Surgical Training 2.0: A systematic approach reviewing the literature focusing on oral maxillofacial surgery - Part II.

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Abstract:

Purpose : Many technologies are emerging in the medical field. Having an overview of the technological arsenal available to train new surgeons seems very interesting to guide subsequent surgical training protocols.

Methods : This article is a systematic approach reviewing new technologies in surgical training, in particular in oral and maxillofacial surgery. This review explores what new technologies can do compared to traditional methods in the field of surgical education. A structured literature search of PubMed was performed in adherence to PRISMA guidelines. The articles were selected when they fell within predefined inclusion criteria while respecting the key objectives of this systematic review. We looked at medical students and more specifically in surgery and analysed whether exposure to new technologies improved their surgical skills compared to traditional methods. Each technology is reviewed by highlighting its advantages and disadvantages and studying the feasibility of integration into current practice.

Results : The results are encouraging. Indeed, all of these technologies make it possible to reduce the learning time, the operating times, the operating complications and increase the enthusiasm of the students compared to more conventional methods. The start-up cost, the complexity to develop new models, and the openness of mind necessary for the integration of these technologies are all obstacles to immediate development. The main limitations of this review are that many of the studies have been carried out on small numbers, they are not interested in acquiring knowledge or skills over the long term and obviously there is a publication bias.

Conclusion : Surgical education methods will probably change in the years to come, integrating these new technologies into the curriculum seems essential so as not to remain on the side.

This second part therefore reviews, social networks, serious games and virtual reality.

This Systematic review is registered on PROSPERO (CRD42020181376).

Introduction and Material & Methods sections are detailed in Part I.

3.4 Social Networks (Figure 1; Figure 2; Table 1)

Within the past decade, the popularity of social media has increased at an exponential rate [1]. Social networks connect people around one or more ideas to create, share and freely exchange data with others [2–4]. Some social networks are well-known like Facebook® (Facebook, Menlo Park, USA) (1 billion users), Instagram® (Facebook, Menlo Park, USA) (500 millions), Twitter® (Twitter, San Francisco, USA) (500 millions), YouTube® (Google, San Bruno, USA), Pinterest® (Pinterest, Palo Alto, USA) or LinkedIn® (Microsoft, Sunnyvale, USA) and used daily for personal reasons which makes their professional use easier because it does not require any prior training [5]. Currently social networks are more used for promotional than for educational purposes [6]. One of the major advantages of these networks is the greater reactivity and commitment that we observe compared to other websites, which make them very interesting to deliver educational messages [6].

The surgeon's level of peer interaction is associated with higher performance on maintenance of certification exams [7]. Social media is an opportunity for this peer interaction. It could be difficult to establish personal connections with mentors "in the real-life". Twitter can help nurture this kind of relationship. These connections can prove beneficial not only for the mentee but also for the mentor, often in the form of "reverse mentoring" in which mentors learn about emerging technologies and skills from their mentees [8]. You can be active (when you post some comments) or passive (just like the comments). It has been shown that there are more comments on midweek days, that means that physicians prefer to use this Social Media during their workflow than in free time. The active engagement and interaction are important, as it can improve surgeons vicarious learning by allowing them to discursively react to one another's ideas and coconstruct a more robust, detailed understanding of their experiences [9].

With the busy and unpredictable schedules of surgical students, it has become difficult nowadays to find time for training. The expectation of 24/7 access to information is a key component of their learner's expectations [9,10]. In these conditions, a new concept has emerged, the "pull" learning, which provides a framework for students in which they must seek knowledge by themselves. An original 4-month experiment consisted of posting one question per day on Twitter® and the best students were rewarded weekly. A final evaluation compared the students who had followed the program and those who hadn't, and results were in favour of the first group. This experience gives us some reflections on the fact that gamification with this system of rewards uses the competitive spirit that often drives medical students and encourage them to give their best. Moreover, it seems that spreading knowledge in the form of quiz is more popular with students than traditional posts of videos or articles by teachers [11].

By posting links on Twitter®, it is now possible to have almost immediate feedback on its performance and to have progress leads for surgical students [5,12]. Crowdsourcing is another way of having an assessment of one's abilities by eliminating the affects that can exist between the senior surgeon and his apprentice. Several solutions exist, and it seems that the opinion of inexperienced people when they are several can lead to the same opinion as expert surgeons. Of course, the more we are willing to pay, faster are the results [13].

The use of hashtags especially has completely changed the possibilities of research and advertising for congresses [2,6,10,14,15]. The scientific journals have understood the interest of these social networks. They developed the #VisualAbstract, which is a concise visual summary of the main finding of an article, which is then posted on the networks [2,3].

Otherwise, massive open online courses are a new way to delivering interactive learning activities on the internet providing free access to academic courses for an unlimited number of participants worldwide. Modules like lectures, interactive patient cases, 3D animations, serious games and interview with well-known experts can be added [16,17]. This type of virtual course was compared to a more traditional lecture method in an amphitheater, and showed similar results in terms of knowledge acquisition and this method of instruction was much more appreciated by the students [18].

On the other hand, the video channels like YouTube® are a great asset for the young surgeon, he will be able to look at and re-maintain interventions, pause if necessary, something impossible in an operating room. Many of these links can be shared by Twitter® or Facebook® [10]. Indeed mounted a base of surgical videos is a very interesting prospect in the perspective of training young surgeons, it is then possible to add comments and make explanatory breaks to emphasize the important and / or delicate points for that the video be as educational as possible [19].

