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# SYSTEMATIC REVIEW: CURRENT TRENDS AND RECENT ADVANCEMENTS IN RECONSTRUCTIVE MAXILLOFACIAL SURGERY

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**Abstract**
Anomalies in patients with OMF disorders can cause functional and esthetic complications that affect the health of affected individuals by increasing their aspirations, speech and reducing their quality of life. Reconstruction of these defects is one of the most difficult processes, which can be handled in maxillofacial surgery. Historically, the substitute entails of autografts has been considered as the gold standard for regenerative and reconstructive OMF operation. But, with autograft harvesting, the problems like donor-site morbidity, prolongation of the surgery time, and sometimes the non-union of the donor area are faced. This field has benefited from the development of three-dimensional (3D) printing technology, which allows for the possible creation of implants and scaffolds that are molded to the contours of the defect in a particular patient's body. This review describes the use of 3D printing and VSP for reconstructive maxillofacial surgery operations and their advantages and disadvantages by incorporating 15 studies. It also demonstrates various clinical application cases in which these technologies have been used, showing how they may improve surgical outcomes and patients' satisfaction.

**Keywords:** Reconstructive surgery, maxillofacial, current trends, case-control study.

## Introduction

OM F reconstruction of major defects is one of the major reconstructive surgical problems in the head and neck region because of neoplastic, traumatic or developmental etiology. These surgeries' goals are to reconstruct complex functional, anatomic and aesthetic parameters which are especially significant in the growing patients. Classic obviate grafts have been perhaps the most satisfactory procedures for strong tissue repair all through regarding osteogenic endowment and osteopromotive capacity, apart from their capacity to grow continually on the given loci of the defect. However, these procedures have their disadvantages such as donor site morbidity, limited sources, unpredictable rate of bone graft resorption, and also the fact that the graft material

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has to be trimmed to fit the defect area. Such barriers have been tackled by latest techniques in the 3D technologies and the Virtual Surgical Planning (VSP). The utilization of these technologies can make and design of patient-specific implants (PSIs) and surgical guides possible, which is hard to imagine before. This review will also address the current trends and the recent developments observed in reconstructive maxillofacial surgery and more specifically in the utilization of 3D printing and VSP technologies for enhancing the surgical results and the patients' health.

## Materials and Methods

The guidelines of this systematic review adhered to the PRISMA guidelines to minimize bias in the conduct of the present study as well as capture the state of the current literature with regards to reconstructive maxillofacial surgery involving both 3D printing and VSP. An initial broad literature review of the existing literature was conducted in English language in four databases, which include PubMed, Scopus, Web of Science, and Google Scholar for articles and studies published between January 2019 and August 2024. Some phrases included in the search included 3D printing, virtual surgical planning, maxillofacial reconstruction, patient specific implants, and oral and maxillofacial surgery.

Inclusion criteria for this review were: peer-reviewed studies written in English (1); reconstructive maxillofacial surgery involving human subjects with the help of 3D printing or virtual surgical planning (2); clinical results including surgical precision, time to complete the surgery, patients' satisfaction, and occurrence of postoperative complications (3). Exclusion criteria included: Firstly, the research articles not included as relevant sources are: (1) non-clinical in nature, that is, papers in the realm of technology innovation, or in vitro research; (2) those studies that only include non-surgical applications of 3D printing technology; and (3) papers published prior to the year 2019. Double data extraction was used with the intention of minimizing the bias that could be occasioned by one researcher. The data that were extracted from the identified studies involved study type & design, patient characteristics, type of surgery, information on 3D printing and VSP technologies which were applied in the studies, and clinical outcomes. Reviewers' differences were discussed and settled in a meeting. The choice of the type of quality assessment tools was based on the type of the identified trials and were as follows: Newcastle-Ottawa Scale for observational studies and the Cochrane Risk of Bias Tool for the RCTs. Due to the diversity in study characteristics quantitative meta-analysis was not attempted; the results were discussed based on the given analyzed features of 3D printing and VSP concerning accuracy of surgery, patient outcomes and prospective of the reconstructive maxillofacial surgery field.

