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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 first part therefore reviews, open field camera, telemedicine and 3D printing.

This systematic review is registered on PROSPERO.

1. Introduction:

How to become a surgeon? The answer to this question has evolved over time. To be quick, bold and precise was the doctrine of yesteryear's surgery [1]. Today, the surgeon needs to acquire competence in technical skills (physical examination, manipulation of tools and psychomotor skills) [2] and in nontechnical skills, such as social skills (communication, teamwork, leadership), cognitive skills (decision making, situational awareness), personal resource skills (managing stress and coping with fatigue) [3].

Training methods have evolved over the time. Traditionally, the surgical training approach often described as the "See one, Do one, Teach one" is ascribed to Sir William Halsted [2]. Surgical education has gone from an "apprenticeship" and "journeyman ship" toward a training model based on knowledge of basic sciences, research and graduated patient responsibility for the resident. The medical learner has changed from Generation X to Generation Y [4]. The advent of new technologies implies a review of training methods in surgery even though it seems clear that a good knowledge of basic surgical procedures remains essential [5].

Currently the most popular new technologies are:

- **Open Field Camera:** The idea is to fix a camera on forehead's surgeon or on the operating table to offer observers the best viewing angle to follow the operation on a screen, possibly remote [6].

- **Telemedicine:** Telemedicine bring the expertise of specialized surgeons in austere or disadvantaged environments through internet [7].

- **Social Networks:** Like Facebook or Twitter, social networks make it possible to share information quickly and inexpensively. They also allow for an easy interactive exchange between people [8].

- Serious Game: A serious game is a stimulating application in which the player will receive educational content while having fun in a subtle "stealthy" fashion [9].

- **Virtual Reality:** It's a simulation of the real world based on computer graphics and a three-dimensional (3D) world. Sometimes, haptic technology is added to provide more immersive simulation [10].

- **3-Dimensional Printing:** Additive manufacturing is a technology that converts 3D digital models into plastic or resin haptic models with a very high fidelity using a specialized printer [11].

This article is a systematic approach reviewing the literature, which will allow to see what is the place of these new technologies in the surgical training. We particularly focused on maxillofacial surgery, which is one of the most recent surgical specialties and which must therefore be in phase with the latest scientific advances. This review explores the impact of exposure to new technologies on medical students and more specifically surgical students. It compares this exposure to traditional education methods by observing the consequences on intervention times, operating complications, satisfaction questionnaires and theoretical knowledge tests.

2. Material and methods:

A comprehensive, structured literature search of published articles was conducted. This was designed by authors P.G. and R.N. We followed a systematic approach to review the literature similar to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Guidelines. Nevertheless, all PRISMA Guidelines have not been achieved because they don't apply to this type of literature review.

2.1 Registration

This review is registered on PROSPERO (CRD42020181376).

2.2 Eligibility criteria, study selection and Analysis

We were interested in medical students, more specifically in surgical students and we observed the impact of new technologies on their knowledge and surgical abilities compared to conventional teaching methods. For this, we focused on operating times, complication rates, satisfaction questionnaires, knowledge tests as well as any reduction in the learning curve. We have only included articles in English, of which we could have the full-text version. All study formats were eligible and there was no limitation on the date of publication. The research strategy was to consider all the articles that deal with new technologies in education and surgery. All those which did not meet these three criteria were excluded from this review. As we wanted to focus more on maxillofacial surgery, we have isolated the articles about this surgery so that we can treat them with particular attention.

2.3 Data Sources

A literature search was performed using the electronic data-base PubMed. In total, we conducted six literature reviews for each new technology, namely, open-field camera, telemedicine, 3D printing, social networks, serious games and virtual reality. The keywords used were selected from key articles to create a broad search as described in Table 1. We screened all the articles, a first selection was made after reading titles, then a second selection after reading abstracts and the final selection was made after reading full-texts. The final search was conducted on November 20, 2020.

2.4 Selected Articles

The primary selection was made by an investigator, this selection was analysed by a second investigator who was able to add or remove certain articles. Then a synthesis of each article was carried out before carrying out a final synthesis which was revised by the second investigator. We identified 4713 articles, which were reduced to 228 after title and abstract review. Following full-text review a further 83 articles were excluded, leaving 145 articles for detailed inclusion including 45 articles on maxillofacial surgery. Each flow chart has been placed at the beginning of each section.

2.5 Risk of bias

In order to avoid selection bias, we carried out an exhaustive literature review to try to leave as few articles as possible aside. This review was recorded on PROSPERO to avoid the deferral bias in order to ensure optimal fidelity to the initial protocol. It is very likely that studies with poor results have not been published, which inevitably leads to publication bias, moreover, the populations studied are not always identical and often the articles are based on small numbers, thus reducing the level of proof of the study, so we have taken all the necessary precautions with our results.

2.6 Difference with PRISMA Guidelines

This review seeks to expose at what technological level we are currently. There is therefore no clearly established judgement criteria which makes it possible to gather all the data. Rather, it is a narrative and explanatory review. Moreover, the format that we proposed explores six different fields and therefore represents rather the addition of six systematic reviews rather than the synthesis to form a single one. This is not provided for in the PRISMA Guidelines, but it seemed to us impossible to do it differently. Despite everything, we have tried to stay as close as possible to the PRISMA recommendations.

3. Results:

3.1 Open field camera (Figure 1; Table 2)

Where is the best point of view to watch an operation? This is the place where all the surgical students would like to place themselves. Placing a camera on the operative field to share with the largest number of people viewing the operation seems like a good idea.

Some studies have focused on what camera would give the best image quality. The laparoscope mounted via an alpha port and controlled by the voice of the operator, currently seems to offer the best image quality [6,12,13]. On all the criteria like the clarity of image, the ability to visualize operative field or the ability to follow operation, alpha-port/laparoscope is better than the sky-cam itself is better than the head-cam [12]. These differences increase with the depth of the operative field [6]. Main problem with head-mounted cameras is movement of the surgeon's head, so it is necessary to obtain the best image quality to have a camera anchored on a fixed point. The sky-cam during open procedures requires extra-personal to control the camera. Placing the camera as close as possible to the operative field increases image quality and allows the surgeon to interact and adjust the camera to have it in the best position. The alpha-port/laparoscope have the potential to open the door to remote surgical teaching and remote surgical mentoring of the open surgical procedure from anywhere in the world [13]. In addition to the best image quality, this video recording device decreases the surgeon's fatigue by allowing him to operate in a more comfortable position, indeed the surgeon can also view the video as the rest of the operating room staff (anaesthesiologists, nurses, resident trainees and medical students) [6].

