and Educational	To investigate the impact of telementoring to improve the delivery of endoscopic retrograde cholangiopancreatography (ERCP) in rural areas.	The common bile duct was successfully cannulated in all 26 cases. The overall cannulation rate at the district hospital rose from 85% to 99% after the introduction of telementoring.
Parker	Clinical and Educational	To validate the use of a smartphone to send intraoperative videos for telementoring.	10 clips of 7-40 seconds were sent to an expert surgeon for review. All 10 clips were deemed adequate for decision making.
Ponce	Clinical and Educational	To evaluate the potential utility of a telementoring system in the operating theatre.	On a 5-point Likert-type scale both trainees and mentors indicated that telementoring was an effective teaching tool (4.23/5), an effective feedback tool (4.43/5) and effective for communication between trainee and mentor (4.23/5).

(continued)

Table 2. (continued)

Lead Author	Outcome Objective	Aim	Key Results
Rosser	Clinical and Educational	To evaluate the role of telementoring in training advanced laparoscopic procedures.	Telementoring cases took longer to complete; however, no significant differences were found compared to on-site mentoring in respect to blood loss, length of hospital stay, or return to normal activity.
Rothenberg	Clinical and Educational	To evaluate the efficacy of remote presence technology in telementoring.	All three cases were completed successfully. No formal scoring scale was used for assessment. The greatest benefits were perceived in the initial setup (trocar placement), identification of abnormal anatomy, and approach.
Safir	Clinical and Educational	To evaluate the impact of telementoring on trainees achieving endoscopic training milestones.	On a 10-point Likert-type scale trainees believed that telementoring had a positive impact on quality of training (8.3/10), rate of learning (8.1/10), proficiency and independence (8.4/10) and autonomy and safety (8.6/10).
Sawyer	Clinical and Educational	To determine the effect of telementoring on safety and efficiency in the operating theatre.	Comparing telementored cases ($n = 6$) against locally mentored cases ($n = 6$), there were no major operative complications in either group ($P > .05$). There was no difference in total operative times or of individual intraoperative steps ($P > .05$).
Schlachta	Clinical and Educational	To demonstrate the feasibility of longitudinal mentoring and telementoring of community surgeons for laparoscopic colorectal surgery.	1-year follow-up demonstrated appropriate case selection, quality surgery and moderate conversion rates for community surgeons following a program of both mentoring and remote telementoring.
Schulam	Clinical and Educational	To demonstrate the use of telecommunications technology for telementoring.	All operations were completed successfully with telementoring of a primary operative surgeon with limited laparoscopic experience.
Sebajang	Clinical and Educational	To assess whether telementoring would improve the laparoscopic colorectal surgery being performed by community surgeons.	2/18 telementored operations suffered postoperative complications, including reoperation for small bowel obstruction and a heamoperitoneum.
Sebajang	Clinical and Educational	To evaluate the efficacy of telementoring to enable community surgeons to conduct advanced laparoscopic surgery.	Of 19 procedures 11% were converted to open. On 5-point Likert-type scale the primary surgeon considered telementoring useful in all cases (4/5) and comfortable with the quality of the laparoscopic surgery performed (4/5).
Sereno	Clinical and Educational	To compare onsite mentoring in comparison with robotic telementoring.	In questionnaire evaluation of type of mentoring onsite mentoring was preferred to telementoring. However, this was only significant ($P < .05$) if the onsite mentoring was delivered prior to telementoring rather than vice versa.
Shenai	Clinical and Educational	To evaluate the VIPAR telementoring platform.	Local surgeons found the remote surgeons' presence helpful. The remote surgeons suffered from increased fatigue using the VIPAR system, but this improved with familiarity with the system.
Shin	Clinical and Educational	To evaluate the feasibility of the Connect for telementoring with the da Vinci surgical robot.	56 cases of mentoring were conducted. There was no significant difference between operative time, blood loss or robotic skill assessment between telementored cases or in-room mentoring. Mentors preferred telementoring to in-room mentoring ($P = .05$).
Snyderman	Clinical and Educational	To assess the efficacy of a telementoring program in endoscopic base of skull surgery.	The median perceived value of telementoring on a 10-point Likert-type scale was 9.5 (range: 8-10).

