The uses of smartphones and tablet devices in surgery: A systematic review of the literature

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Background. *Smartphones and tablet devices have become ubiquitous, and their adoption in the health care arena is growing. Reviews have looked at their utilities within medical specialties. Despite the many surgical apps available currently, there has not been a comprehensive literature review evaluating uses of these platforms within surgical disciplines. We reviewed the literature systematically in this regard.*
Methods. *Embase, MEDLINE, Health Management Informatics Consortium, and PsychINFO databases were searched for empiric quantitative studies evaluating interventions based in the use of smartphone or tablet device within surgical disciplines targeted at surgeons, patients, or the wider public.*
Results. *Of the 39 studies included, 24 evaluated smartphone-based interventions and 15 looked at tablet devices, whereas 30 were app-based interventions and 9 were not. A wide range of effective and innovative utilities were identified and categorized into 8 domains; Diagnostics (n = 11), telemedicine (n = 9), operative navigation (n = 6), training (n = 5), data collection (n = 3), patient education (n = 2), behavior change (n = 2), and operative planning (n = 1).*
Conclusion. *This comprehensive systematic literature review of smartphone and tablet device use in surgery demonstrates a wide range of innovative utilities in the pre-, intra-, and postoperative contexts. Although results of individual studies generally were favorable, limitations in methodologies existed in many, and although studies clearly highlight the substantial potential of smartphone and tablet devices in the surgical setting, trials of greater quality will be necessary to pave the way for their widespread adoption. (Surgery 2015;158:1352-71.)*

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THE PAST 2 DECADES HAVE SEEN A SURGE IN CONSUMER DEMAND FOR PORTABLE HAND-HELD COMMUNICATION DEVICES. Since 2007, the handsets of the older mobile phones and personal digital assistants have been replaced gradually by more sophisticated devices, such as smartphones and tablet computers, capable of running stand-alone software applications or "apps." These technologies have spread and evolved at an unprecedented rate.[1] It is estimated that 65% of the United States population now owns a smartphone and 48% owns a tablet device.[2]

Substantial interest has arisen around the use of smartphone and tablet technologies in the health care context. This interest has brought the field of mobile health (mHealth), defined as the delivery of health care and health-related services via communications devices, into sharp focus.[3] Such devices are carried in the pockets of the majority of health care professionals working in developed health care systems,[4-6] and there are currently more than 40,000 mHealth apps available for download through app stores.[7] The mHealth sector as a whole is expected to generate approximately $26 billion by the end of 2017.[8]

Although limited currently, the evidence base for health care interventions delivered over these platforms is growing steadily. Recent literature reviews have evaluated the uses of smartphones and tablet devices both within the context of

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specific disease processes such as diabetes[9] and the general medical field as a whole.[10]

Over the decades, surgeons often have challenged the status quo and adopted new technologies in their endeavors to enhance operative technique and improve patient outcomes,[11] as demonstrated by the adoption of laparoscopy. Despite a tradition rich in innovation and more than 600 surgery-related apps available already for download,[12] to date there has not been a comprehensive literature review that evaluates the uses of smartphone and tablet platforms within the house of surgery.

We adopted a systematic approach to identify, appraise, and discuss the available literature addressing the uses of smartphones and tablet devices, both app- and nonapp-based, within surgical disciplines and included interventions targeted at surgical health care professionals, patients, and the public.

METHODS

This review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement for systematic reviews.[13]

Database search. The Embase, MEDLINE, Health Management Informatics Consortium, and PsychINFO databases were searched through OVID on May 5, 2014 with the search string Smartphone.mp OR Smart phone.mp OR Nokia.mp OR Symbian.mp OR iPhone.mp OR iPod.mp OR iTunes.mp OR Apple.mp OR Android.mp OR iOS.mp OR Blackberry.mp OR Windows.mp OR mHealth.mp OR Mobile Health.mp OR App.mp OR Google Play.mp OR App Store.mp OR Tablet.mp OR iPad.mp, combined with the term Surg*.mp using the 'AND' Boolean operator. The search was limited to articles published in the English Language from the year 2007 onwards, because this year was the release year of the first modern-day smartphone and tablet device.

Inclusion and exclusion criteria. For the purposes of this review a smartphone was defined as a mobile phone offering additional functionality through built-in sensors and capable of running stand-alone software applications or apps. A tablet device was defined as a single panel, handheld, general-purpose computer. Only devices running the iOS, Android, BlackBerry, Symbian, or Windows operating systems were included. Use of such operating systems are a defining feature of newer devices. Older mobile phones and personal digital assistants were excluded from the review due to their comparatively limited functionality.

Empiric quantitative studies evaluating the use of smartphone or tablet-based interventions within surgical disciplines were included, regardless of the target population (eg, the public, patients, surgeons) or outcome measures, in keeping with the broad nature of this review. Dermatology and dentistry were not considered to be surgical specialties and were excluded.[14] Voice call- and short-message-script–based interventions were also excluded because these have been reviewed extensively in earlier works[15-18] and are not unique to smartphones. Other article types, that included case studies, conference proceedings, editorials, and reviews, were also excluded.

Screening process. Screening of article titles and abstracts was performed by 3 reviewers (M.M., M.J., U.S.). Full texts of potentially relevant studies were retrieved and reviewed against the specified inclusion criteria (M.M., M.J.). Any disagreements were resolved through discussion with a third investigator (D.K.) for consensus. Reference lists of included studies were scanned to identify other potentially relevant articles.

Quality assessment. Quality assessment of included articles was undertaken using the quality checklist for quantitative studies of the Alberta Heritage Foundation for Medical Research.[19] This specific tool was chosen, because it provided a quantitative means of evaluating the wide range of study designs included in the review. Because of the limited amount of literature relevant to our review question, studies were not excluded based on their quality assessment scores.

RESULTS

Database search results. The database search identified 2,706 articles (Fig 1). Initial screening of titles and abstracts excluded 2,554. Further abstract screening of the remaining 153 articles against a more strictly defined set of inclusion criteria excluded another 85. In this regard, reviewers screened independently 10% of articles, and the consistency of selection was high ($\kappa = 0.818$, $P = .001$). After the removal of duplicates, 44 articles were retained for full text review. Thirty-three of these met the inclusion criteria, and a further 6 studies were identified and included through screening of the reference list, bringing the total number of included studies to 39. Each of these studies evaluated a single smartphone or tablet-based intervention.