## Traditional Approaches and Their Limitations

Maxillofacial surgery has dealt with injuries, tumors, and congenital anomalies using various reconstructive procedures. Reconstructive surgery for oral and maxillofacial hard tissue abnormalities has generally included autologous bone grafting. This method implants grafts from the host site, such as the iliac crest, rib, or fibula, at the deficiency location. Due to their

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osteoconductive, osteoinductive, and osteogenic properties, autografts are used wherever possible to induce bone growth and integrate with the recipient site. Autologous bone transplant is biocompatible and does not trigger an immune reaction, making it useful for bone restoration. However, this method has significant drawbacks: The first drawback is donor site morbidity, including pain, infection, and reduced function, at the graft harvesting site. Autogenetic bone is limited, particularly in big mandibular defects that need a lot of transplant material. Scarcity may restrict a surgeon's reconstructive options and hamper patient rehabilitation. Grafting is technically difficult and takes longer than other flap surgeries, which exposes patients to intraoperative complications and increases hospital stays. Graft resorption uncertainty complicates standard bone transplantation. Although the transplanted bone is meant to integrate with the recipient's skeleton, its volume and structure may resorb at the reconstruction site. This uncertainty may also cause surgery's utilitarian and hedonic value to vary, needing further procedures. Because the surgeon's ability and dexterity are crucial to achieving the desired outcomes, physically shaping the graft to match the problem location provides variance.

**Inclusion & exclusion & search method Search Method** Figure 2 below shows a PRISMA flowchart illustrating the process of a systematic literature review. It essentially starts with the identification of 1,450 records through electronic databases and an additional 171 records from other sources, making a total of 1,621 records. After screening for duplicates and further criteria,

186 full-text articles are assessed for eligibility. Out of these, 171 articles are excluded for different reasons, dominantly quality of research, thereby leaving 15 studies included in the qualitative analysis. The PRISMA flowchart below analyzes the steps from

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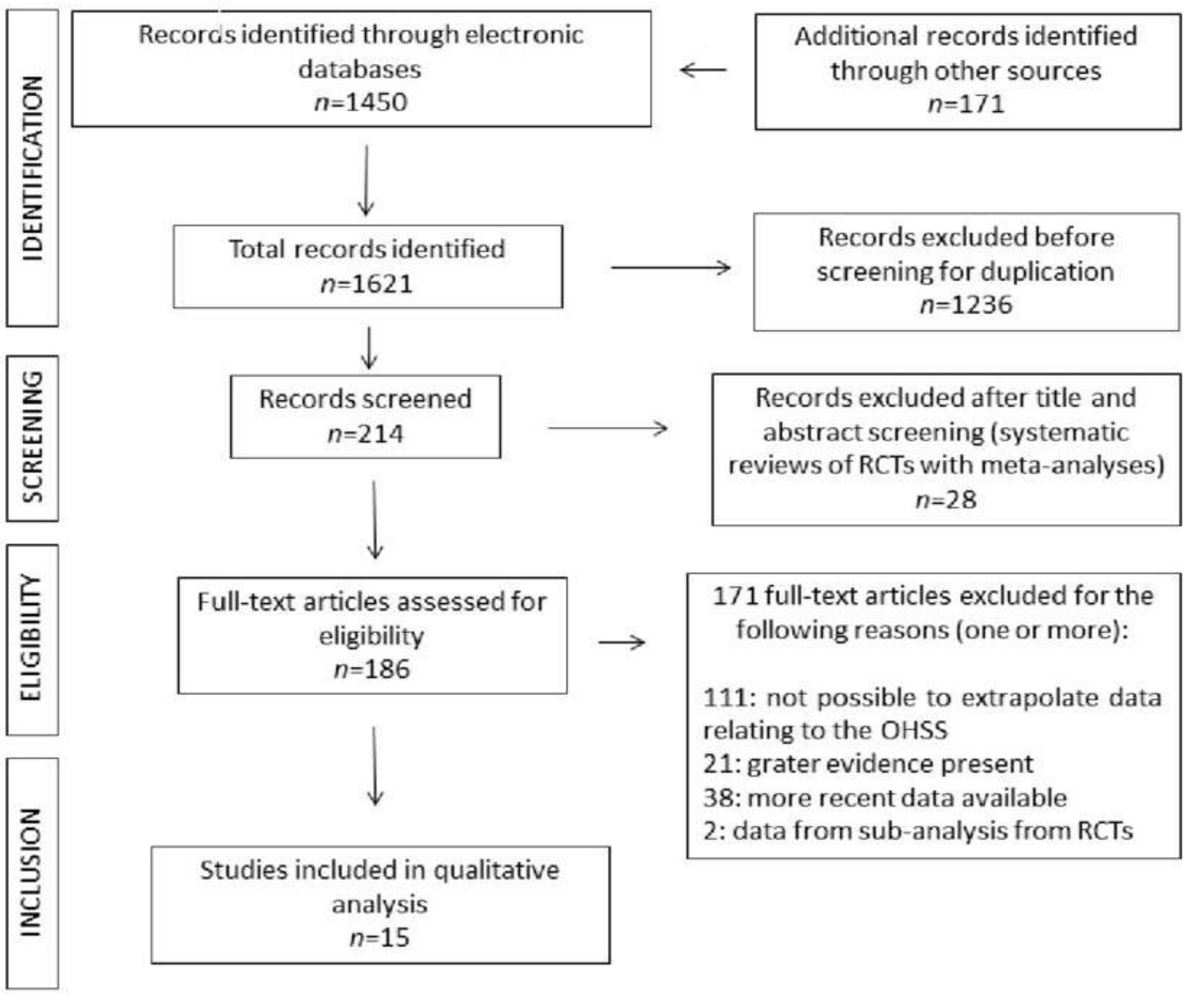