(continued)

Table 2. (continued)

Lead Author	Outcome Objective	Aim	Key Results
Treter	Clinical and Educational	To report program experience with telementoring	Operative times were comparable to those reported in literature. Both patients suffered no morbidity or mortality. There was 1 episode of dropped signal over 2 procedures.
Vera	Clinical and Educational	To compare an augmented reality telementoring (ART) platform against traditional mentoring in an intracorporeal suturing task.	ART provided faster skill acquisition ($b = -0.567$) than traditional mentoring ($b = -0.453$), with the participants conducting fewer mistakes compared to those who used traditional mentoring techniques. 89% of subjects agreed or strongly agreed that ART is an effective telementoring device.
Okrainec	Educational	To determine the effectiveness of telementoring for teaching the fundamentals of laparoscopic skills (FLS) to surgeons in a resource-poor setting.	Participants who had telementoring had higher posttest FLS scores compared with those who used self-practice ($P = .001$). All trainees in the telementoring group received FLS certification in comparison to 38% in the self-practice group.
Panait	Educational	To compare telementoring against real-time mentoring for structured skill acquisition.	After exposing each group of participants to either telementoring or real-time mentoring each group demonstrated significant reduction in right- and left-hand path length and time ($P < .05$). However, there was no significant difference between those who were exposed to telementoring and conventional mentoring.
Smith	Educational	To assess whether of a remotely controlled platform to provide guidance and supervision in the anatomy lab felt more 'lifelike'.	80% of the students reported that after they became comfortable with the robot's presence. Students and proctors thought that the system felt "lifelike."
Agarwal	Feasibility	To evaluate the efficacy of a novel telementoring system, the Roboconsultant.	The Roboconsultant was easy to operate and was used in 2 cases without connection failure or interruption.
Ali	Feasibility	To develop the capability for a remote mentor to provide 3D telestration in robotic surgery.	Over 99 trials, participants took significantly longer to complete simulated tasks with 3D simulation ($P < .05$). There was no significant difference between the rate of errors committed with either 2D ($n = 3$) or 3D ($n = 6$; $P > .05$) telestration.
Datta	Feasibility	To evaluate the feasibility of wearables and web-based performance rating for long-term international proctoring.	Surgeons at 2 locations were successfully trained over 4 procedures to meet all criteria for the Operative Performance Rating Scale.
Gambadauro	Feasibility	To test the functionality of the NEST (network enhanced surgical training) telementoring system.	Surgeons developed and tested a telementoring system developed without information and technology experts and trialed in 20 cases. This showed subjectively good audio and video quality. Latency was experienced but did not subjectively affect with intersurgeon interaction.
Hashimoto	Feasibility	To assess the safety of using Google Glass by assessing video quality.	50% rated the Google Glass video as fair. The other 50% rated it as bad to poor. 82.4% rated the video quality as inadequate for telementoring.
Jarc	Feasibility	To evaluate whether mentors would use 3D telestration if available during robot-assisted surgery.	Mentors used the 3D plane of movement using "ghost tools" ($P < .001$). Questionnaires identified that both mentors and trainees found telementoring to be useful in: identifying anatomy, teaching/learning surgical skills and improving confidence as a surgeon. The participants also believed 3D telestration to be more helpful than 2D.