The leading digital platform in live surgery is the Advances In Surgery Channel® (AIS Corporate, Barcelona, Spain) [3]. VuMedi® (Vumedi,inc., Oakland, USA) permits to learn specific techniques through videos and lectures on various procedures. These videos do not take the place of formal mentorship training but is an another outlet for learning in an ever-evolving field [20]. The collaborative projects like Wikipedia® (Wikimedia Foundation, San Francisco, USA) or more professional the "sages" wiki created by the Society of American Gastrointestinal and Endoscopic Surgeons are great educational tools that allow for knowledge acquisition of disease process, as well as technical tips pertaining to an operation. These sites encouraging the members to participate and create more wikis [10].

One of the particularities of social networks is their free access for everyone. It is therefore obvious that certain precautions are necessary in particular professional secret [20]. Each professional must keep in mind that each shared data can be found one day. That are the reasons why each must stay polite and avoid cyber-bullying. You must to be very careful if you meet your patients on these networks and try to redirect them to the professional sites and especially stay professional [4,5]. Social media and online professionalism become important components of surgical education. Some program directors use didactics and online tutorials to educate residents on the proper use of social media. It's very important to know who will have access to published data, Facebook® allows to select viewers what does not allow Twitter® [1]. Another special feature is the lack of verification of sources of information. You don't have the same rigorous review of the contents than the scientific reviews. The surgeon's expertise can't be controlled and there is a lack of self-declared conflicts of interests [1,3,5,10,20]. But some sites exist with peer-review who shares videos like the Hospital for Special Surgery eAcademy [20].

One of the tricky facilities offered by these sites is the superficial reading of information without access to source documents that can't always be summarized in such a simple way. [2,3]. Concerning massive open online courses, the number of participants may inhibit the potential participation of some students. A static one-way online educational approach is another disadvantage [17].

These social networks seem to be excellent allies for the education of surgeons but require further studies to explore all possibilities and to better understand how to engage users in the field of surgery [3,6,9–11,13,14,16,17]. We can imagine that social medias developers will continue to create and expand their Social Media sites providing an abundance of tools that will can certainly be explored in surgical education [10].

In dentistry, everyone agrees on recognizing the potential value of these networks, some studies have shown that the students are ready and very enjoying at the idea to have some learning activities on social media and on smartphone, but it seems to be largely underused and this technology hasn't been formally included in the curriculum [5,21]. In oral and maxillofacial surgery, a department has published the use of WhatsApp® (Facebook, Menlo Park, USA) as a means of monitoring patients. All the medical information collected during the tour was transcribed on the application. This allowed the entire healthcare team to be aware of the situation even if they were not there. This also makes it possible to quickly disseminate any information concerning the life of the service [22]. However, we must be careful because this type of application has little protection against hacking.

3.5 Serious Games (Figure 3; Table 2)

The access to corpses, and the increase of the number of students in the operating theatres seem to be obstacles to the progression of the surgical teaching. We need to create surgical experts in a time- and cost-efficient manner. This requires finding new ways of learning [23–25].

Take a topic that seems unappealing, unflavouring and try to mix it with modern fun technology to get an engaging product that stimulates student's desire to learn and you'll get what we can described as a serious game. They are supposed to bring new knowledge or new surgical abilities while trying to bring the feeling of fun and captivate the attention of students as do video games usually, for example [26–28]. A serious game can be defined as any software with a purpose other than gaming [29]. A well-designed serious game combines psychological factors, design, and technology to engage learners in voluntary training [24].

The serious game can be positioned at different stages of the patient's care. During the operation, in orthopaedics for example, to help students better understand the management of bleeding in surgery, a simulation game has been developed with features such as networking or timed challenges [26]. Another plastic surgery software called Z-DOC allows students to practice Z-plasty, also with a scoring system [27]. These games can occur at different times during the surgical formation, like PeriopSim® (Conquer experience, Surrey, Canada) which is a neurosurgical application which teaches the young beginners the name of the different surgical instruments with a system of score and time defined to create a competition's feeling between students and thus to motivate them to learn [30]. Another serious game is interested in the management of undesirable events as well as equipment malfunctions. It's an arcade game which has shown that graphic high fidelity is not necessary to allow good quality teaching as long as the game's functional fidelity remains adequate [28].

Other serious games focus on the preoperative by developing the diagnostic aspect of patient management. One of them, for example, places the student in the emergency room and he must take care of the patient from diagnosis to medical treatment, while exposing him to the consequences of his mistakes as the undesirable effects of certain treatments [31]. A virtual patient simulator was created to train young surgical students, especially on diagnostic issues by offering a great deal of freedom in interrogation and in choice of complementary exams [32,33]. It can also go through a quiz game in which time-pressure and competition is used to trigger the intrinsic motivation of the player like in visceral surgery to train correct diagnosis and management of biliary tract disease or in ENT to improve the ability to diagnose tympanic membrane problems [24,34].

It is also possible to divert software intended for the general public for medical purposes. Second Life® (Linden Lab, San Francisco, USA), one of the most popular internet 3D-universes, has been used by the Imperial College of London to help young surgical novices become familiar with the operating room. The advantage is the ease of access from any computer and the ability to repeat experiments as often as necessary, which would not be possible in real life [10].