The main problem with the alpha-port/laparoscope is its expensive cost. Cheaper solutions exist certainly at the price of a lower image quality but with a sufficient resolution to be used as teaching. GoPro and Contour cameras seem to be good alternatives. According to Chaves et al., these methods of video recording were satisfactory for observers [14].

Software is being developed to determine motion kinetics associated with various operative technical tasks and could measure the differences in performance between surgeon of varying skill levels. A recent study shows that suturing task evaluation was the most sensitive [15].

Others have tried to see if using three cameras (front/top/side) gave the surgeon a three-dimensional view of the surgical procedure, especially to have an idea of the depth of the surgical site. Even though most of the time the top view was used, results were better with these three cameras than with just one. But to integrate this device into an operative field seems too bulky today and requires working on miniaturization [16].

Although it's true that having an active surgical participation increases the interest and the attention for the operation of the students, open field camera technology seems to be an interesting prospect. It reduces the number of people in the operating room and therefore reduces the risk of infection while offering the greatest number of people the opportunity to observe the surgery. There is a wide range of prices to afford a camera and many possibilities from this technology are available today or tomorrow.

In maxillofacial surgery, it has been published the keys to record its interventions inexpensively. For $850, it is possible thanks to a modified GoPro® (GoPro, San Mateo (USA)) (to record for 14 hours an intervention without connection, leaving any freedom of movement, the GoPro® being placed on the forehead of the surgeon. The quality of the recording was acceptable [17]. Another initiative to say the least was to fix a smartphone with an optimal angle of view a bit like the alpha-port/laparoscope. The certainly artisanal method, however, has the advantage of not requiring investment because everyone has a smartphone [18]. These video systems seem very interesting, especially to numerically keep rare surgical procedures, such as major malformations surgeries, and it would better visualize some deep operations with little visibility such as closed rhinoplasty approaches or surgical procedures of the temporomandibular joints.

3.2 Telemedicine (Figure 2; Table 3)

Telemedicine is a fast-growing trend practice. The principle is to transmit medical information via electronic communication. It includes telesurgery, teleconsultation, telediagnose, teleproctoring, telepresence and any more. But as far as surgical education is concerned, telementoring seems to be the most interesting application of telemedicine.

Telementoring is a relationship, facilitated by telecommunication technology, in which an expert provides guidance to a less experienced learner from a remote location [19–22]. At a time when surgeon's needs are increasing. Telementoring seems to be one of the solutions to increase the volume of surgical education. It can help to bring new skills to rural centres or simply democratized complex surgeries to the entire territory [19,23–26].

The easiest access to telementoring remains Skype® (Microsoft Skype Division, Palo Alto, USA) [23,27]. Unfortunately, this interface is not secure enough for sharing medical information and can't be used in a sustainable way. Other more secure platforms exist. Telementoring is like a car, many options can be added to it like telestration and laser pointers. These technologies can reduce operating times by up to 30% [21]. The frequent mentoring interventions are for identification of anatomy, extent of exposure, extent of resection, and surgical technique [21,28–30].

The few studies on the effectiveness of telementoring have shown that there is no significant difference in operating time and postoperative complications between young telemented residents and experienced surgeons [23]. Simultaneously, there were also no significant difference between on-site mentoring and telementoring in terms of complications and operative times [19,21,30–32]. Nevertheless, telementoring has some limitations. The most frequently encountered problem is the difficulty of indicating the correct dissection plan [32]. In addition, respect for national health authorities, which differ most of the time between countries, seems to be an obstacle to the spread of international telementoring [32]. Telementoring can finally create a source of miscommunication. The fact that the mentor is not physically present in the operating room may call into question the traditional leadership of the surgeon [21].

After reading the various published articles, we can propose the essential points of the ideal telementoring:

- Technically:

    - A video resolution of 768x492 and higher seems to be the minimum in order to be able to discern the different anatomical structures [20,23].

- The use of a secure network seems essential [33].
- A high level of encryption is required for the protection of medical information such as the 256-bit Advanced Encryption Standard (AES) [20,32].
- The minimum bandwidth for telementoring should be around 40Mbit/s [20,32].
- Telestration and annotation are desired features and essential for surgical education [20,34].
- Telementoring system should be portable and affordable [20,34].

- Organization:

  - Initial training in the mentor's centre with on-site mentoring would allow the mentees to have solid knowledge of the intervention [29,35].
  - The mentor and the mentee must meet before the intervention, to become familiar and to have an idea of the approach of the intervention [29,31,34,36,37].
  - Communication and explanation to all members involved in the intervention is one of the keys to success [24,25,29].
  - Debriefings after telementoring session are essential to the proper personal progression of the mentor and the mentee [21,29].

- The telementoring must be in agreement with the governmental authorities of the country where the intervention is practiced [20].

- Competences:

- The mentee must having the competences to finish the intervention alone if the telementoring doesn't work [21,22,29,31–34].
- A training course in telementoring pedagogy is a prerequisite that seems very interesting to have for the mentor [21,34].
- The mentor must be recognized as an expert and must justify a certain number of operations carried out beforehand.

Another important point is who is funding this technology. The price of this technology can range from $ 50,000 to $ 85,000 and $ 15,000 worth of maintenance [23,27,33,35]. In the future, with the technology development we could hope that the cost decreases and this technology can become a routine [22].

Apart from training, telementoring finds other applications especially in certain extreme situations where the urgency of the situation requires immediate intervention without a surgeon can be present [38]. Indeed, it was possible to perform discharge fasciotomies on simulators and this in a rather correct way by doctors not surgeons.