(continued)

Table 2. (continued)

Lead Author	Outcome Objective	Aim	Key Results
Lee	Feasibility	To evaluate the feasibility of international telementoring.	Telementoring was successfully conducted between the United States and Asian and European nations. There were technical limitations of establishing telecommunications across ISDN lines.
Ponce	Feasibility	To report a case of the use of Google Glass for telementoring.	The Google Glass was convenient and relatively unobtrusive. However, the battery life was poor at 20-30 minutes.
Rafiq	Feasibility	To report the use of telecommunications systems for mentoring.	A remote audience was able to confirm greater than 90% of anatomical landmarks across 25 cases. Subjectively good video quality was also obtained.
Rodas	Feasibility	To report a single case of telementoring in open surgery.	Video transmission was sufficient for the consulting surgeon to identify 9 predetermined anatomical landmarks. The transmission also served as a teaching tool to medical students.
Shenai	Feasibility	To evaluate the feasibility of the Visual Interactive Presence (VIP) platform in telementoring.	Cadaveric neurosurgical simulation was successfully performed in 2 cases.
Singh	Feasibility	To describe a set-up design for telementoring within one institution.	Telestration allows for certain complex procedures to be attempted at remote locations where there is a lack of previous experience. Asynchronous relay can be used in trainee education. However, it faces financial, technical and ethical constraints.
Ye	Feasibility	To determine the feasibility of video transfer using smartphones during microscopic ocular surgery.	The remote viewer clearly identified each step of the procedure except for one incident where it was interrupted by incoming phone call.

Table 3. Capability of Telementoring Systems.[a]

Lead Author	Fidelity	Operations (n)	Primary Surgeons (n)	Distance	Capability	Mentor Device
Jarc	Animal model	3	7	b	d	Display and Console
Andersen	Simulation	NA	20	b	d	Tablet
Brewer	Simulation	NA	11	b	b	Google Glass
Bruns	Patients	2	1	e	d/f	Computer
Davis	Patients	15	5	c/e	d	Tablet (iPad)
Singh	Patients	NR	NR	NR	c	Computer
Snyderman	Patients	10	NR	e	d/e	Computer
Budrionis	Patients	NR	12	c	d	Computer/tablet /phone
Budrionis	Simulation	NA	8	c	d	Laptop
Datta	Patients	8	2	e	c	NR
Forgione	Patients	2	1	e	d	Tablet
Fuertes-Guiró	Patients	20	NR	d	d	Computer
Hashimoto	Patients	NR	34	NA	NA	Google Glass/iPhone
Kirkpatrick	Simulation	NA	18	c	c	Laptop
Safir	Patients	10 per week	21	c	d	Computer
Shin	Patients	55	21	c/d	d	Computer/laptop
Ye	Patients	3	NR	e	c	Computer/tablet/phone
Hinata	Patients	30	4	d	d	Laptop
Ponce	Patients	15	6	c	d	Computer
Ponce	Patients	1	1	d	d	Computer
Ponsky	Patients	6	NR	e	d	Laptop

(continued)

Table 3. (continued)

Lead Author	Fidelity	Operations (n)	Primary Surgeons (n)	Distance	Capability	Mentor Device
Shenai	Cadavers	1	1	d	d	Computer
Vera	Simulation	NA	19	c	c	Audio-video processor and laparoscopic simulator
Påhlsson	Patients	26	NR	c/d	c	Computer
Treter	Patients	2	2	d	c	NR
Marttos	Patients	50	NR	c	c	Computer
Miller	Patients	3	1	e	c	Computer
Shenai	Cadavers	1	1	NR	d	Computer
Okrainec	Simulation	NA	8	e	c	Computer
Parker	Patients	10	NR	c	b	Phone (Blackberry Pearl)
Schlachta	Patients	6	NR	d	d	Computer
Ali	Simulation	6	3	NR	d	Computer
Gambadauro	Patients	20	2	c	c	Computer
Rothenberg	Patients	3	2	d	d	Computer
Agarwal	Patients	2	NR	c/d	c	Laptop
Latifi	Patients	21	NR	d	c	Computer
Sereno	Animal model	NR	40	c/e	d	Computer
Pradeep	Patients	1	1	d	c	Lecture theatre
Sebajang	Patients	18	4	d	d/f	Television and touchpad
Bruschi	Patients	8	1	d	d	Computer
Challacombe	Patients	4	1	e	NR	NR
Di Valentino	Patients	36	NR	c/d	c	Monitor and touchpad
Mendez	Patients	6	NR	d	d/e	Monitor and touchpad
Panait	Simulation	NA	20	e	d	Computer
Schneider	Patients	237	NR	d	e	Monitor and touchpad
Sebajang	Patients	19	4	d	c	NR
Smith	Cadavers	2	8	c	c	Computer
Rafiq	Patients	25	7	c	d/e	Computer
Bove	Patients	14	2	e	d/e/g	Monitor, console, and touchpad
Netto	Patients	2	NR	e	d	Computer
Burgess	Patients	87	NR	c	d	Workstation
Klapan	Patients	2	NR	d	c	NR
Rodas	Patients	1	1	e	c	Videoconferencing system
Rogers	Patients	26	NR	d	c	Television
Bauer	Patients	11	NR	e	d/e	Computer
Byrne	Patients	34	1	c	c	Television
Lee	Patients	5	5	e	d/f/g	NR
Micali	Patients	5	NR	e	d	Computer
Sawyer	Patients	6	NR	c	d	Videoconferencing system
Cubano	Patients	5	NR	e	c	Computer
Deaton	Patients	7	NR	c/d	c	NR
Lee	Patients	3	NR	e	d	Computer
Docimo	Patients	27	NR	c	d/e	Computer
Rosser	Patients	12	NR	d	d	Command center
Schulam	Patients	7	NR	d	d/e/f	Computer
Moore	Patients	23	NR	d	d/e	Computer