The most used application in surgical training currently is Touch Surgery® (Touch Surgery Enterprise, London, UK). It is a free app-based simulator which comprises a catalogue of several hundred operations and practical procedures. This app used the cognitive task analysis, it details the different steps of surgical operations, beginning with prepping the patient and ending with wound closure including training in instrument selection and application in operative situations. Assessment of each step is done with multiple-choice questions to train cognitive decision-making. There are graphics and animations to create an interactive virtual reality cognitive task simulation and rehearsal tool [23,25,29,35–37]. This application increases cognitive abilities rather than the practical abilities of students. In some studies, the use of this app seems superior to traditional teaching [25,29,35–37]. It's very useful because you can immediately review your mistakes. It procures repetitive practice which is very important. With this training, it's already a second nature to anticipate the next step. Also, senior surgeons teaching the steps of a procedure can often emphasize the steps deemed most important while underemphasizing or ignoring the steps performed through automated knowledge while Touch

Surgery® does not make that difference and treats all the steps with equal importance. The various studies carried out show that the students are very enthusiastic about the idea of integrating this application into the surgical curriculum in the future. This app could significantly reduce training time [25,29,35–37]. Main shortcoming is that this software offers only one approach for each surgery and we must not forget that it has no influence on the dexterity and manual skills of students [25,29,37].

Serious games are not necessarily accessible on computers. Indeed, an original initiative in vascular surgery has reused the concept of the escape room (this popular concept where participants must solve puzzles in one hour to get out of the room) using challenges requiring surgical skills to unlock the exit. Students expressed a high level of satisfaction with this experience, which encourages collaboration and communication among participants [38].

Valid serious games have the potential to shorten surgical trainees learning curves in clinical reasoning and problem-solving and increasing time efficiency in surgical training. One of the ideas of clinical education is the transfer of declarative ("what to do") into procedural knowledge ("how to do it"). These apps have been very well received by students and they hope that they can more use multimedia in their training [24,26,27,30–33]. All these new "games" allow above all to bring an experience to the learners without risk of causing damage to real patients in a safety-controlled setting and allow the trainer to assess the trainee's knowledge of the procedure prior to entering the operating theatre. It seems that an early exposure to simulation is critical in surgical training [23,24,26,35,39]. In all these "games", the importance of a feedback seems indispensable whether it is in the form of a computer correction or an explanation session with a teacher [32,33].

The high cost of development for these new applications is one of the major obstacles to the expansion of these technologies (about 200,000 euros for a simulation game) [10,31]. More studies are needed to evaluate the voluntary participation of students because if they use these applications only if this is mandatory, it is not of great interest anymore [28]. Maybe more levels of difficulty should be added to speak to a wider panel of surgeons. The information retained in the long term is also a data to be evaluated in future studies [35,36]. Of course, we must not forget that a patient is more complex than any application can create. All these didactic means must therefore remain complementary tools to traditional training [32,33].

In maxillofacial surgery, there are no studies on this subject. But we can quite imagine that these technological innovations could very well benefit our specialty. Currently, there are no less than 19 operations corresponding to maxillofacial surgery on the Touch Surgery® application such as condylectomy of the temporomandibular joint, nasoorbitoethmoid fractures or anterolateral thigh flap. We just have to hope that these programs will not stay longer as subjects of study but will quickly integrate surgical training.

3.6 Virtual reality (Figure 4; Figure 5; Table 3)

Unfortunately, work hours restrictions, increased resident supervision and patient requests to minimize resident participation in their care have crowded the scale of resident operative exposure [40–44]. The lack of availability and the cost of cadavers forced the search for other educational alternatives [40,45,46]. It is difficult to balance the need for surgical training with patient safety [47]. "First observing and then doing on the patient" no longer seems to be the ideal educational path, the student must become more independent in his learning journey [48,49]. This is how the first simulator was developed for endoscopy on soft tissue probably because it uses the same interface [47,50].

A simulator has been defined as a device for replacing the real world or its components, with a simulation allowing users to gain experience and skills by interacting with visual, tactile and auditory signals [40,49,51]. The essential points of virtual reality (VR) surgery are a 360° experience of an operating room, close-up stereoscopic visualisation of surgery and 3D interaction [41]. We can differentiate non-immersive VR (the user is focalized only on his task), the immersive VR (the user is in a virtual world around his task) and the augmented reality (it's a mix of reality where virtual reality is added) [51]. To develop a good simulation system, it is important to identify errors that may occur during surgical procedures and to allow the possibility of reproducing them in the simulators [45]. Developing haptic feedback in these systems is a fundamental element to be a good teaching tool [45,52].

VR has many advantages, it gives the opportunity to repeat the same task several times on different anatomies and pathologies [44,46,50,52–54]. There is a possibility of training without putting a real patient at risk [43,46,49,53,55–57]. You can fail without consequences, which would not be ethical in real life [49,58]. These simulators were able to show a significant reduction in operative complications in real life by allowing young surgeons to train before practicing on a real patient, which was not the case previously for certain procedures [49,55,59]. VR provides access to complex and non-routine operations which are rarely accessible to novice in real life [50,57]. It also allows young surgeons to be exposed to complications that rarely occur but will someday happen [49,51,57,58]. Studies have shown that after five to seven repetitions of the same intervention the learning curve reaches a plateau [44,60]. Some studies highlight the transfer of capacities that can take place between virtual simulation and the operating room [52,61]. This training seems superior to traditional teaching by reducing the operating times and increasing the efficiency of the gestures [40,43,44,48–50,52,54,62]. Some studies have shown a division by 5 of the learning time compared to traditional methods [41,44,48,63]. It seems that four hours of virtual reality simulator training is significantly more efficient than a half day of supervised training on patients using the traditional apprenticeship model [39]. The time saved can be used to learn nonprocedural skills like ethics, patient management and teamwork [63]. It would seem that the quality of the realism and the difficulty of the simulation must increase with the surgeon's experience to adapt better to the needs of each, the establishment of levels seems essential [44,47,53,63]. VR increases the confidence that young surgeons can have before entering the operating room more than traditional learning [41,49]. This permit to the students to react appropriately in stressful circumstances [41,47]. Other simulators have been developed to increase the diagnostic capabilities of students. The person is immersed in a virtual universe recreating emergencies and he must take care of the patient and prescribe the right complementary exams [64].