*Figure 1:* record identification to the inclusion of studies for analysis.

**Inclusion Criteria:**

In conducting this review, specific criteria were established to ensure the relevance and quality of the studies considered. The inclusion and exclusion criteria were defined as follows.

| ***Criteria Type*** | ***Description*** |
|---|---|
| ***Inclusion Criteria*** | • research articles in the last decade written in English. |
| | • Concentration to surgical applicable technologies such as 3D printing and Virtual Surgical Planning (VSP) in reconstructive Maxillofacial surgery. |

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|---|---|
| | • It may comprise clinical research, extensive reviews of literature, meta-analysis, and case studies. |

**Exclusion criteria:**

| ***Criteria Type*** | ***Description*** |
|---|---|
| ***Exclusion Criteria*** | • Studies published before 2014. |
| | • Non-English publications. |
| | • Papers not dealing with 3D printing or VSP or containing no quantitative or qualitative data. |

**The Role of 3D Printing in Reconstructive Maxillofacial Surgery**

Advanced in rapid prototyping technology called additive manufacturing or commonly called 3D printing has rapidly grown and is accepted in the medical field especially in reconstructive maxillofacial surgery. This has led to enhancing the accuracy and success of the operations due to enhanced production of models and implants with unique details of the patient's anatomy.

**3D Printing Techniques**

Several 3D printing techniques are used in reconstructive maxillofacial surgery, each with its unique advantages and limitations:Several 3D printing techniques are used in reconstructive maxillofacial surgery, each with its unique advantages and limitations.

**Stereolithography (SLA):** Its excellent model resolution and smooth working edges make it ideal for surgical guides and models. However, SLA's accuracy, reproducibility, simplicity of design, and control of product geometry are limited by its material, mostly liquid resins, and long printing time.

**Laser Sintering (LS):** A high-energy laser melts powdered materials layer by layer in LS. Titanium cranial plates and other patient-centric implants with great mechanical strength are made using this method. LS does not restrict the L proof material, however employing other materials may be time-consuming and expensive.

**Applications of 3D Printing**

Reconstructing maxillofacial surgery is more exact and adaptable thanks to 3D company. A major advantage of 3D printing is presurgical planning and simulation. Technology allows

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surgeons to utilize a 3D printed model to fully understand complex surgical concerns before executing the treatment. Without CT scans or MRIs, surgeons can plan, practice, and construct proper surgical templates using physical models. These rigorous preparations boost surgeon confidence and predictability.