In oral and maxillofacial surgery, this technology remains unfortunately still little used. Perhaps the few operations requiring endoscopic means is an explanation for this lack of use (majority of telementoring studies are on endoscopic surgeries). Some articles describe the use of telemedicine to make the turn postoperatively when the operator is not on site. [36] Telerounding seems to be a good alternative to the bedside rounding even if it must not replace the bedside round. [39] A more interesting experiment showed the use of telemedicine as a means of opening up international trade by removing travel expenses. Using Skype, a fibular osseocutaneous free flap for mandibular reconstruction was retransmitted between Mexico and the United States. The students could interact with the surgeons and the feelings of this experience seemed very positive [40]. More recently, with the COVID 19 pandemic, students could no longer go to operating rooms. This prompted a team to develop a system in a 2-way audio-visual communication, which allows direct interaction between students and operators [41]. Mitsuno et al. developed a telementoring demonstration in craniofacial surgery with Hololens® (Microsoft, Redmond, USA) and Skype®. This system seems easy to use at low cost although the lack of encryption security of Skype® must be taken into consideration [42]. Overall, in view of these few encouraging studies, everyone agrees that the field of oral and maxillofacial surgery must continue to be open to telemedicine in general, whether in education or in daily practice [43]. Although this technology seems to be full of promise, there is still a lack of randomized controlled trials to make this method of the future a method of today [21].

3.3 3D Printing (Figure 3; Figure 4; Table 4)

The current method of learning consists in assisting surgical procedures and taking over parts of the surgery step-by-step with the traditional adage "See one, Do one, Teach one" [44,45]. The angle of view is not very easy for the trainee to have a good vision of the operation and vice versa it may be challenging for the teacher to supervise all trainee's action [44,46]. With increasing procedure complexity, minimally invasive approaches, limited teaching resources, work-hours restrictions, the expanding body of medical knowledge and the increased service requirements, there is a need of realistic, extensive and repetitive hands-on training to prepare surgical students [47,48]. Learners must become more independent in the way they progress [49,50].

Cadaver models have been used for a long time, but they do not allow the various pathologies to be reproduced, they are expensive, they have medical restrictions due to prion disease and pose some ethical problems

[45,50–58]. Certain pathologies are rare or cannot be sufficiently preserved at the time of prosection [56,59–62]. The tissue stiffness caused by the fixation process procures unrealistic soft tissue haptics [44]. Animal cadaveric models are certainly more affordable, but they have also ethical problems and the anatomy is sometimes very far from human anatomy [44,48,52,53,58,63]. Some companies also offer industrial 3D-models which are generally very well made but which have the disadvantage, in addition to the price, of not offering a wide variety of pathologies [44,51,53,56].

But a new solution has emerged in recent years. Three-dimensional printing, also known as rapid prototyping, additive manufacturing or solid free-form technology, is a process used to make a 3D entity from series of two-dimensional images [54,56,60,64–67]. It is a method made by fusing or depositing materials in layer to create a 3D object [54,62]. It is a recent development, the first applications date from 1980s with Charles Hull [54,68]. In medicine, it is possible to use data coming from scans or MRIs to recreate 3D models [54,60,66,69]. All the software that can transform a scan into a 3D digital image can be found online free of charge, they are easy and intuitive to use and there are several online tutorials giving accurate instructions. The main software are OsiriX® (Pixmeo, Geneva, Swiss), Meshlab® (Instituto di Scienza e Tecnologie dell'informazione, Roma, Italia) Netfabb® (Autodesk, San Rafael, USA) and Blender® (Blender Foundation, Amsterdam, Netherlands) [70]. No special training and no specific prior knowledge are required [47,71]. The capability of printing at a resolution as low as 89 microns, which means any human structure observed under a microscope or endoscope can be recreated in computer assisted drawing software, can be printed using 3D printing specific devices [55].

This new technology can change the way of training residents, especially in delicate surgical procedures [64,71]. It's revealed as important teaching aids in all levels of medical and residency training [45,55,56,59]. It provides a safe learning environment without pressure from the operating room and has the ability to expose the trainee to problems of varying complexity levels to ultimately improve technical and cognitive skills [46,49,52,53,55–57,60,64,72]. This technology makes it possible to produce anatomically realistic models with extreme precision [45,60,61,72,73]. It allows to increase the 3D perception with tactile feedback of different anatomies [54,56,61,65,66,72,74]. Students have a better comprehension of location, size and intended surgical intervention than with other 2D imaging modalities. [48,54,56,61,65,66,69,72,74]. Participants with fewer experiences seemed to benefit more from 3D printed model compared with experienced participants [74]. A systematic review of 17 studies have shown for practicing physicians immediate and sustained improvements [25]. In some studies, these simulations have highlighted to improve long-term trainee performance and competency in procedures [52,55]. It also significantly increases the confidence that residents may have in future procedures [66,73,75,76]. 3D printing permits to deal with abnormal anatomy, it can replace the anatomy dissection and leave the anatomy rooms. The learning curses can be made in normal classrooms. [66,68,77]. Certain pathologies vary a lot, particularly in terms of anatomy from one individual to another. 3D printing allows training in various cases [76,77]. 3D-printed simulator proved to have realistic haptic feedback, especially for the bony dissection [49]. This allows you to have a first surgical experience before practicing in the operating room [55]. It reduces morbidity by helping residents to develop the competency to tackle these difficult surgeries in the operating room [60,61].

Alrasheed et al. and Barber et al. showed the possibility to use endoscopic systems on 3D models as shown in these ENT studies on endoscopic sinus surgery [49,57]. These studies tried to combine 3D printing with virtual reality with very encouraging results, particularly in terms of navigation, although it was not possible to carry out virtual dissection. Other simulators have been created for transcanal endoscopic ear surgery, for choledocoscopy, for bronchoscopic procedures, for otosclerosis, for retroperitoneal anatomy, for aneurysm clipping, for microtia surgery, for congenital heart diseases surgery and many others... [45,50,55,60,72,74,76–78]

The costs for 3D printing technology constantly declining and inexpensive 3D printers are now available in the consumer market [25,46,47,51,55,56,64,65,68,71,74,75,79]. The low-cost printers are between 750 and $1250 [61,68,75]. The initial design of a new anatomical region costs about $5000 and the production of one training model costs about $200, and most of time these simulators can be reused or it is enough to replace only a small part of the model [44,56]. Further inquiry and development are needed to increase access to this technology [49,50,64]. Larger scale studies and randomized control trials are essential to prove the scientific validity of this new technology [46,60,66,72,74,75]. The evaluation of efficacy of such training models in education constitutes the next phase of investigation [71,80]. It will also be important to assess long-term skills retention [72].