Study characteristics. Among included studies, a variety of intervention types were identified and

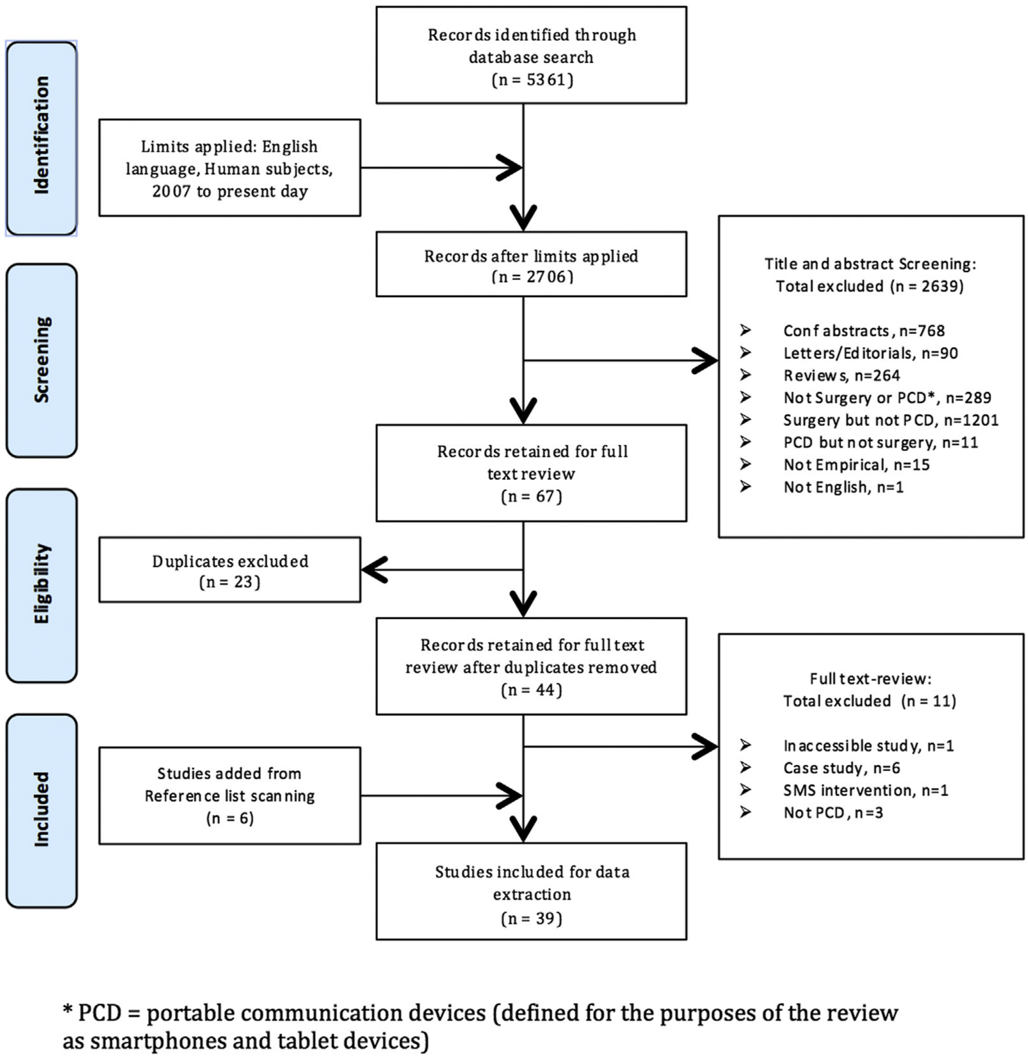

Fig 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram.

categorized into 8 domains; diagnostics, telemedicine, operative navigation, operative planning, training, data collection, patient education, and behavior change (Fig 2). Interventions were smartphone-based in 24 studies and tablet-based in 15 (1 study involved use of 2 types of smartphone; see Fig 3); 30 studies involved use of an app, and the remaining 9 papers evaluated non-app–based interventions.

In terms of surgical discipline, the majority of study interventions focused on orthopedic surgery (n = 17), general surgery (n = 4), and ENT (ear, nose, and throat) surgery (n = 4) (see Fig 4). Eleven study interventions made use of the inbuilt smartphone or tablet camera, 9 used the in-built accelerometer, and 2 used both of these sensors.

Quality assessment. The mean quality assessment score of included papers was 0.62 (SD ± 0.16, range 0.23–0.86) with only a single, randomized, controlled trial identified. Seven studies (18%) achieved a score ≥0.8.

Trials varied considerably in terms of their aims, methodologies, and outcome measures, and as such, it was not feasible to perform a meta-analysis of results. In the remainder of this review, the literature is discussed according to the identified categories of interventions as outlined earlier.

Diagnostics. Ten orthopedic studies[20-29] and a single ENT study[30] evaluated the use of smartphone apps as diagnostic tools (Table I). In the orthopedic discipline measurement of joint angles and range of movement is essential to establish the severity of joint deformity and level of disability post-injury. It is also important in operative planning and as an outcome measure after joint surgery and rehabilitation.[31,32] Ten orthopedic

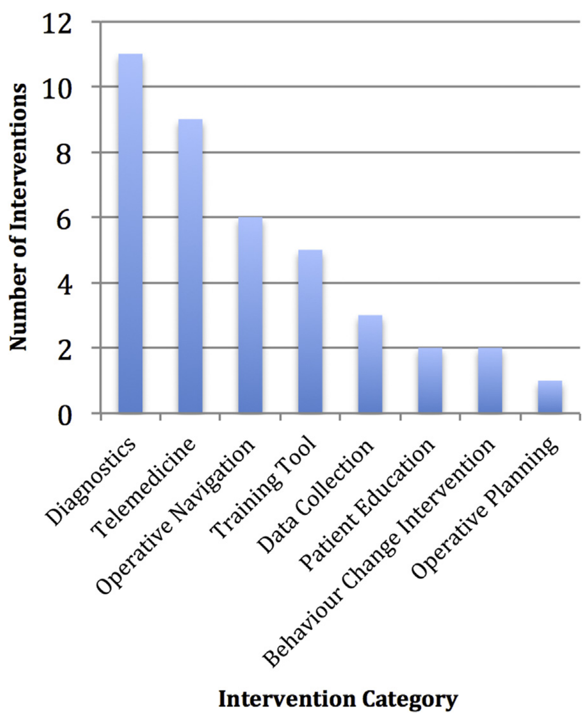

Fig 2. Number of interventions according to domain type.