Like all new technologies, there are still flaws and areas for improvement. A distinction must be made between intrinsic and extrinsic feedback. Intrinsic feedback corresponds to all auditory, visual and tactile signals that are sent to the student while he is practicing, while extrinsic feedback corresponds to signals from an external source that will directly signal success or not a manoeuvre for example [65]. One of the challenges for the coming years is to successfully develop a performing haptic feedback system, especially in maxillofacial surgery, which is a specialty closely linked to bones

[42,48,49,51,54,57,59,60,62,66]. Indeed the majority of VR software offers only a torque feedback of 12N which is insufficient for the bone [50]. Misuse of extrinsic feedback can also create dependence and lead to poorer progress on the learning curve. This feedback should therefore be used sparingly [63,65]. It seems that a final feedback is more acceptable than a continuous feedback, which make an "information overload" [47,63].

One of the shortcomings of VR is that most current systems only take into account the key stages of the procedure without thinking about the surrounding tissues [59,62]. The use of immersive VR, which recreates the entire universe of the operating room in contrast to conventional VR, which only focuses on the surgical technical procedure, seems to be the last level of difficulty in preparing the young surgeon to operate [56,58]. The future of VR will also have to focus on developing interactions with the staff and the various surgical instruments and the decisions taken on the environment will have an impact on the procedure [56,58]. Some systems even allow you to simulate a procedure for an entire surgical team [57,58]. The concept of bleeding also seems to be an important parameter, which is often overlooked due to the properties of liquids, to take into account in the development of future simulators [47–49,60].

Like all new technologies, the current cost is still very high, but it is very likely to decrease in the years to come and the savings made on cadavers are far from trivial [41,46,53–55,57]. Some systems like Google Daydream® (Google, Mountain View, USA) and Google Cardboard® (Google, Mountain View, USA) could reduce the cost of Virtual reality systems. [66] A very interesting study used a commercial video game console (the Nintendo Wii U® (Nintendo, Kyoto, Japan)) to perform laparoscopic procedures. The results were very encouraging, and this lead is perhaps the best to disseminate virtual reality to as many people as possible at a reduced cost. [61] Other studies seem necessary in particular to assess the transfer of capacities in operating rooms. [46] Overconfidence should also be explored in the future. [41]

This technology can become a means of assessing students before letting them operate in reality [47,48,53]. VR must be considered as a new educational weapon and not as a teaching modality which must replace the others, because the mentor-mentee relationship could never be totally replace [46,47,49,63]. This new technology is greeted with great enthusiasm by young surgeons [42,50,53,57,66]. This needs to be further developed and access needs to be extended to all young surgeons [46,49,61,62,66]. This teaching modality should be integrated into new surgical training processes [39,43,48,49,51,54,56,57,63,66].

In oral and maxillofacial surgery, there are not many simulators. A virtual reality system to realize bilateral sagittal osteotomy has been developed [45,59]. Another simulator has been developed to reproduce Le Fort 1 osteotomy, this system has the particularity of being able to be used online and therefore to have feedback from its mentors [41,50,66]. Some simulators are very interesting because it is possible to load patient specific data, so their software can also be used for the preparation of surgeries and not only for training [45,62]. Another VR reality system has been developed for endoscope-assisted submandibular gland removal [60]. After DentSim® (Image Navigation Ltd., New York, USA) (the first simulator in dentistry), some VR simulators have also been developed in dental surgery like VR-MFS, VirTeasy Implant Pro. These simulators allow surgeon to practice to removal the root of a tooth, or the implantation of dental implant, or surgical removal of mandibular third molars, or apicectomy... [40,48,52,53,55,62]. Another interesting track combining serious game and VR allows students to explore the Pterygopalatine Fossa like a “first person shooter”, with questions as the anatomy is discovered [67]. Even if it is necessary to solve the problem of haptic feedback, VR seems entirely suitable for oral and maxillofacial surgery and it is likely that its use will democratize quickly in surgical training.

4. Conclusion

So, there are many future prospects for surgical education. It seems that the closest technologies to integrate our daily life are social networks and 3D printing. Indeed, these are the most financially accessible teaching methods and which do not require the intervention of a third party in order to set up the devices. For oral and maxillofacial surgeons, 3D printing seems to be the most promising technology essentially because it is the most suitable for bone procedures.

After this travel through new technologies, it seems obvious that there are great prospects for the future of surgical training. These advances should not be taken individually but rather as a whole. So, we can try to imagine an ideal surgical education which would start with a theoretical acquisition of knowledge, thanks to 3D models, virtual exploration of the anatomy, dynamic modes of data dissemination through social networks or even educational games. Then the student could start training to operate in virtual reality on 3D models, all in the form of serious gaming in order to strengthen the enthusiasm of the participants. Then finally the last step before autonomy would be the operation in telementoring all with optimal image quality thanks to the best open field camera techniques.