Abbreviations: NA, not applicable; NR, not recorded.
[a]Computer indicates a stationary computer system; laptop indicates a portable computer system. Distance: a—in theatre scrubbed; b—in theatre unscrubbed; c—in hospital, but not in theatre; d—outside of hospital; e—different country. Capability: a—audio only; b—video only; c—audio and video; d—ability to notate on the screen; e—ability to move camera; f—robotic assistance; g—control of energy device.

Table 4. Technical Features.[a]

Technical Features	Overall (n = 66); n (%)
Distance of mentor from trainee	
In theatre (scrubbed)	0
In theatre (unscrubbed)	3 (5)
In hospital	22 (33)
Outside of hospital	24 (36)
Outside of country	20 (30)
Capability of device	
Audio only	0
Video only	2 (3)
Audio and video only	22 (33)
Screen notation	38 (58)
Camera maneuverability	8 (12)
Robotic assistance	4 (6)
Control of energy device	2 (3)
Extracorporeal annotation	1 (2)
Bandwidth (kbps)	
⩽150	2 (3)
150-512	12 (18)
>512	10 (15)
Latency (ms)	
⩽100	3 (5)
100-500	11 (19)
>500	8 (12)

[a]"In theatre" and "in hospital" indicate where the trainee and mentor were in the same room or building, respectively. For each individual study, the mentoring did not always occur in an operating theatre or health care setting.

Costs of Telementoring

Only 6 studies reported the associated costs of their telementoring set up.[7,19,22,28,53,67] Reporting of cost was heterogeneous throughout these studies. Only 2 studies reported yearly costs, which ranged between US$10 000 and US$20 000.[22,67] Median initial set-up costs for professional systems were US$75 000 (range: US$10 000-50 000). One study reported a one-off cost of US$2750 for a self-created low-cost system, created using readily available equipment, including personal computers, the laparoscopy stack and a video capturing system, with free videoconferencing software.[28]

Telementoring Versus Traditional Mentoring

Twelve separate studies directly compared telementoring against on-site mentoring.[17,19,23,25,30,41,44,54,57,63,66,71] Seven (58%) showed no difference in outcomes; 1 found telementoring was subjectively rated as inferior to on-site mentoring; 3 found telementoring to have prolonged operative times; and 1 found telementoring to be superior to on-site mentoring.