It seems that the use of vasculature to simulate blood flow will be crucial for operative models to provide next generation surgical training for residents and attending alike [45,65,73]. For example, some initiatives search to create an epistaxis training model where the residents were able to practice identifying and treating sources of bleeding with nasal packing materials [59]. In neurosurgery, an aneurysm clip simulator allows you to practice with a simulation of blood flow [50]. Actually, it is still difficult to produce models with hard and soft tissues [44,54]. Indeed it seems that the most difficult to achieve is to find the right consistency for soft tissue, many projects are concentrated elsewhere [49,55,69,72]. Otherwise, multimaterial 3D printers have now been described which can greatly improve the training experience but the costs of these machines remain very important [54].

To resume, specific materials have specific use:

- PLA: It is the better choice for most of simulation models because it is biodegradable, non-toxic and most similar to bone at low temperature while drilling, but it requires a continuous cooling to prevent melting [71].
- ABS: It is easier to process, because it is more resistant to melting and easier to cut, it could be the better choice for training models that require extensive drilling when a non-cooled rotary instrument is desired [71].

- Silicone: It seems to be the best material for soft tissue simulation. It is possible to modify the viscosity of silicone to obtain different degrees of resistance [71]. It is a material of choice to simulate costal cartilage [60]. It also permits to simulate brain tissue. It is five orders of magnitude softer than acrylonitrile butadiene styrene [73].
- Polyamide: It is an excellent material to simulate the immature skull bone of infants, allowing osteotomies and give good tactile feedback to surgeons [53].
- Acrylic resin: It seems to be a good alternative for hard tissue [64].
- Calcium phosphate: An excellent material for axial tooth insertion, drilling, milling, and sawing [81].
- Acrylonitrile-butadiene-styrene: It permits to produce hollow elastic vessel model, which could receive a clip in the performance of simulations [50]. It can also be used to simulate bone [60].

This technology is very well received by the students. It seems obvious that 3D printing will take up more space in the future in institutional surgical educational programs [48,55,66,72,74,76,77]. Indeed, there is an enthusiasm for this new learning method, in the face of reduced operating time and time pressures for junior surgeons. It is a low-cost and accessible alternative [66,69,73,74] Educational institutions could share their printable files, it will be a considerable benefit for the entire educational community [47,71].

The ability of spatial representation is one of the most important competences of an oral surgeon. 3D printing which can simulate the anatomic complexity of bone, soft tissues, teeth and neuromuscular bundle seems to be a great asset for this surgical discipline [68,80]. Training is essentially based on extracted human teeth, the main drawbacks are that the selection of suitable teeth is time-consuming, there are ethical considerations, cross-infection and it is non-standardized anatomy for test situations [47]. Artificial teeth have been promoted but they are a high cost (about $1000 per model), there is a limited selection of tooth types and delivery times must be considered [47,71]. Industrial models are widely used but have the disadvantage of offering a small range in terms of individual specificities and pathologies [67]. Currently it is possible to create teeth using 3D printing. The selection is no longer limited, they have good radiopacity. The disadvantage of the resin is that it is less hard than human dentin [47]. Future projects should seek find resin with physical properties that are more similar to dentine in terms of hardness and radiopacity. [47]

A model has been developed to train the treatment of craniosynostosis, a challenging surgery which requires multidisciplinary approach [53]. This surgery requires an advanced technical competence with complex anatomy that is difficult to visualize in the operating room [51] (Figure 4). The 3D-printed models in polyamide may provide an accurate reproduction of bone anatomy and specific pathologic nuances [53]. It is a unique opportunity to the training surgeon or even the most experienced surgeon to develop a 3D perception of the normal and pathologic skull and skull base anatomy [53,82]. This model offered the opportunity to identify the ideal force to bend the bone without breaking it [53]. It demonstrates objective improvement in a resident learner's technical knowledge of craniofacial surgery by means of milestone advancement, accuracy of the preoperative plan and decreased time needed to formulate the plan [51]. It costs about $100 and less if there are more models. The main drawback is the absence of soft tissue [53]. Another skull model was designed with soft tissues to reproduce metopic craniosynostosis. It was possible to simulate the surgical approach step-by-step, used real instruments, cut the skin, perform the osteotomies and dissect according to plan, with appropriate tactile feedback [83].

Bertin et al. developed a new 3D-model training for bilateral sagittal split osteotomy to correct a class II malocclusion. Residents reported an improvement in their surgical skills and a significant increase in the self-assessment scores [63]. Orbital surgery is technical and highly demanding, training is especially important for this kind of procedure [44]. An innovative 3D-printed simulator reproduced an isolated orbital floor infraction and the model was capable of reproducing the relevant anatomical properties realistically. Trainees were generally satisfied with the characteristics of the system and felt that this method would allow them to progress quickly. The main difficulty of this simulator was also to reproduce the soft tissues [44]. Rhinoplasty also has its silicone training model [64]. Acrylonitrile butadiene styrene was used for the bony construct and different types of medical grade silicone for the cartilage, skin and mucosa. This simulator allowed students to increase their skills significantly [60]. A silicone simulator of a cleft lip using CAD/CAM was designed to train cheiloplasty. This simulator gave to students the firm impression that they were operating on a real patient. It permits to train on different types of clef lips [84]. Another one was developed for impacted third molar extraction surgery. Students find that this model have a positive effect on their clinical ability to plan and practice separate steps. This training might compensate and improve the performance of low-spatial learners more than high spatial learners [58,80]. We can also find surgical training model for root tip resection [67] or for the surgical extraction of supernumerary teeth [85].

We can see that 3D printing already finds many applications in oral and maxillofacial surgery. This specialty indeed seems particularly well suited to this new technology in particular by its close relationship to the bone. It seems obvious that 3D printing should be one of the avenues for the future for this surgery.

Compliance with Ethical Standards

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Tables and Figures :

Table 1. Literature search strategy

Table 2. Open Field Camera Training Articles

Table 3. Telemedicine Training Articles

Table 4. 3D Printing Training Articles

Figure 1. PRISMA flow diagram related to surgical education through Open Field Camera technology

Figure 2. PRISMA flow diagram related to surgical education through Telemedicine technology

Figure 3. PRISMA flow diagram related to surgical education through 3D Printing technology

Figure 4. 3D printed models of craniosynostosis education: an example of the use of 3D printing in cranio-maxillo-facial education

Tables

TABLE 1. Literature search strategy. Search Strings 1 and 2 and 4 were combined using the Boolean term AND. Then search strings 1 and 3 and 4 were combined. This process was carried out for each category.