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Compliance with Ethical Standards

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Tables and figures :

Table 1. Social Networks Training Articles

Table 2. Serious Games Training Articles

Table 3. Virtual Reality Training Articles

Figure 1. PRISMA flow diagram related to surgical education through Social Networks

Figure 2. Word Cloud on Social Networks

Figure 3. PRISMA flow diagram related to surgical education through Serious Games

Figure 4. PRISMA flow diagram related to surgical education through Virtual Reality

Figure 5. Interaction with the 3D models of the maxillofacial anatomy.[1]

1. Illustration from Pulijala Y, Ma M, Pears M, Peebles D, Ayoub A, Effectiveness of Immersive Virtual Reality in Surgical Training - A Randomized Control Trial, *Journal of Oral and Maxillofacia Surgery* (2017), doi: 10.1016/j.joms.2017.10.002. **With the agreement of the publication.**

TABLE 1. Social Networks Training Articles

Title	Authors	Publication Year	Article Type	Surgical Specialty	Number of subjects
Virtual versus traditional classroom on facial traumatology learning: Evaluation of medical student's knowledge acquisition and satisfaction.	Morice et al.	2020	Non-randomized control trial	Maxillofacial surgery	136 students
Use of WhatsApp in an oral and maxillofacial surgery department at a major trauma centre and its role during major incidents: our experience.	Dungarwalla et al.	2019	Open research article	Maxillofacial surgery	A surgery department
Assessment of digital literacy and use of smart phones among Central Indian dental students.	Saxena et al.	2018	Cross-sectional Study	Oral Surgery	260 students
Teaching Surgical Procedures with Movies: Tips for High-quality Video Clips.	Jacquemart et al.	2016	Open research article	Maxillofacial surgery	7 surgical procedures
The risks and benefits of social media in dental foundation training.	Bhola et al.	2016	A review	Oral Surgery	44 articles
Social media: physicians-to-physicians education and communication.	Fehring et al.	2017	Free article	Orthopaedic surgery	Free opinion
Innovating clinical kidney transplant education by a massive open online course.	Reinders et al.	2016	Letter to the editor	Urological Surgery	An online course
Innovation in Pediatric Surgical Education for General Surgery Residents: A Mobile Web Resource.	Rouch et al.	2015	Open research article	Paediatric Surgery	32 residents
Social Media in Surgical	Ovaere et al.	2018	A review	Surgery	43

Training: Opportunities and Risks.					articles
Social Media as a Platform for Surgical Learning: Use and Engagement Patterns Among Robotic Surgeons.	Myers et al.	2018	Open research article	Surgery	A Facebo ok group
The comparison of teaching efficiency between massive open online courses and traditional courses in medicine education: a systematic review and meta-analysis.	Zhao et al.	2018	Meta-analysis	Surgery	4 studies
Educational content and the use of social media at US departments of surgery.	Nikolian et al.	2018	Open research article	Surgery	32 Twitter account s
The academic tweet: Twitter as a tool to advance academic surgery.	Logghe et al.	2018	A review	Surgery	69 articles
Gamified Twitter Microblogging to Support Resident Preparation for the American Board of Surgery In-Service Training Examination.	Lamb et al.	2017	Open research article	Surgery	45 resident s
Social Media: Changing the Paradigm for Surgical Education.	Petrucci et al.	2017	A review	Surgery	50 articles
Getting Started: A Social Media Primer.	Ferguson et al.	2017	A review	Surgery	55 articles
Balancing Privacy and Professionalism: A Survey of General Surgery Program Directors on Social Media and Surgical Education.	Langenfeld et al.	2016	Open research article	Surgery	110 progra m director s
Evaluating the Use of Twitter to Enhance the Educational Experience of a Medical School Surgery Clerkship.	Reames et al.	2016	Open research article	Surgery	66 student s
Social Networks, Social	Vohra et al.	2015	Open	Surgery	An

Media, and Innovating Surgical Education.			research article		opinion
Using Social Media to Increase Accessibility to Online Teaching Resources.	O'Kelly et al.	2015	Open trial	Surgery	93 students
Crowd-Sourced Assessment of Technical Skills: a novel method to evaluate surgical performance.	Chen et al.	2014	Open research article	Surgery	1 robotic experiment
An exploration of the use of social media by surgical colleges.	Ralston et al.	2014	Open research article	Surgery	5 organizations

TABLE 2. Serious Games Training Articles

Title	Authors	Publication Year	Article Type	Surgical Specialty	Number of subjects
Interactive iPhone/iPad App for Increased Tympanic Membrane Familiarity.	Samra et al.	2016	Open trial	ENT	21 students
Serious Games in Surgical Medical Education: A Virtual Emergency Department as a Tool for Teaching Clinical Reasoning to Medical Students.	Chon et al.	2019	Non-randomized control trial	Digestive surgery	140 students
Validation of the mobile serious game application Touch Surgery™ for cognitive training and assessment of laparoscopic cholecystectomy.	Kowalewski et al.	2017	Non-randomized control trial	Digestive surgery	105 participants
Game-based training improves the surgeon's situational awareness in the operation room: a randomized controlled trial.	Graafland et al.	2017	Randomized control trial	Digestive surgery	24 participants
Embedding a Virtual Patient Simulator in an Interactive Surgical lecture.	Kleinert et al.	2016	Open research article	Digestive surgery	360 students
Design, Realization, and First Validation of an Immersive Web-Based Virtual Patient Simulator for Training Clinical Decisions in Surgery.	Kleinert et al.	2015	Open research article	Digestive surgery	25 students
A serious game can be a valid method to train clinical decision-making in surgery.	Graafland et al.	2014	Open research article	Digestive surgery	41 participants
A pilot study to assess the utility of a freely downloadable mobile application simulator for undergraduate clinical	Bartlett et al.	2017	Randomized control trial	Urological Surgery	62 students