Robotic assisted laparoscopic radical prostatectomy (RALP) mentoring techniques were clinically compared and showed no significant difference between clinical outcomes for telementoring or on-site mentoring.[30] A further study comparing the efficacy of on-site versus telementoring in robotic surgery found that on-site mentoring was preferred by trainees.[63] Free-text analysis of trainee responses determined that the reason for this difference was because mentors were unable to demonstrate movements with their hands during telementoring. Shin et al[66] used the Global Evaluative Assessment of Robotic Skills form to compare mentoring techniques and showed no significant difference between primary surgeon operative skills when either technique is used.

Multispecialty studies comparing clinical outcomes have shown no differences between telementoring and traditional mentoring. Outcomes assessed included operative time, blood loss, postoperative pain management, time to recovery, hospital stay, complications. There were no major complications in either group, with no significant difference in operative times.[19,25,57] Of the 3 studies that did identify differences in operative times, no statistical difference in clinical outcomes were detected between mentoring techniques.[17,41,54]

In 1 study, a "fundamentals of laparoscopic skills" (FLS) course was delivered by on-site mentoring or telementoring to trainees for 30 minutes.[44] Both modalities significantly improved task performance, and economy of movement with no significant difference between either modality.

Augmented reality telementoring (ART) uses an overlay of a mentor's instruments onto a trainee's screen. One study showed that ART reduces time taken to complete tasks from an FLS course. It did not however affect the number of errors committed by the participants.[71]

Telementoring Versus No Alternative

Four studies compared telementoring against a complete absence of mentoring.[12,27,32,42] Three (75%) found outcomes demonstrating benefit as a result of telementoring. Bariatric trainee surgeons within their learning curve,[27] when telementored using telestration, had reduced operative times, length of hospital stay, conversion, and postoperative complication rates compared with unmentored cases. In a resource-poor setting,[42] it was found that telementoring using AV increased the FLS performance scores of telementored participants in comparison with those who learnt via self-practice. All surgeons who had telementoring support achieved full FLS certification compared to only 38% of the self-practice group. Google Glasses (Google, Alphabet Inc, Mountain View, CA, USA) when used in a simulated field to allow a mentor to visualize a trainee's view helped the mentor reduce the mean composite error of the trainees carrying out the task.[12] Telementoring improved confidence in trauma surgeons treating acute bleeding in a simulated environment, but there was no significant difference between remote telementoring via AV assistance or performing the simulation without mentorship with regard to blood loss.[32]

Discussion

The results of this review demonstrate that in the future telementoring may occupy a niche in surgical education by enabling the education of surgeons within and between hospitals. It has been shown in some settings to be a safe and effective method of implementing remote mentoring. In addition, the review suggests that telementoring might provide a benefit to clinical outcomes when on-site mentoring cannot be established. This review also highlights specific technological parameters that institutions should look toward such as bandwidth and latency, as well as the technological capabilities of different telementoring systems. Finally, the review demonstrates a paucity of high-quality literature describing experience with telementoring.

The results described above are supported by previous reports in the field. However, this is the most comprehensive and recent review on the topic. The previous review of this topic compared telementoring against on-site mentoring.[5] This identified that across the included studies there is no significant difference in outcomes, either clinically or educationally, for those trainees who receive telementoring or on-site mentoring. The results of this systematic review are similar, showing that 58% of included studies found no significant difference between outcomes, while 9% found telementoring to be superior. Four studies (33%) found telementoring to be inferior in some aspect. Of these, 3 showed prolonged operating times. In 1 study, trainees cited that they preferred on-site mentoring as mentors were able to guide trainees by using their hands. More recent telecommunication technologies would certainly help to improve the perception of telementoring within this trial, particularly the advent of augmented and virtual reality.[31,71] All 4 studies reported no effect on postoperative or objective educational outcomes.