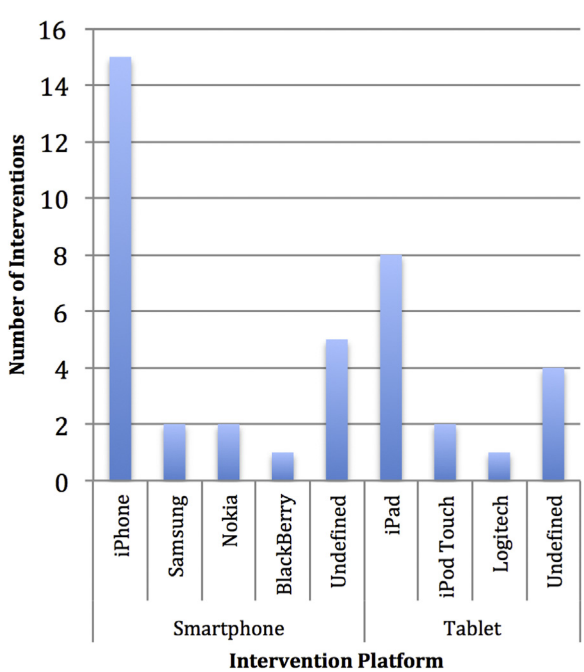

Fig 3. Number of interventions according to platform type.

studies evaluated smartphone apps designed to measure joint angles and range of movement, either in real-time on live patients or from photographs or radiographic images of joints; these studies compared these novel methods with other well-established "gold-standard" techniques (see Table I).[20-29] Spinal,[24-26] shoulder,[27] elbow,[28] knee,[20-23] and metatarsophalangeal[29] joint angles were measured by apps using either the in-built smartphone accelerometer or a virtual in-app goniometer.

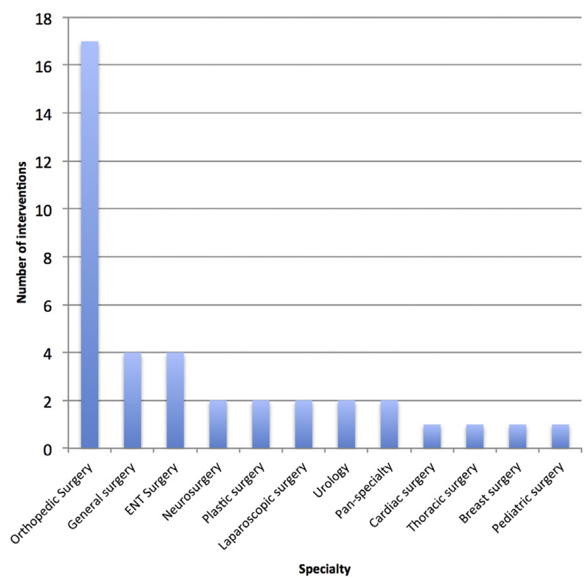

Fig 4. Number of interventions according to operative discipline.

Although study results generally supported the use of smartphone apps as effective alternatives to traditional well-established techniques, findings must be interpreted with caution because of study limitations. Some trials used nonrepresentative samples consisting wholly of healthy participants, hence negating the ergonomic challenges associated with measuring joint angles in those with pathology or obesity.[20,21] Others used non-gold standard control groups as seen in the studies by Jacquot et al[25] and Qiao et al,[26] who used protractor based measurements of spinal angles where computer software has already been shown to achieve greater precision.[33]

In the evaluation of hearing impairment, a single ENT study demonstrated that automated air conduction audiometry using a smartphone app ("EarTrumpet") was a reliable, inexpensive, less complex, and more convenient alternative to conventional manual audiometry in both a sound booth and quiet room environment.[30] The platform was preferred by 90% of participants.

Telemedicine. Telemedicine is defined as the remote delivery of health care services by means of telecommunications technology to aid diagnosis, treatment, and prevention of disease or for

Table I. Diagnostics

Author(s)	*Specialty*	*Intervention*	*Device*	*Study details*	*Results*
Hambly et al, 2012[20]	Orthopedics	iGoniometer – app measures angles.	Smartphone (iPhone)	Compare smartphone (Sm) and long-arm goniometer (Gm) measurements of maximum active knee flexion in 96 healthy volunteers.	High intraobserver reliability (Gm r = 0.892, vs Sm r = 0.894) and levels of agreement between the 2 methods (Gm r = 0.803 vs Sm r = 0.795).
Ockendon and Gilbert, 2012[21]	Orthopedics	'Knee goniometer' – app measures angles.	Smartphone (iPhone)	Compare smartphone (Sm) and long-arm goniometer (Gm) measurements of simulated knee fixed flexion deformities in 5 healthy volunteers by 2 observers.	High intraobserver (Gm ±9.6°, r = 0.927 vs Sm ±4.6, r = 0.982), and interobserver reliability (Gm ±8.4°, r = 0.952 vs Sm ±2.7°, r = 0.994), and LoA between methods (r = 0.947, mean diff 0.4°).
Ferriero et al, 2013[22]	Orthopedics	'DrGoniometer' – app measures angles.	Smartphone (iPhone)	Compare smartphone (Sm) and standard universal goniometer (Gm) measurements of knee flexion angles from photographs of 10 healthy volunteers by 10 observers.	High intraobserver (r = 0.996) and interobserver correlation (r = 0.994). 95% LoA between methods = 14.1° (−6.6° to +7.5°).
Jenny 2013[23]	Orthopedics	'Angle' – app measures angles.	Smartphone (iPhone)	Compare smartphone (Sm) and Surgical Navigation System measurements of intraoperative knee flexion angles in 10 consecutive patients during total knee arthroplasty performed by 2 observers.	Good intraobserver (Sm r = 0.81) and interobserver reliability (Sm r = 0.79). No statistically significant difference between methods and significant correlation between the 2 methods (r = 0.09, $P < .001$).
Franko et al, 2012[24]	Orthopedics	'Scoliogauge' – app measures angles.	Smartphone (iPhone)	Compare smartphone (Sm) and standard scoliometer (Ss) measurements of 60 random angles marked on a sheet of paper, by 4 observers.	All measurements using Sm were taken in 3–5 seconds. Near-perfect correlation between the 2 methods for each provider and all providers overall (r ≥ 0.999, $P < .001$).