skills training: a single-blinded, randomised controlled trial.					
Using Touch Surgery to Improve Surgical Education in Low- and Middle-Income Settings: A Randomized Control Trial.	Bunogerane et al.	2018	Randomized control trial	Orthopaedic surgery	27 surgery residents
The technological evolution in surgical skills.	Seewoonarain et al.	2017	Open research article	Orthopaedic surgery	Expert opinion
A Mobile-Based Surgical Simulation Application: A Comparative Analysis of Efficacy Using a Carpal Tunnel Release Module.	Amer et al.	2017	Open trial	Orthopaedic surgery	100 students
Learning blood management in orthopedic surgery through gameplay.	Qin et al.	2010	Open research article	Orthopaedic surgery	Introduce a new software
Break out of the Classroom: The Use of Escape Rooms as an Alternative Teaching Strategy in Surgical Education.	Kinio et al.	2019	Open research article	Vascular surgery	13 participants
Simulation-based training for burr hole surgery instrument recognition.	Clarke et al.	2016	Randomized study	Neurosurgery	18 trainees
Z-DOC: a serious game for Z-plasty procedure training.	Shewaga et al.	2013	Open research article	Plastic surgery	Introduce a new software
Creation and Global Deployment of a Mobile, Application-Based Cognitive Simulator for Cardiac Surgical Procedures.	Brewer et al.	2016	Open randomized trial	Cardio-thoracic surgery	16 students
Social Media: Changing the Paradigm for Surgical Education.	Petrucci et al.	2017	A review	Surgery	50 articles
Technology for teaching: New tools for 21st century surgeons.	Eskander et al.	2016	A review	Surgery	39 articles

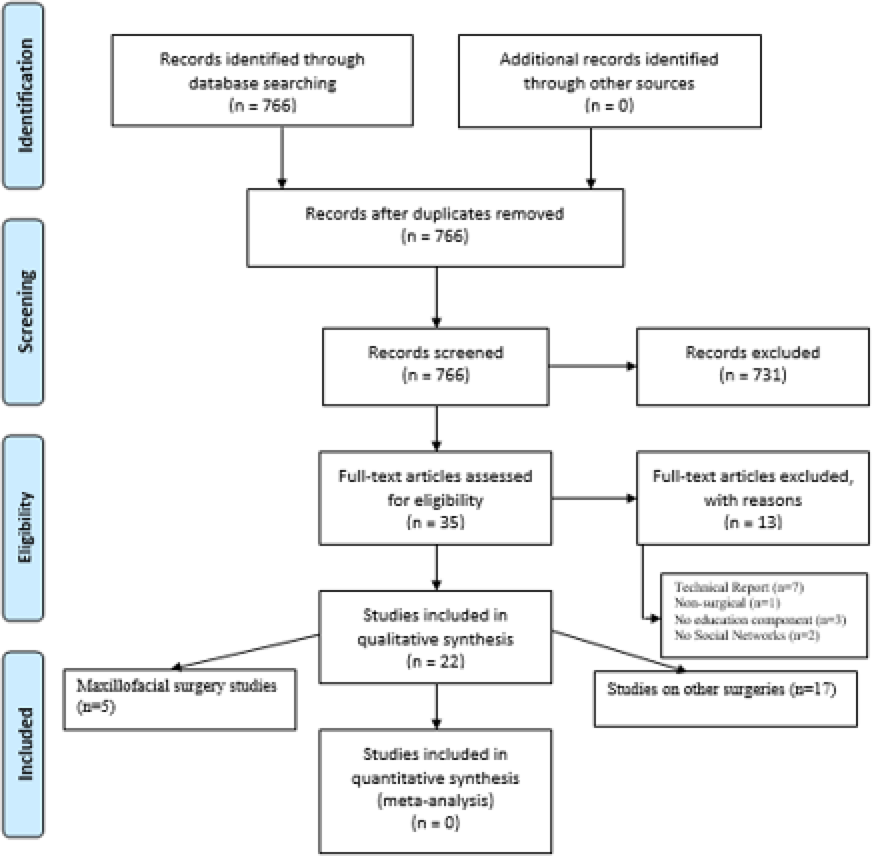
TABLE 3. Virtual Reality Training Articles

Title	Authors	Publication Year	Article Type	Surgical Specialty	Number of subjects
From CT to 3D Printed Models, Serious Gaming, and Virtual Reality: Framework for Educational 3D Visualization of Complex Anatomical Spaces from Within-the Pterygopalatine Fossa.	Javan et al.	2020	Open research article	Maxillofacial surgery	Introduce new software
Simulation-based training in maxillofacial surgery: are we going to be left behind?	Ahmed et al.	2019	Open research article	Maxillofacial surgery	57 students
Haptic, Physical, and Web-Based Simulators: Are They Underused in Maxillofacial Surgery Training?	Maliha et al.	2018	A review	Maxillofacial surgery	17 articles
An innovative virtual reality training tool for orthognathic surgery.	Pulijala et al.	2018	Open research article	Maxillofacial surgery	Introduce new software
High Fidelity Virtual Reality Orthognathic Surgery Simulator.	Arikatla et al.	2018	Open research article	Maxillofacial surgery	Introduce a new software
A review of haptic simulator for oral and maxillofacial surgery based on virtual reality.	Chen X et al.	2018	A review	Maxillofacial surgery	103 articles
Effectiveness of Immersive Virtual Reality in Surgical Training-A Randomized Control Trial.	Pulijala et al.	2018	randomized control trial	Maxillofacial surgery	91 residents
Development of a virtual reality training system for endoscope-assisted submandibular gland removal.	Miki et al.	2016	Open research article	Maxillofacial surgery	Introduce new software
A virtual training system for maxillofacial surgery using advanced haptic feedback and immersive workbench.	Wu et al.	2014	Open research article	Maxillo-facial surgery	Introduce new software