1 = ''Training'' OR ''Education'' OR ''Teaching'' OR ''Assessment'' OR ''Skills'' OR ''Abilities''
2 = ''Surgery''
3 = ''Oral Surgery'' OR ''Craniofacial Surgery'' OR ''Maxillofacial Surgery''

Open Field Camera
4 = ''Open Field Camera''
Telemedicine
4 = ''Telementoring'' OR ''Teleproctoring'' OR ''Telemedicine'' OR ''Ehealth'' OR ''Telehealth''
Social Networks
4 = ''Massive Open Online Courses'' OR ''Social Networks'' OR ''Smartphone'' OR ''Facebook'' OR ''Twitter'' OR ''What's App'' OR ''YouTube''
Serious Game
4 = ''Serious Game'' OR ''Game Based Training'' OR ''Mobile Apps''
Virtual Reality
4 = ''Immersive Virtual Reality''
3D printing
4 = ''3D printing'' OR ''Three-Dimensional Printing'' OR ''3D Printed'' OR ''Additive Manufacturing''

TABLE 2. Open Field Camera Training Articles

Title	Authors	Publication Year	Article Type	Surgical Specialty	Number of subjects
Modified GoPro Hero 6 and 7 for Intraoperative Surgical Recording-Transformation into a Surgeon-Perspective Professional Quality Recording System.	Ganry et al.	2019	Open research article	Maxillofacial surgery	Introduce new system
Video-recording using smartphones during surgical procedures in outpatients.	Lin et al.	2019	Open research article	Dental and maxillofacial surgery	Introduce new system
An Innovative Streaming Video System with a Point-of-View Head Camera Transmission of Surgeries to Smartphones and Tablets: An Educational Utility.	Chaves et al.	2017	Open research article	Gynaecological surgery	21 students
A marker-less technique for measuring kinematics in the operating room	Frasier et al.	*2016*	Open research article	Digestive surgery and Thoracic surgery	16 cases
Laparoscopic Telescope with Alpha Port and Aesop to View Open Surgical Procedures	Russell et al.	2001	Open research article	Digestive Surgery	4 doctors
Investigation of gaze patterns in multi view laparoscopic surgery	Kottayil et al.	2016	Open research article	Non-human experience	20 students
A Novel Telemedicine Method for Viewing the Open Surgical Field	Broderick et al.	2002	Open Research article	Non-human experience	11 attendees
Evaluation of Operative Imaging Techniques in Surgical Education.	Kothari et al.	2004	Open research article	ENT	14 students

TABLE 3. Telemedicine Training Articles

Title	Authors	Publication Year	Article Type	Surgical Specialty	Number of subjects
Creation of an Interactive Virtual Surgical Rotation for Undergraduate Medical Education During the COVID-19 Pandemic	Chao et al.	2020	Open research article	ENT	Introduce new system
Virtual rounding via videoconference-enabled smartphones: a case for multifacility rounds	Kaltman et al.	2012	Case report	Maxillofacial surgery and ENT	3 cases
Telementoring Demonstration in Craniofacial Surgery With HoloLens, Skype, and Three-Layer Facial Models	Mitsuno et al.	2020	Open research article	Craniofacial surgery	Introduce new system
Telemedicine and Surgical Education Across Borders: A Case Report.	Gosman et al.	2009	Case report	Craniofacial surgery	1 case
Teledentistry: a systematic review of the literature.	Mariño et al.	2013	A review	Oral surgery	59 articles
The Impact of Telementoring.	Andreassen et al.	2018	Open research article	Digestive surgery	8 surgeries
Assessing the impact of telestration on surgical telementoring: A randomized controlled trial.	Budrionis et al.	2016	Randomized control trial	Digestive surgery	8 attendees
Wearable Technology for Global Surgical Teleproctoring.	Datta et al.	2015	Open research article	Digestive Surgery	10 patients
Telementoring: The Surgical Tool of the Future.	Ponsky et al.	2014	A review	Digestive and vascular surgeries	33 articles
Telementoring systems in the operating room: a new approach in medical	Wachs et al.	2013	Open research article	Digestive surgery	1 surgery

training.					
A comprehensive review of telementoring applications in laparoscopic general surgery.	Antoniou et al.	2012	A review	Digestive surgery	10 studies
Telerounding & telementoring for urological procedures.	Sen et al.	2016	Open research article	Urological surgery	10 patients
The “tele” factor in surgery today and tomorrow: implications for surgical training and education.	Gambadauro et al.	2013	A review	Urological and digestive surgeries	66 articles
A pilot study of surgical telementoring for leg fasciotomy.	Talbot et al.	2018	A pilot study	Orthopaedic surgery	4 surgeries
Live transference of surgical subspecialty skills using telerobotic proctoring to remote general surgeons.	Ereso et al.	2009	Open research article	Heart, Neuro and Orthopaedic surgeries	8 surgeons
Surgical telementoring: A new model for surgical training.	Snyderman et al.	2016	Prospective study	Neurosurgery	10 surgeries
Trans-Atlantic Telementoring with Pediatric Surgeons: Technical Considerations and Lessons Learned.	Bruns et al.	2016	Case report	Paediatric surgery	2 cases
Telementoring of Surgeons: A Systematic Review.	Erridge et al.	2019	A review	Surgery	66 studies
White paper: technology for surgical telementoring—SAGES Project 6 Technology Working Group.	Bogen et al.	2019	Working Group	Surgery	Expert meeting
Effectiveness of Telementoring in Surgery Compared with On-site Mentoring: A Systematic Review.	Bilgic et al.	2017	A review	Surgery	11 studies
Educational implications for surgical telementoring: a current	Augestad et al.	2017	A review	Surgery	Expert opinion

review with recommendations for future practice, policy, and research.					
The evolution of surgical telementoring: current applications and future directions	El-Sabawi et al.	2016	A review	Surgery	37 articles
Video Telementoring to Accelerate Learning of New Surgical Techniques.	Julien et al.	2016	A review	Surgery	7 articles
Project 6 Summit: SAGES telementoring initiative.	Schlachta et al.	2016	Working Group	Surgery	60 attendees
Technology for teaching: New tools for 21st century surgeons.	Eskander et al.	2016	A review	Surgery	39 articles