(*continued*)

Table I. (*continued*)

Author(s)	*Specialty*	*Intervention*	*Device*	*Study details*	*Results*
Jacquot et al, 2012[25]	Orthopedics	'Cobbmeter' – app measures angles.	Smartphone (iPhone)	Compare smartphone (Sm) and manual protractor (Pr) measurements of Cobb angle from 20 radiographs of kyphotic spines by 6 observers.	High intraobserver (Sm r = 0.977) and interobserver reliability (Sm r = 0.965). No significant difference and excellent correlation between methods (r = 0.963).
Qiao et al, 2012[26]	Orthopedics	'Cobbmeter' – app measures angles.	Smartphone (iPhone)	Compare smartphone (Sm) and manual protractor (Pr) measurements of Cobb angle from 53 radiographs of scoliotic spines by 5 observers.	High intraobserver (Pr r = 0.955, Sm r = 0.985) and interobserver reliability (Pr r = 0.936, Sm r = 0.956). Mean measurement time Pr = 37.9 vs Sm = 13.7 seconds.
Shin et al, 2012[27]	Orthopedics	'Clinometer-Level' and 'Slope Finder' – apps measure angles.	Smartphone (Samsung Galaxy S)	Compare smartphone (Sm) and double arm goniometer (Gm) measurements of passive and active shoulder range of movement in 41 patients with unilateral pathology by 3 observers.	Generally high intraobserver reliability ($r > 0.9$) and satisfactory interobserver reliability ($r > 0.7$) with both methods for most movements. Good LoA between methods (r = 0.79–0.97).
Ferriero et al, 2011[28]	Orthopedics	'DrGoniometer' – app measures angles.	Smartphone	Compare smartphone (Sm) and universal goniometer (Gm) measurements of elbow range of movement/angles from 28 healthy volunteers by 7 observers.	High intraobserver (Sm r = 0.998) and interobserver reliability (r = 0.998). 95% LoA between methods = 10.26° (−5.75° to +4.51°).

(*continued*)

Table I. (*continued*)

Author(s)	*Specialty*	*Intervention*	*Device*	*Study details*	*Results*
Walter et al, 2013[29]	Orthopedics	'Halux Angles' – app measures angles.	Smartphone (iPhone)	Compare smartphone (Sm) and computer software (PACS) measurements of foot angles from 30 radiographs of patients with hallux valgus by 3 observers.	High intra-observer (PACS $r > 0.91$, Sm $r > 0.82$) and inter-observer reliability (PACS $r > 0.89$, Sm $r > 0.79$) using both methods when measuring hallux valgus angle and intermetatarsal angle.
Foulad et al, 2013[30]	ENT surgery	'EarTrumpet' – app performs automated audiometry.	Smartphone (iPhone)	Compare smartphone automated audiometry (Sm) and conventional manual audiometry (Ma) performed on 42 patients. Sm values within 10 db of Ma values represented acceptable level of variance.	94–96% of threshold values obtained using Sm were within 10 dB of corresponding values obtained using Ma. 90% of participants preferred Sm to Ma.

ENT, Ear-nose-throat; *LoA*, levels of agreement; *PACS*, picture archiving and communication system.

education of healthcare providers.[34] Since conception, telemedicine platforms have taken various guises, but the advent of portable communication devices has paved the way for ubiquitous use. Nine studies evaluated smartphone- or tablet device–based telemedicine interventions and were subcategorized in to tele-radiology,[35-37] tele-mentoring,[38,39] tele-diagnosis,[40-42] and tele-rounding[43] domains (Table II).

Tele-radiology. Telemedicine is well established for radiologic purposes, where fixed cross-site workstations running PACS (Picture Archiving Communication System) allow convenient, cost-effective transfer of radiologic images.[41] Three studies evaluated the contribution of smartphones and tablet devices to this field, either as modalities for image capture and transfer or for image viewing.

Using a 5-megapixel camera, Goost et al[36] captured and e-mailed photographs of 100 radiographs for interpretation on a laptop by 4 orthopedic surgeons and a radiologist. A correct diagnosis was made 83% of the time. Although the authors concluded that smartphone use in this way facilitates decision-making, the clinical implications of an incorrect diagnosis 17% of the time cannot be underestimated. Tennant et al[37] used tablets to view and interpret radiographs of ankle fractures and compared this approach with PACS workstations. High intra- and inter-observer reliability was demonstrated, and 76% of observers were comfortable using the mobile device as the primary viewing tool. Choudhri et al[35] compared the dedicated tablet DICOM (Digital Imaging and Communication in Medicine) viewer app ('OsiriX'), and the PACS workstation-based interpretations of computed tomography images in suspected appendicitis. The tablet platform exhibited an extremely high sensitivity, specificity, and negative and positive predictive values (98–100%) for diagnosing acute appendicitis, strongly supporting its clinical use.

Tele-mentoring. Telemedicine is a useful means of obtaining real-time subspecialist expertise during complex situations or operations, a process referred to as tele-mentoring.[44,45] In this regard, 2 studies evaluated very different contributions of smartphones and tablet devices. In the first study, the mentoring surgeons viewed video snippets of laparoscopic cholecystectomies (demonstrating the cystic duct prior to its clipping) on a smartphone and were able to identify the duct in the majority of cases.[39] Although they were only happy to give the go-ahead for clipping 60% of the time, mentors commented that they would have felt more confident had they been able to

Table II. Telemedicine

Author(s)	*Specialty*	*Intervention*	*Device*	*Study details*	*Results*
Choudhri et al, 2012[35]	General surgery	TR: DICOM viewer app ('OsiriX').	Smartphone (iPhone)	Compare smartphone DICOM viewer (Sm) and PACS workstation (Pw) interpretations of 25 CT scans of patients with RIF pain by 5 radiologists.	Sm sensitivity = 98.6%, Specificity = 100%, PPV = 100%, NPV = 98% for diagnosing appendicitis.
Goost et al, 2012[36]	Orthopedics	TR: Smartphone to capture/transmit photos of radiographs (nonapp).	Smartphone (Nokia N95)	100 pathologic radiographs (various anatomical regions) photographed and emailed using smartphone for interpretation on a laptop by 1 radiologist and 4 orthopedic surgeons.	Diagnosis correctly identified in 83.2% of cases. No correlation between image quality and diagnosis ($r = -0.15$, $P > .1$). 61% radiographs correctly interpreted by all observers.
Tennant et al, 2013[37]	Orthopedics	TR: tablet's standard image viewing software used to view radiographs (nonapp).	Tablet (iPod touch)	Compare tablet (Tb) and DICOM workstation (Dw) interpretations of 16 ankle fracture x-rays viewed by 93 orthosurgeons. MCQs completed regarding diagnosis, severity, need for CT and immediate ortho input, treatment plan.	Excellent intraobserver ($\kappa = 0.82$–0.87, $r = 0.9$), moderate-good inter-observer agreement for all outcomes for both methods (Dw $\kappa = 0.47$–0.62, $r = 0.79$ vs Tb $\kappa = 0.45$–0.62, $r = 0.83$). 76% observers comfortable using Sm as primary viewing tool.