Telementoring is unlikely to ever supersede on-site mentoring completely and is likely to be mostly used as an adjunct to traditional mentoring and clinical practice. It has previously been used as a step within formalized training programs to enable increased autonomy for trainee surgeons alongside appropriate levels of supervision.[58] Therefore, while it is important to show similar safety and efficacy to on-site mentoring, it will be applied most in situations where on-site mentoring is not feasible. A limited number of studies compared on-site mentoring against no mentoring, likely as a result of the ethical issues this produces outside of a simulated environment. Out of the 4 studies that made this comparison in the review, 3 suggested a benefit of telementoring over no mentoring. Three examples of where telementoring could be potentially disruptive are the following: "Global Surgery",[22,42] surgery in rural locations, and the dissemination of new surgical techniques and technology. A recent survey from the "American College of Surgeons Advisory Council for Rural Surgery" identified that surgeons who operate in remote locations would find telementoring useful (79%).[73] Those surveyed also indicated that they would use the technology mostly for learning new techniques (47%) or help with intraoperative challenges (39%).

There is a clear clinical need for improved access to surgical care in low-income countries[1]; however, there are a number of barriers to widespread implementation of telementoring (Supplementary Material 2, available in the online version of the article), the most inhibitive of which is cost. Only a few studies reported the costs of implementing their systems. The cheapest available was reported at US$2750.[28] This was a self-created system and is therefore limited to those surgeons with both the drive and technological abilities to replicate the system. The most expensive required an initial cost of US$50 000 to US$80 000 without taking into account yearly expenses.[67]

In addition to cost burden, there are technical limitations to widespread implementation. There are specific criteria by which the system used should meet in order to be used effectively in telementoring, including minimum resolution of 480p and minimum bandwidth of 512 kbps.[4] This was only achieved in 10 out of the 24 studies that reported bandwidth. Telementoring is also dependent on a secure, HIPAA (Health Insurance Portability and Accountability Act) compliant, internet connection to reduce failed connection, and loss of both audio and visual data packets from either site. Internet penetration is poor in low-income countries and internet connectivity is concentrated within cities globally. Without global internet coverage it will be hard for telementoring to reach its full potential. Cyber security will also play a crucial role in developing telementoring programs in the future. Sensitive patient information will need be transmitted across secure internet connections, particularly for transmissions between different institutions and different countries. It is important therefore to create agreed framework to ensure that personal and sensitive information is encrypted and handled with care.

In the future it is important that there is a focus on producing high-quality studies that evaluate the potential impact of telementoring. These results suggest telementoring is a safe training modality and whilst also promising for the efficacy of telementoring, further studies of improved methodology analyzing the educational impact of incorporating telementoring into formalized training programs are required. Homogenous recording of specific clinical and educational outcomes in future studies would also help to strengthen this claim; including operative time, intraoperative complications, accuracy of reporting and assessment of intraoperative technique using validated scoring criteria. In addition, the field would benefit from standardized reporting of technical capabilities of the systems used, including type of device, distance between mentor and mentee, the presence of on-screen notation, bandwidth, and latency. This would allow for thorough comparison between technical system use and outcomes, which is not possible with the current evidence base.

Our review has a number of limitations. The studies included typically low numbers of patients and were all observational in nature, with 74% of selected articles only demonstrating level IV evidence. As a result, there is the potential for a number of the included studies to be subject to selection bias, with low-risk cases more likely to be chosen for remote mentoring. However, by broadening the inclusion criteria and then breaking down the reporting of the results this allowed for a comprehensive review of the various applications of telementoring and the different systems used. There was significant heterogeneity across the included studies. This includes the differences between telecommunication systems, operations, trainee skill level, as well as study design. This is an inherent flaw in the literature describing telementoring as a whole. In the future telementoring would benefit from focused, quality research in specific areas rather than the production of lower quality studies with fewer patients.

This systematic review identifies that telementoring is a safe modality for providing surgical education intraoperatively. The results shown also suggest that telementoring provides some equivalence to on-site mentoring with regard to clinical and educational outcomes, proving feasibility. However, this cannot be stated with certainty as there is a paucity of high-quality studies analyzing the potential impact and application of telementoring. It is important that future studies analyze long-term longitudinal data of telementoring programs to establish the precise role it should play in surgical training. This will be aided by the formation of consensus guidelines for reporting in telementoring research.

Authors' Note

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Declaration of Conflicting Interests

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