TABLE 4. 3D Printing Training Articles

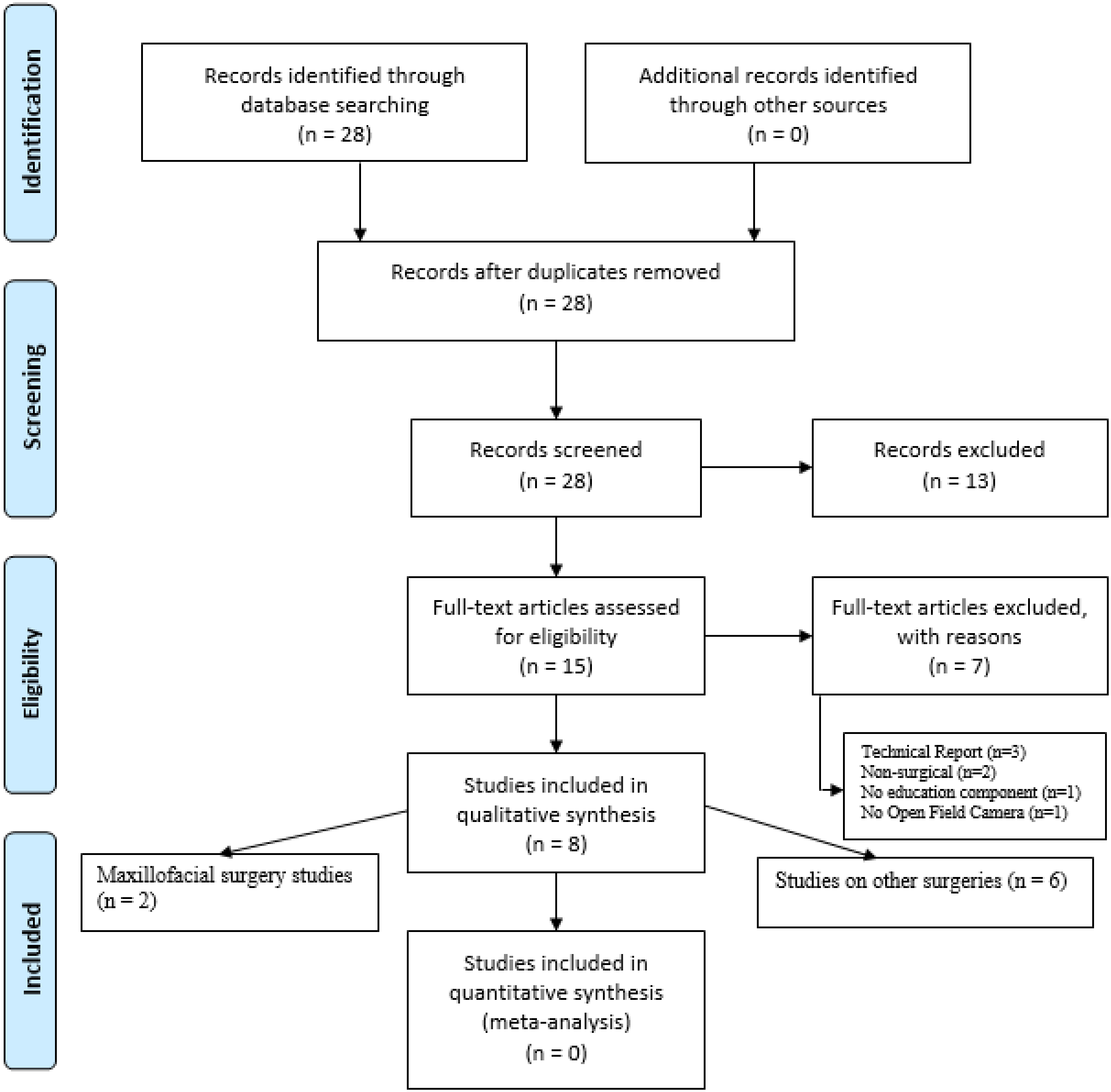
Title	Authors	Publication Year	Article Type	Surgical Specialty	Number of subjects
Bilateral sagittal split osteotomy training on mandibular 3-dimensional printed models for maxillofacial surgical residents.	Bertin et al.	2020	Open research article	Maxillofacial surgery	22 students
3D printed bone models in oral and cranio-maxillofacial surgery: a systematic review	Meglioli et al.	2020	A review	Maxillofacial surgery	64 articles
3D-printed patient individualised models vs cadaveric models in an undergraduate oral and maxillofacial surgery curriculum: Comparison of student's perceptions	Seifert et al.	2020	Open research article	Maxillofacial surgery	34 students
Use of 3D printed models in student education of craniofacial traumas.	Nicot et al.	2019	Open research article	Maxillofacial surgery	Introduce new method
3D Printed Surgical Simulation Models as educational tool by maxillofacial surgeons.	Werz et al.	2018	Open research article	Maxillofacial surgery	Introduce new model
3D-Printed Craniosynostosis Model: New Simulation Surgical Tool.	Ghizoni et al.	2018	Open research article	Maxillofacial surgery	Introduce new models
Study of medical education in 3D surgical modeling by surgeons with free open-source software: Example of mandibular reconstruction with fibula free flap and creation of its surgical guides.	Ganry et al.	2018	Open research article	Maxillofacial surgery	22 surgeons
Haptic, Physical, and Web-Based Simulators: Are They Underused in Maxillofacial Surgery Training?	Maliha et al.	2018	A review	Maxillofacial surgery	17 articles
3D-Printed Simulation Device for Orbital Surgery.	Lichtenstein et al.	2017	Open research article	Maxillofacial surgery	10 surgeons

CAD/CAM silicone simulator for teaching cheiloplasty: description of the technique.	Zheng et al.	2015	Open research article	Maxillofacial surgery	Introduce new model
Augmented reality and physical hybrid model simulation for preoperative planning of metopic craniosynostosis surgery	Coelho et al.	2020	Open research article	Craniofacial surgery	38 senior surgeons
Modeling Medical Education: The Impact of Three-Dimensional Printed Models on Medical Student Education in Plastic Surgery	Lane et al.	2020	Randomized control trial	Craniofacial surgery	44 students
The Use of Patient-Specific Three-Dimensional Printed Surgical Models Enhances Plastic Surgery Resident Education in Craniofacial Surgery.	Lobb et al.	2019	Open research article	Craniofacial surgery	Introduce new model
Validation of a three-dimensional printed model for training of surgical extraction of supernumerary teeth	Chae et al.	2020	Open research article	Oral surgery	30 students
Measuring the impact of simulation practice on the spatial representation ability of dentists by means of Impacted Mandibular Third Molar (IMTM) Surgery on 3D printed models.	Yao et al.	2019	Open research article	Oral surgery	21 students
3D-printed Surgical Training Model Based on Real Patient Situations for Dental Education	Hanisch et al.	2020	Randomized Control trial	Dental surgery	68 students
3D printed replicas for endodontic education	Reymus et al.	2019	Open research article	Dental surgery	105 students
3D Printing: current use in facial plastic and reconstructive surgery.	Hsieh et al.	2017	A review	Plastic surgery	41 articles