(*continued*)

Table II. (*continued*)

Author(s)	*Specialty*	*Intervention*	*Device*	*Study details*	*Results*
Ereso et al, 2009[38]	Surgery (all specialties)	TM: Tablet and stylus control remote camera and laser pointer in OR (nonapp).	Tablet (Logitech)	3 robotic surgical tele-mentoring platforms controlled with different input methods—6 degrees of freedom (DoF), mouse (Ms), Tablet (Tb)—evaluated by 5 surgeons by simulating incisions on paper.	Tb and Ms superior to DoF in all quantitative (4.1 and 4.3 vs 1.7, $P < .001$) and qualitative metrics (4.6 and 4.8 vs 1.7, $P < .001$). Surgeons preferred Tb to Ms/DoF as stylus simulated scalpel.
Parker et al, 2010[39]	General surgery	TM: Smartphone standard viewing software used to view video clips (nonapp).	Smartphone (BlackBerry 8830 World)	10 short videos of the critical view (displaying CD anatomy) from 5 laparoscopic cholecystectomies were viewed on smartphone by 3 mentoring surgeons.	87% felt image quality sufficient, 93% felt CD adequately displayed, 60% would give go ahead for CD clipping. Good interobserver reliability (Cronbach's alpha = 0.71) and internal consistency reliability (KR rho = 0.80).
Martinez-Ramos et al, 2009[40]	Surgery (all specialties)	TD: Smartphone to capture/transmit photos of wound (nonapp)	Smartphone (Nokia 6600)	96 day-surgery patients asked to use Sm to capture and e-mail photos of their wound if concerned, for interpretation and management by 3 physicians.	30 wounds photographed—only 1 hospital attendance for physician review. 16 patients stated that if they did not have telemedicine system, they would have attended hospital. Patient satisfaction score with system 8.9/10.

(*continued*)

Table II. (*continued*)

Author(s)	*Specialty*	*Intervention*	*Device*	*Study details*	*Results*
Engel et al, 2011[41]	Plastic surgery	TD: Smartphone to capture/transmit photo of flap (nonapp).	Smartphone (unspecified)	103 free flaps monitored remotely using smartphone (Sm) or in-person clinical examination (Cx) by 7 surgeons. Flap re-explored if compromise suspected.	Accuracy Cx = 98.7% vs Sm = 94.1%. Interobserver reliability Sm = 96.4%. Re-exploration time Cx = 180 ± 104 min vs Sm = 8 ± 3 min. Greater salvage rate (75% vs 40%), lesser failure rate (2.2% vs 7.1%) in Sm ($P > .05$).
Hwang et al, 2012[42]	Plastic surgery	TD: 'Kakao Talk' app used to capture/ transmit, and discuss flap photos.	Smartphone (iPhone and Samsung Galaxy S)	Pre & post-implementation study. 61 flaps monitored using Doppler and clinical review (Cx) compared with 62 flaps monitored using smartphone (Sm).	Greater flap survival (100% vs 96.7%), and salvage rates (100% vs 50%) with Sm but not significant. Time from suspected flap compromise to re-exploration significantly shorter with Sm (1.4 vs 4 h, $P < .05$).
Kaczmarek et al, 2012[43]	Urology	TRo: 2 tablets running video-call apps (skype/facetime).	Tablet (iPad)	32 postoperative urology patients reviewed by their consultant surgeon remotely on day 1 postoperatively using Tb, and in-person on day 2.	91% patients felt care better with Tb, 97% felt Tb should be regular part of inpatient care, 94% felt communication with Tb easier, 84% felt comfortable with daily Tb review.

CD, Cystic duct; *DICOM*, Digital Imaging and Communication in Medicine; *KR*, Kuder Richardson; *NPV*, negative predictive value; *MCQ*, multiple-choice questions; *OR*, operating room; *PACS*, picture archiving and communication system; *PPV*, positive predictive value; *RIF*, right iliac fossa; *TD*, tele-diagnosis; *TM*, tele-mentoring; *TR*, tele-radiology; *TRo*, tele-rounding.

communicate with the operating surgeon or obtain further anatomic views. In the second study, the mentoring surgeons used a tablet device and stylus to control a camera and laser pointer located in a remote operating room compared with 2 other control systems[38]; The tablet scored highly in all objective and subjective measures of outcome.

Tele-diagnosis. Tele-diagnosis refers to "a diagnosis that is made at a remote location and is based on the evaluation of data transmitted from instruments that monitor the patient and a transfer link to a diagnostic centre."[46] In the field of plastic surgery, Engel et al[41] and Hwang et al[42] investigated the use of smartphones for remote monitoring of operatively constructed tissue flaps by capturing and transmitting photographs of flaps to senior surgeons for assessment compared with in-person clinical review and Doppler assessment. Smartphone use decreased statistically the re-exploration time when compromise of the flap was suspected, with greater rates of flap salvage and lesser rates of failure; statistical significance was not reached in the latter 2 outcomes. A final study demonstrated a decrease in unnecessary hospital presentations using a smartphone-based telemedicine platform to address the wound concerns of patients after day-case surgery.[40]

Tele-rounding. The first report of remote patient rounding was described by Ellison et al[47] and involved an expensive robotic platform. Portable, hand-held devices represent a more convenient and inexpensive platform for this utility as demonstrated by Kaczmarek et al[43] who used two tablet computers and a video conferencing app; they found greater levels of patient satisfaction with the system. Unfortunately, perspectives of the surgeons, who may have expressed less satisfaction because of the inherent inability to examine patients remotely, were not evaluated.

Operative navigation and planning. Six studies described the use of smartphones and tablet devices for operative navigation (Table III). These platforms were used to guide the placement of acetabular cups during total hip arthroplasty,[48] fixation of the femur after fracture,[49] insertion of pedicle screws during lumbar spine fusion,[50] puncture of the collecting system by trainees during percutaneous nephrolithotomy with a decrease in radiation exposure[51] (using a tablet device to display an augmented reality view of underlying anatomic structures), placement of cranial ventricular catheters[52] (using an app and smartphone accelerometer to dictate necessary fine-angle adjustments to a guiding tool through which a ventricular catheter was inserted transcranially), and for anatomic guidance during lung segmentectomy in patients with primary or metastatic lung cancer[53] (using a dedicated mobile DICOM viewer ("OsiriX") to view reconstructed computed tomography scan images intraoperatively). While the aforementioned studies demonstrated feasibility, it is difficult to draw reliable conclusions regarding safety and efficacy because of limitations in study methodologies, mainly small sample sizes and lack of control groups for comparison. Consequently, results should be interpreted with caution.