Failure mode and effects analysis in designing a virtual reality-based training simulator for bilateral sagittal split osteotomy.	Sofronia et al.	2013	Open research article	Maxillofacial surgery	Introduce new software
A patient-specific haptic drilling simulator based on virtual reality for dental implant surgery.	Chen et al.	2018	Open research article	Oral surgery	Introduce new software
Learning by doing virtually.	von Sternberg et al.	2007	Open randomized trial	Oral surgery	41 students
Computerized Virtual Reality Simulation in Preclinical Dentistry: Can a Computerized Simulator Replace the Conventional Phantom Heads and Human Instruction?	Plessas	2017	A review	Dental surgery	16 articles
Comparison of oral surgery task performance in a virtual reality surgical simulator and an animal model using objective measures.	Ioannou et al.	2015	Open non-randomized trial	Dental surgery	14 students
Virtual dental surgery as a new educational tool in dental school.	Pohlenz et al.	2010	Open research article	Dental surgery	Introduce new software
Effect of augmented visual feedback from a virtual reality simulation system on manual dexterity training.	Wierinck et al.	2005	Open randomised trial	Dental surgery	42 students
Playing to your skills: a randomised controlled trial evaluating a dedicated video game for minimally invasive surgery.	Harrington et al.	2018	Single-blinded randomised control trial	Digestive surgery	20 students
New dimensions in surgical training: immersive virtual reality laparoscopic simulation exhilarates surgical staff.	Huber et al.	2017	Non-randomized trial	Digestive surgery	10 participants
Establishing the minimal	Duarte et al.	2013	Non-	Digestive	11

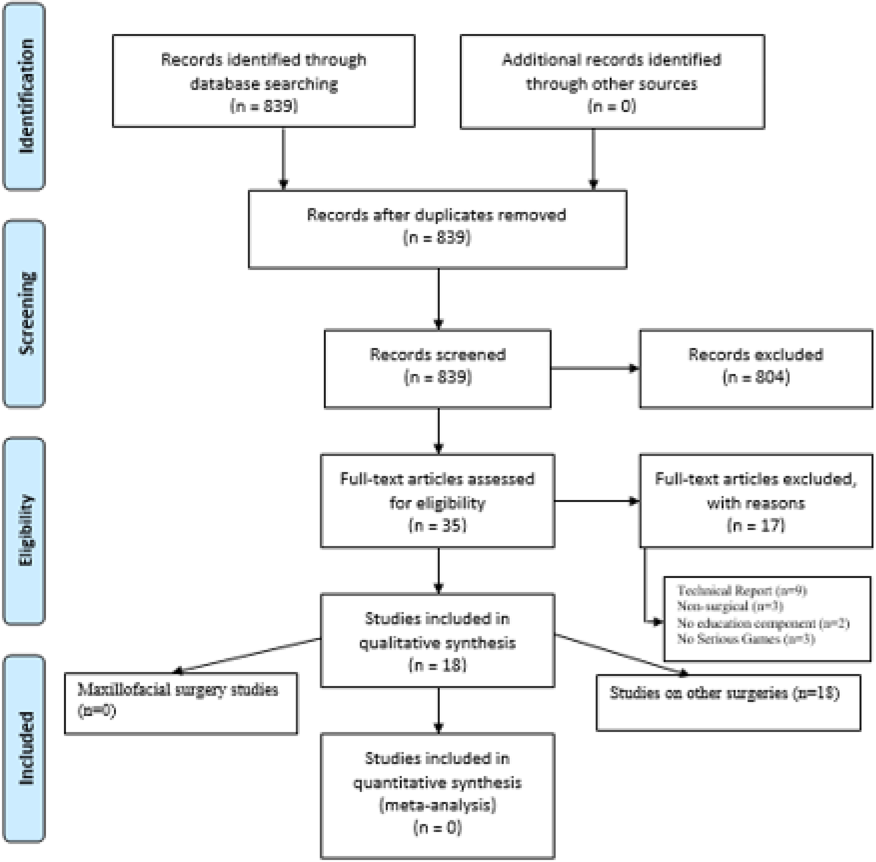
number of virtual reality simulator training sessions necessary to develop basic laparoscopic skills competence: evaluation of the learning curve.			randomized trial	surgery	students
Cognitive load and performance in immersive virtual reality versus conventional virtual reality simulation training of laparoscopic surgery: a randomized trial.	Frederiksen et al.	2019	randomized control trial	Gynaecological surgery	31 residents
Design of a Serious Game for Handling Obstetrical Emergencies.	Jean Dit Gautier et al.	2016	Open research article	Gynaecological surgery	Introduce a new software
Virtual Reality-Based Simulators for Cranial Tumor Surgery: A Systematic Review.	Mazur et al.	2018	A review	Neurosurgery	9 articles
Virtual reality cerebral aneurysm clipping simulation with real-time haptic feedback.	Alaraj et al.	2015	Open research article	Neurosurgery	Introduce new software
Virtual reality simulation: basic concepts and use in endoscopic neurosurgery training.	Cohen et al.	2013	A review	Neurosurgery	29 articles
The development of a virtual simulator for training neurosurgeons to perform and perfect endoscopic endonasal transsphenoidal surgery.	Rosseau et al.	2013	Open research article	Neurosurgery	Introduce New Software
Role of cranial and spinal virtual and augmented reality simulation using immersive touch modules in neurosurgical training.	Alaraj et al.	2013	Open research article	Neurosurgery	Introduce New Software
Endovascular repair of ruptured abdominal aortic aneurysm: technical and team training in an immersive virtual reality environment.	Rudarakanchana et al.	2014	Non-randomized trial	Vascular surgery	10 operating room teams