Applications of 3-Dimensional Printing in Facial Plastic Surgery.	Schwam et al.	2016	A review	Plastic surgery	5 articles
Clinical applications of three-dimensional printing in otolaryngology-head and neck surgery: A systematic review.	Hong et al.	2019	A review	ENT	61 articles
3D-printed tracheoesophageal puncture and prosthesis placement simulator.	Barber et al.	2018	Open research article	ENT	10 surgeon s
Virtual Functional Endoscopic Sinus Surgery Simulation with 3D-Printed Models for Mixed-Reality Nasal Endoscopy.	Barber et al.	2018	Open research article	ENT	Introduc e new model
Development and validation of a 3D-printed model of the ostiomeatal complex and frontal sinus for endoscopic sinus surgery training.	Alrasheed et al.	2017	Open research article	ENT	20 surgeon s
Three-Dimensional Printing and Its Applications in Otorhinolaryngology-Head and Neck Surgery.	Crafts et al.	2017	A review	ENT	76 articles
Modifications to a 3D-printed temporal bone model for augmented stapes fixation surgery teaching.	Nguyen et al.	2017	Open research article	ENT	13 surgeon s
Emerging Role of Three-Dimensional Printing in Simulation in Otolaryngology.	VanKoevering et al.	2017	Open research article	ENT	Introduc e new model
3D-printed pediatric endoscopic ear surgery simulator for surgical training.	Barber et al.	2016	Open research article	ENT	6 surgeon s
Impact of 3D Printing Technology on Comprehension of Surgical Anatomy of Retroperitoneal Tumor.	Yang et al.	2018	Open research article	Digestive surgery	30 particip ants

The Use of Three-Dimensional Printing Model in the Training of Choledochoscopy Techniques.	Li et al.	2018	Open research article	Digestive surgery	24 surgeons
Three-dimensional printing: review of application in medicine and hepatic surgery.	Yao et al.	2016	A review	Digestive surgery	52 articles
Three-dimensional intracranial middle cerebral artery aneurysm models for aneurysm surgery and training.	Wang et al.	2018	Open research article	Neurosurgery	6 residents
Three-Dimensional Printed Skull Base Simulation for Transnasal Endoscopic Surgical Training.	Zheng et al.	2018	Open research article	Neurosurgery	13 surgeons
Fabrication of cerebral aneurysm simulator with a desktop 3D printer.	Liu et al.	2017	Open research article	Neurosurgery	Introduce new model
Using 3D Printing to Create Personalized Brain Models for Neurosurgical Training and Preoperative Planning.	Ploch et al.	2016	Open research article	Neurosurgery	10 surgeons
A simulated training model for laparoscopic pyloromyotomy: Is 3D printing the way of the future?	Williams et al.	2018	Open research article	Paediatric surgery	27 surgeons
Digital Design and 3D Printing of Aortic Arch Reconstruction in HLHS for Surgical Simulation and Training.	Chen et al.	2018	Open research article	Paediatric surgery	Introduce new model
Realistic 3D-Printed Tracheobronchial Tree Model from a 1-Year-Old Girl for Pediatric Bronchoscopy Training.	Hornung et al.	2017	Open research article	Paediatric surgery	Introduce new model
Current status of 3D printing in spine surgery.	Garg et al.	2018	A review	Orthopaedic Surgery	42 articles
Three-Dimensional Printing of Life-Like	Yamada et al.	2017	Open research	Cardiac surgery	Introduce new

Models for Simulation and Training of Minimally Invasive Cardiac Surgery.			article		model
Systematic Review of the Use of 3-Dimensional Printing in Surgical Teaching and Assessment.	Langridge et al.	2018	A review	Surgery	49 articles
3D printing for preoperative planning and surgical training: a review.	Ganguli et al.	2018	A review	Surgery	138 articles
Three-dimensional printing of surgical anatomy.	Powers et al.	2016	A review	Surgery	27 articles
Technology for teaching: New tools for 21st century surgeons.	Eskander et al.	2016	A review	Surgery	39 articles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Screening
Eligibility
Included
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Full-text articles excluded, with reasons (n = 7)
Technical Report (n=3)
Non-surgical (n=2)
No education component (n=1)
No Open Field Camera (n=1)
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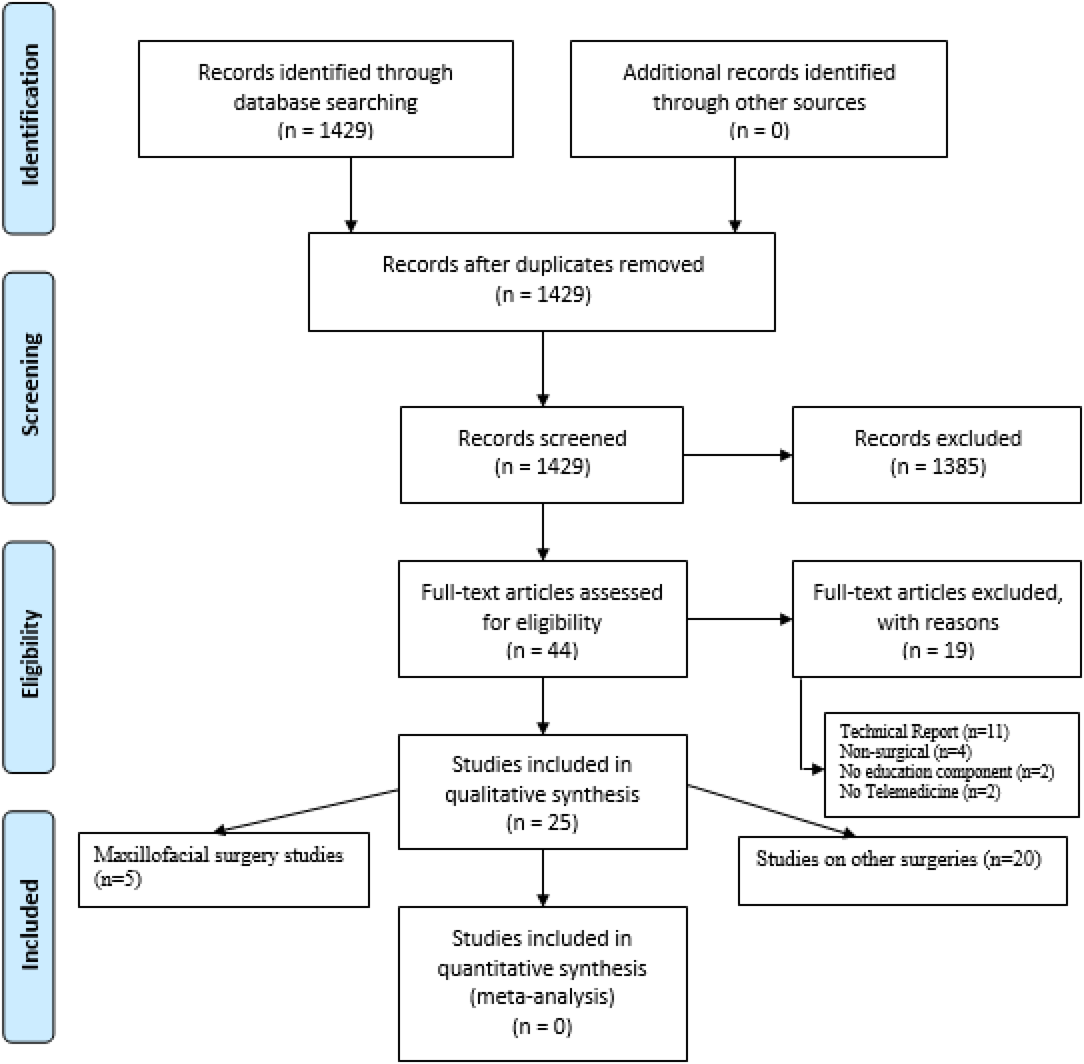
Maxillofacial surgery studies (n = 2)
Studies on other surgeries (n = 6)
Studies included in quantitative synthesis (meta-analysis) (n = 0)