A single report by Larrosa et al[54] described a smartphone-based ear-nose-throat (ENT) app that supported operative planning before rhinoplasty. The app used tactile contouring and morphing software to alter the photograph of the patient profile and display potential rhinoplasty outcomes. On subjective evaluation, ENT surgeons significantly preferred the app to gold-standard photo-tracing methods.

Training. Several studies demonstrated innovative uses of smartphones and tablet devices in supporting surgical training (Table IV). Grayeli et al[55] developed and validated a mastoidectomy simulator using a tablet and stylus. An anatomic specimen was displayed on the tablet device, and users were asked to "reproduce drill movements on the tablet in order to achieve the removal of the mastoid cortex for a safe, efficient, and large mastoidectomy." The simulator was capable of distinguishing experts from beginners and was able to detect the effects of training.

Davis et al[56] demonstrated significant improvement in simulated chest drain insertion technique among healthcare staff immediately after viewing a 3-minute, tablet-based educational module, highlighting the potential of using such platforms in the "just-in-time learning" and cognitive rehearsal contexts. Although the control group in this trial received no instruction, the authors argued that this was true to life because smartphones and tablets allow doctors to access educational content rapidly at the point-of-care delivery.

Gonzalez et al[57] restructured the neurosurgical teaching program at their institute and provided trainees with tablet devices as an educational resource, with a consequent significant improvement in exam scores. Ninety-two percent of trainees attributed increased time spent studying outside of hospital to the provision of tablets, and 67% used these devices as the primary means of accessing educational resources. This application of tablet devices is particularly relevant in

Table III. Operative navigation and planning

Author(s)	*Specialty*	*Intervention*	*Device*	*Study details*	*Results*
Peters et al, 2012[48]	Orthopedics	ON: 'Angle' and 'Camera Protractor Lite' apps measure angles intraoperatively.	Smartphone (iPhone)	Smartphone used to ensure correct orientation of acetabular cup placement during 50 consecutive primary total hip arthroplasties. Final placement checked with radiographs.	No significant difference in inclination angle pre-, intra-, and postoperatively (40.64° vs 41.02° vs 39.96°, respectively). All acetabular cups were placed within the safe zone (ie, inclination of 40 ± 10° and anteversion of 15 ± 10°).
Hawi et al, 2013[49]	Orthopedics	ON: App (unspecified) used to measure angles intraoperatively.	Smartphone (iPhone)	Compare smartphone (Sm), CT and surgical navigation tool (SNT) measurements of femoral ante-torsion (FA) in 12 cadaveric femora. Femurs then fractured and fixed with 10–15° FA using Sm guidance and compared to SNT and CT postfixation measurements.	Good correlation between Sm and CT pre- (r = 0.733) and postfixation (r > 0.898). Fair correlation between Sm and SNT pre- (r = 0.467) and good correlation postfixation (r = 0.898). No significant difference in mean measurements using Sm, CT, or SNT.
Jost et al, 2013[50]	Orthopedics	ON: App (not specified) used to measure angles intraoperatively.	Tablet (iPod touch)	Required screw insertion angles of 5 consecutive patients undergoing lumbar spine fusion calculated preoperatively using CT/MRI. Tablet app used intraoperatively to place screw at desired angle – postoperative position confirmed on CT.	Mismatch (between CT-confirmed postoperative angle and planned angle) was <3° in 16 out of 20 screws, 7° in 2 screws, 8° in 1 screw, 13° in final screw. All screws were placed entirely within pedicle and vertebral body.
Muller et al, 2013[51]	Urology	ON: Tablet app displays augmented reality image of anatomy	Tablet (iPad)	Compare tablet based augmented reality-guided (Tb) PCNL to fluoroscopic (Fl) and ultrasound-guided (US) insertion by 1 trainee and 2 experts; 53 punctures performed in phantom model.	81% (Tb), 70% (US), 64% (Fl) successful punctures by trainee (100% for experts regardless of method). Trainee fastest using Tb. Radiation exposure 3× less in trainee (P = .011) and 1.8× less in experts (P = .174) using Tb.

(*continued*)

Table III. (*continued*)

Author(s)	*Specialty*	*Intervention*	*Device*	*Study details*	*Results*
Thomale et al, 2013[52]	Neuro-surgery	ON: app calculates fine angle adjustments to a guiding tool for VC insertion.	Smartphone (iPhone)	Part 1: 27 smartphone-assisted VC insertions into phantom model followed by 35 VC insertions in real patients.	On phantom, mean angle deviation (intended vs actual angle as measured on CT) of 1.1 ± 0.7°. In live patients, first pass CSF puncture rate of 100%. No VC failure seen over a 9.1- ± 5.3-month follow-up.
Eguchi et al, 2012[53]	Thoracic surgery	ON: Tablet DICOM viewer app ('OsiriX') used to view CT.	Tablet (iPad)	3D CT reconstructions viewed intraoperatively during 14 lung segmentectomies to define anatomy before vessel/bronchi division and ensure adequate tumor margins.	All segmentectomies successful. Mean operative time 210 minutes (range, 134–297). Mean blood loss 21 mL (range, 5–57). No postoperative complications. All margins clear on histology.
Larrosa et al, 2013[54]	ENT surgery	OP: App displays potential rhinoplasty outcomes from patient photos.	Smartphone (iPhone)	21 ENT surgeons used Smartphone (Sm) to edit photo of a rhinoplasty candidate compared with Photo-tracing method. Completed 4-item survey subjectively evaluating the methods.	App scored more highly on all outcomes ($P < .001$): Patient-doctor communication; 7.8 vs 5.4, $P < .001$. Processing time; 7.0 vs 3.6, $P < .001$. Surgical planning; 7.0 vs 5.5, $P < .001$. Help during surgery; 4.7 vs 3.9, $P < .001$.

CT, Computed tomography; *ENT*, ear-nose-throat; *MRI*, magnetic resonance imaging; *ON*, operative navigation; *OP*, operative planning; *PCNL*, percutaneous nephrolithotomy; *VC*, ventricular catheter.