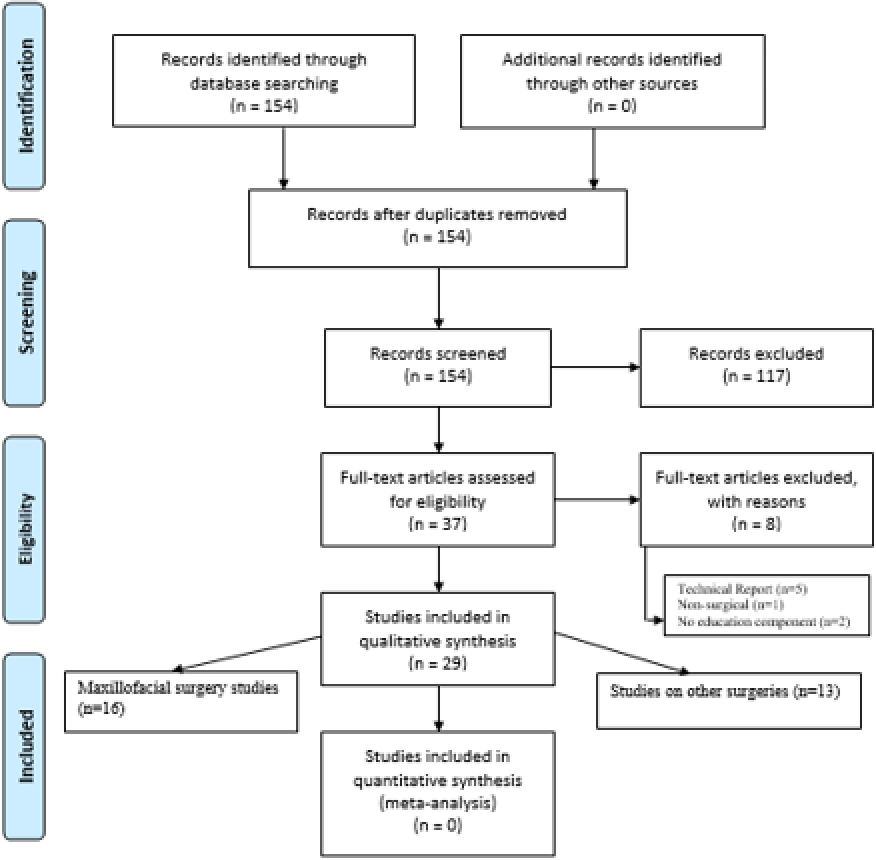
Technology for teaching: New tools for 21st century surgeons.	Eskander et al.	2016	A review	Surgery	39 articles
The role and validity of surgical simulation.	Agha et al.	2015	A review	Surgery	79 articles



Identification
Records identified through database searching (n = 766)
Additional records identified through other sources (n = 0)
Screening
Records after duplicates removed (n = 766)
Records screened (n = 766)
Records excluded (n = 731)
Eligibility
Full-text articles assessed for eligibility (n = 35)
Full-text articles excluded, with reasons (n = 13)
Technical Report (n=7)
Non-surgical (n=1)
No education component (n=3)
No Social Networks (n=2)
Included
Studies included in qualitative synthesis (n = 22)
Maxillofacial surgery studies (n=5)
Studies on other surgeries (n=17)
Studies included in quantitative synthesis (meta-analysis) (n = 0)


Social
Networks
Media
Educate
Learn
Post
Professional
Video
Twitter
Facebook
Youtube
Share
Online
Sites
Peer
Connect
Data
Idea
Interaction
Information
Wiki
Users
Skills
Source
Opinion
Pinterest
Quiz
Whatsapp
Comments
People
Published
Passive
Vumedi
Encourage
Instagram
Internet
Popular
Training
Participate
Free
Create
Access
Channel
Links
Exchange
Open
Abilities
Active
Microsoft
Linkedin
Google
Feedback
Follower
Framework
Viewers
Hashtags
Gamification
Relationship
Competitive
Progress
Wikipedia
Application
Data
Create
Post
Learn


Identification
Screening
Eligibility
Included
Records identified through database searching (n = 839)
Additional records identified through other sources (n = 0)
Records after duplicates removed (n = 839)
Records screened (n = 839)
Records excluded (n = 804)
Full-text articles assessed for eligibility (n = 35)
Full-text articles excluded, with reasons (n = 17)
Technical Report (n=9)
Non-surgical (n=3)
No education component (n=2)
No Serious Games (n=3)
Studies included in qualitative synthesis (n = 18)
Maxillofacial surgery studies (n=0)
Studies on other surgeries (n=18)
Studies included in quantitative synthesis (meta-analysis) (n = 0)


Identification
Screening
Eligibility
Included
Records identified through database searching (n = 154)
Additional records identified through other sources (n = 0)
Records after duplicates removed (n = 154)
Records screened (n = 154)
Records excluded (n = 117)
Full-text articles assessed for eligibility (n = 37)
Full-text articles excluded, with reasons (n = 8)
Technical Report (n=5)
Non-surgical (n=1)
No education component (n=2)
Studies included in qualitative synthesis (n = 29)
Maxillofacial surgery studies (n=16)
Studies on other surgeries (n=13)
Studies included in quantitative synthesis (meta-analysis) (n = 0)