Identification
Screening
Eligibility
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No education component (n=2)
No Telemedicine (n=2)
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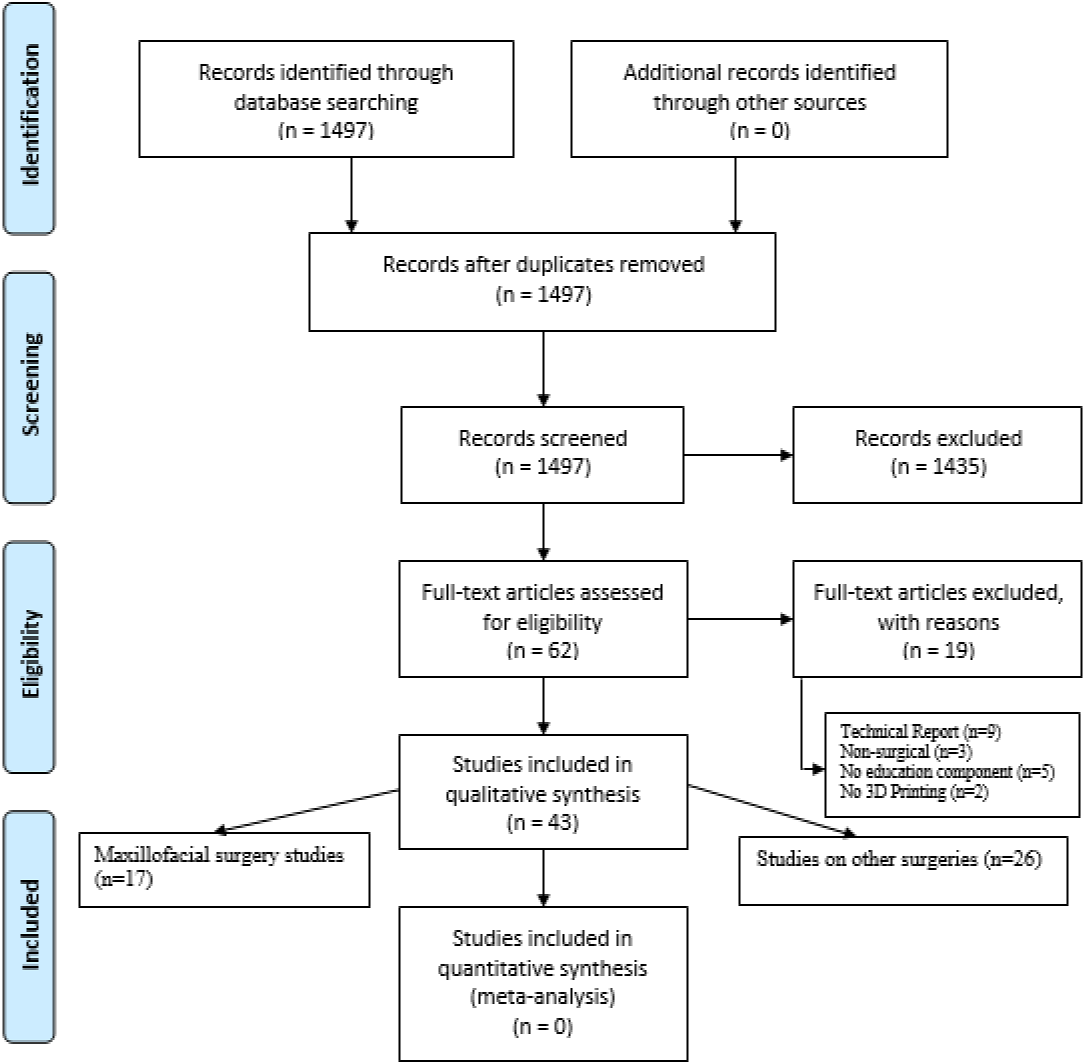
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Full-text articles excluded, with reasons (n = 19)
Technical Report (n=9)
Non-surgical (n=3)
No education component (n=5)
No 3D Printing (n=2)
Studies included in qualitative synthesis (n = 43)
Maxillofacial surgery studies (n=17)
Studies on other surgeries (n=26)
Studies included in quantitative synthesis (meta-analysis) (n = 0)