Table IV. Training

Author(s)	*Specialty*	*Intervention*	*Device*	*Study details*	*Results*
Grayeli et al, 2010[55]	ENT surgery	Tablet app and stylus used to mimic drilling of mastoid on anatomic image	Tablet	12 ENT trainees and 4 experts performed simulated mastoidectomy using Tablet (Tb). Trainees re-performed simulated mastoidectomy following a training course.	Experts out-performed trainees in 3 outcomes (surface, circularity, perimeter: $P < .05$), and similarly in 2 outcomes (drill pressure, trajectory). Improvement ($P < .05$) in surface, circularity, drill trajectory postcourse.
Davis et al, 2012[56]	General surgery	App teaches proper chest drain insertion technique.	Tablet (iPod Touch)	128 participants (students, trainees, military) allocated to intervention (Tablet [Tb]) or control (no instruction) group. Simulated chest drain technique then evaluated.	Tb performed significantly better (11.1 ± 3.1 vs 7.2 ± 3.6, $P < .001$). On subanalysis, those with <10 real-life drain insertions significantly improved with Tb (9.7 vs 3.9, $P < .001$).
Gonzalez et al, 2012[57]	Neurosurgery	Tablets used to access neurosurgery apps/digital resources.	Tablet	12 trainees given tablets. Efficacy evaluated through survey and exam scores pre and 1-y postprovision of tablet and implementation of a lecture-based teaching program.	92% increased time spent studying outside hospital due to tablets and digital resources. 100% found digital resources useful or very useful. Significant improvement in examination scores postintervention (13% improvement, $P = .04$).
Bahsoun et al, 2013[58]	Laparoscopic Surgery	Box trainer - tablet replaces lap stack (nonapp).	Tablet (iPad)	10 inexperienced surgeons performed basic lap task (passing suture through 3 hoops) and completed surveys regarding the platform (Likert scale questions)	Regarding the trainer - Training capacity: 4–4.4/5. Performance: simple to set up = 3.5–4.5/5. Usability: 70% stated easy to use and 100% would continue using it.
Ruparel et al, 2014[59]	Laparoscopic surgery	2 box trainers – tablet replaces lap stack (nonapp).	Tablet (iPad)	10 surgeons (4 junior trainees, 4 senior trainees, 2 experts) performed 3 laparoscopic tasks on 2 tablet trainers and standard box trainer. Performances video-taped and scored.	Senior trainees out-performed juniors on 6 of 9 tasks. Experts out-performed trainees on all tasks and box-trainers.

ENT, Ear-nose-throat; *lap*, laparoscopic.

the current training climate, where surgeons are expected to reach proficiency despite a decrease in working hours.

The final 2 studies used trainees and experts performing basic laparoscopic tasks to validate several inexpensive and easily constructible box trainers in which tablet devices were used in place of a laparoscopic stack and camera.[58,59]

Data collection. Patient-reported outcome measures explore the perceptions of the patient regarding the care they receive and have become an integral part of service evaluation and bench marking within health care, impacting on hospital payments and encouraging quality improvement.[60] Collection of such data has become paramount.

Gurland et al[61] and Dy et al[62] demonstrated greater response rates, fewer omitted questions and unscorable forms, and increased patient satisfaction when using tablets to collect outpatient patient-reported outcome measures data compared with traditional paper surveys (Table V). Cook et al[63] evaluated use in the inpatient setting and again noted high completion rates despite an average participant age of 68 years (range, 52–85) and concerns regarding technologic literacy in this age group. Other cited benefits of the use of tablet devices in these studies included streamlined data management with transmission directly into electronic patient records and the ability to manage large amounts of data simultaneously and rapidly, although these benefits were not evaluated specifically.

Patient education. Two survey-based studies evaluated the use of smartphones in the patient education context (Table V). Glynn et al[64] explored the effect of smartphone ownership on the behaviors of health information–seeking parents of children with ENT pathology and demonstrated that individuals owning an internet-enabled handset were more likely to browse the internet for pertinent health information (37% vs 24%, $P = .001$). This benefit is likely a result of the portability and connectivity of these devices. Gautschi et al[65] described a modular educational app designed to prepare patients for elective spinal surgery and demonstrated high patient satisfaction with the platform.

Behavior change. Two final studies evaluated smartphone app–based interventions as a means of promoting behavior change (Table V). The first intervention taught and encouraged breast self-examination through the provision of educational content, video tutorials, reminders, and performance tracking.[66] Use of the app increased self-examination rates in women younger than the age of 30 (36–82%, $P = .002$), as well as the overall proportion examining at the optimal time (2.2–33.3%, $P < .001$). Selection bias attributable to recruitment through advertising was a limitation in this study.

Lee et al[67] provided smartphones running commonly available gaming apps to children undergoing surgery as a distraction prior to and during the administration of anesthesia. These investigations found the smartphone intervention to be more effective than standard dose midazolam at decreasing anxiety levels. Furthermore, a combination of the 2 interventions was more efficacious than either intervention alone. It is noteworthy that this was the only randomized controlled trial identified through this review.

DISCUSSION

The unparalleled connectivity, portability, accessibility, and ubiquity of smartphone and tablet devices among the public and health care professionals mean that these technologies have tremendous potential to revolutionize healthcare delivery processes. Ubiquitous use of these platforms in non-medical settings has meant that migration into the health care and clinical arena has faced fewer barriers than has been the case traditionally with other technologies.

In a recent literature review of 60 papers, Ozdalga et al[10] explored the uses of smartphones within the general medical field and noted functions ranging from patient care and monitoring to communication, education, and research, allowing information to be accessed readily at the point of care delivery. A host of apps targeted at the layperson were also discussed, most of which were interventions in behavior change aimed at encouraging healthy living. Although this paper discussed extensively the uses of portable communication devices within medical specialties, it is also imperative that surgical healthcare professionals have an understanding of their potential roles within the field of surgery.

Kulendran et al[12] searched app repositories and identified more than 600 surgery-related apps with a host of functions, including clinician training, patient education, data collection, and diagnostic support. Although the authors also performed a literature review this was non-exhaustive and focused on app-based smartphone interventions only.

In the current climate of evidence-based practice, surgeons need to be aware of the evidence base pertaining to the uses of portable

Table V. Data collection, patient education, and behavior change

Author(s)	*Specialty*	*Description of intervention*	*Device*	*Study details*	*Results*
Gurland et al, 2010[61]	General surgery	DC: App based PROM collection. Data integrated into EMR.	Tablet (Tb)	116 patients attending colorectal clinics completed tablet based PROMs (Tb). Compared with historical data of 153 patients asked to complete paper surveys.	Greater completion rate with Tb (96% vs 25%). Patients felt Tb easy method for completing PROMs (median satisfaction score 9/10) and preferred this to paper surveys.
Dy et al, 2012[62]	Orthopedics	DC: Patients complete DASH survey on tablet app.	Tablet (Tb; iPad)	Pre- and postimplementation study: 222 patients in hand surgery clinic completed paper DASH (pre-Tb), compared with 264 patients completing Tablet DASH.	Greater number of omitted questions with paper surveys (2.6 ± 4 vs 0.1 ± 0.8, $P < .01$). Greater number of unscorable paper surveys (24% vs 2%, $P < .001$).
Cook et al, 2013[63]	Cardiac surgery	DC: App based to-do-lists, and self-assessment & reporting modules (SAMs)	Tablet (iPad)	1418 SAMs administered to 149 elective cardiac surgery patients. SAMs included 'Early screen for discharge planning' (ESDP), pain scale, and mobility scale.	1384 of 1418 SAMs completed (97.6%). 100%, 100%, 97% completion of EDSP, mobility scale, and pain scale respectively.
Glynn et al, 2013[64]	ENT surgery	PE: Smartphone (Sm) for internet browsing (nonapp).	Smartphone	629 surveys administered to the parents of children attending ENT outpatient clinics and day surgery units.	79.5% response rate. Those with Sm more likely to browse internet for pertinent medical info (36.9% vs 23.4%, $P = .001$).
Gautschi et al, 2010[65]	Orthopedics	PE: Education app (8 chapters and videos on lumbar surgery)	Tablet	52 consecutive patients undergoing elective lumbar disc surgery used Tablet education module pre-operatively.	82% felt system was helpful in preparing for surgery. 98% were content/very content with the info provided. 85% found video appealing. 86% would recommend the app to others.
Heo et al, 2013[66]	Breast surgery	BC: App supports breast self-examination (BSE).	Smartphone	59 females surveyed before (pre-intervention) and 2 months after downloading the app (postintervention) to evaluate BSE behaviors.	BSE at optimal time increased with Sm (2.2% to 33.3%, $P < .001$). On subanalysis, BSE increased (36% to 82%, $P = .002$) in <30-year-olds.

(*continued*)

Table V. (*continued*)

Author(s)	*Specialty*	*Description of intervention*	*Device*	*Study details*	*Results*
Lee et al, 2014[67]	Pediatric surgery	BC: Apps used to distract children and reduce pre-operative anxiety.	Smartphone	120 children due elective surgery randomized to midazolam (M), smartphone app (Sm), or both (SmM). Anxiety measured in holding area, and at theatre entrance.	Anxiety levels reduced by all interventions ($P < .01$). Sm reduced anxiety more than M ($P < .01$), and SmM reduced anxiety level more than M or Sm alone ($P < .01$).

BC, Behavior change; *DASH*, Disabilities of the Arm, Shoulder, and Hand; *DC*, data collection; *EMR*, electronic medical record; *ENT*, ear-nose-throat; *PE*, patient education; *PROMs*, patient-reported outcome measures.

communication devices both app and non-app based, within surgery. To the best of our knowledge, the presented work is the first comprehensive systematic review of the literature to address this issue. By providing a broad, "state-of-the-moment" review the work enables surgeons to attain a better understanding of the potential roles for these technologies and how they may be used to enhance day-to-day surgical practice in the future. It further servers to provide a useful reference and roadmap to guide future research and app development within the surgical field. A total of 39 quantitative, empiric studies evaluating use of these technologies, either as stand-alone platforms or components of larger systems, were included.

The review provides several broad but important findings. First, our study demonstrates the far and wide-reaching potential of smartphone and tablet platforms within surgery. Authors have published works spanning 10 surgical specialties and 8 intervention domains targeting both patients and health care professionals. Arguably, some of the most innovative uses for these technologies have been demonstrated within the surgical field. Preoperatively, these technologies have been used to aid surgical diagnosis, for the purposes of operative planning, to educate patients regarding upcoming operations and to decrease anxiety levels in children before surgery. Intraoperatively, these technologies have been used for the purposes of tele-mentoring and surgical navigation during total hip arthroplasty, spinal fusion surgery, placement of ventricular catheters, percutaneous nephrolithotomy, and lung segmentectomy. Postoperatively, these platforms have been used to monitor and review patients remotely. In the context of operative training, we have seen tablet devices used as simulators and as a means of improving accessibility to educational content both at the user's convenience and at the point of care delivery. Such findings clearly demonstrate the diverse impact that smartphone and tablet technologies may have on aspects of everyday surgical practice. It is not farfetched to state that the potential uses for these technologies within the surgical field are limited only by the imagination of app developers and surgical health care professionals.

It should be noted, however, that many included studies were limited in their methodology. Consequently, claims of efficacy and safety should be interpreted with caution. Only a single, randomized controlled trial was identified, and just 7 of the 39 included papers scored ≥0.8 on quality assessment. Small and nonrepresentative samples, comparison with non–gold-standard controls, and the use of subjective outcome measures were common limitations. Furthermore, despite the frequently cited economic benefits of such technologies, only a single study evaluated cost-effectiveness. These findings highlight the need for greater-quality clinical trials that incorporate calculations of cost-effectiveness as a facet of the evaluation of interventions so that surgeons, other health care providers, and policy makers can attain a better understanding of their potential economic as well as the impact on clinical care. This is imperative for their widespread adoption.

It also should be mentioned that compared with the large number of surgical apps already available (more than 600), published studies were relatively limited in number and only evaluated a very narrow scope of potential uses. Many useful and popular interventions designed for smartphones and tablet devices have not been evaluated rigorously to date, for example the elogbook app that allows surgeons to record performed surgical procedures, the SurgAware app that facilitates informed consent, the Safe Surgery app which essentially offers a mobile version of the World Health Organization Surgical Safety Checklist, and the Touch Surgery app which allows surgeons to rehearse cognitively operative procedures.

Although clinical trials represent the gold standard in the evaluation of health care interventions, the associated expense and the sheer number of apps already available along with an ever-increasing number of new releases mean that it is simply not feasible to trial every app. Furthermore, some apps do not lend themselves well to this form of evaluation (for example, the surgical logbook app). Consequently, although clinical trials should be encouraged wherever possible and mandatory in certain circumstances (eg, high-risk apps that are classified as medical devices according to the US Food & Drug Administration[68]), there is also the need for an alternative form of evaluation capable of appraising apps more rapidly, allowing consumers to readily identify those of greater quality from the many available. In this regard, the National Health Service in the United Kingdom has set out plans recently to kite-mark trusted mHealth apps in the UK (United Kingdom) in a bid to increase consumer confidence in their use.[69,70] Although this concept is an improvement on the status quo and will likely encourage wider adoption, it is crucial that such evaluation and regulation is both robust and proportionate and does not stifle innovation in this rapidly evolving sector.

While every effort was made to capture all relevant articles through careful construction of the search string and methodology, we recognize that some relevant papers may have been missed inadvertently.

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