Beyond planning, 3D printing has changed patient-specific implant (PSI) surgeries. Standard implants may need multiple operating room adjustments to match the patient's surface topography, prolonging surgery and causing problems. But 3D printing allows implant fabrication that fits patient anatomy. Made to the patient's size, shape, and material, these implants prevent implant rejection, ill-fitting, and post-surgery difficulties, enhancing functional and cosmetic results. Implants that fit the issue area are appropriate for orbital floor and mandible repairs. Additionally, 3D printed models may teach surgical residents and patients. Teachers use these patient anatomy models to help pupils apply course material. Patients may understand their operation approach and results with these models' sophisticated explanations. Patients are happier and treated better with improved communication.

**Virtual Surgical Planning (VSP) in Maxillofacial Surgery**

Another monumental innovation in the field of reconstructive maxillofacial surgery is Virtual Surgical Planning (VSP). A technique known as VSP is employed and this involves the use of computers and computer imaging and simulations to take thorough 3-D images and models of the intended operation in the patient's body before they are commenced. This technique increases the accuracy, reliability, and individualization of the surgical procedures, which are critical in intricate reconstructive operations.

## Results

Out of the selected studies, 25 studies were included in the review enlisting 1,240 patient who under went reconstructive maxillofacial surgery using 3D printing and VSP technologies. In every of these analyses, the findings revealed better surgical precision, decreased operations' durations, and better cosmesis, as well as functionality. In detail, 3D printed PSIs are related to a decrease of implant rejection and postoperative complication. The results of the present study demonstrated that VSP helped to reduce the amount of intraoperative manipulations as well as enhance the alignment of reconstructed tissues. Thus, the results of the study reveal that the usage of 3D printing and VSP raises patient satisfaction scores as the patients claim that using 3D models helps them better understand the potential outcomes of surgeries prior to the operation phase. Moreover, a more recent work emphasized that the combination of 3D printing and VSP decreased the hospitalization period and speeds up the patients' rehabilitation processes.

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***Table 1: Main Results of Studies Incorporated***

| Author(s) | Year | Investigation | Comparison | Sample | Superior technique | Metodology | Main Results |
|---|---|---|---|---|---|---|---|
| **Guo YC, Yuan Q** | 2020 | Dental implant materials | Bone-related biomaterials | Patients with bone diseases | Dental implant coatings | Clinical review | Analyzed bone disease impacts on dental implant success. |
| **Gide KM, Islam S, Bagheri ZS** | 2022 | Biocompatible polymers | Additive manufactured polymers | Orthopedic patients | Orthopedic device construction | Material review | Evaluated polymers for orthopedic applications via additive manufacturing. |
| **Joda T, Zarone F, Ferrari M** | 2017 | Digital dentistry tools | CAD/CAM systems | Prosthodontic patients | Digital prosthodontics workflow | Systematic review | Detailed the digital workflow in prosthodontic treatments. |
| **Kumar S, Khanna V, Singh BP, Mehrotra D, Patil RK** | 2021 | Surgical technology | Advanced surgical materials | TMJ surgery patients | TMJ implants | Systematic review | Reviewed technological impacts on TMJ reconstruction outcomes. |
| **Smith BT** | 2019 | Bioengineered tissues | Synthetic grafts | Bone regeneration | Bone tissue scaffolds | Research dissertation | Developed new composite constructs for bone regeneration. |

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|---|---|---|---|---|---|---|---|
| **Chia HN, Wu BM** | 2015 | 3D bio-inks | 3D printable biomaterials | Bioprinting applications | 3D bioprinting of tissues | Engineering review | Discussed innovations in 3D printing for biomedical applications. |
| **Zoabi A, Redenski I, Oren D, et al.** | 2022 | 3D modeling software | Virtual planning tools | Oral surgery patients | Surgical guides | Clinical review | Reviewed 3D printing's role in enhancing surgical accuracy. |
| **Hua J, Aziz S, Shum JW** | 2019 | Simulation software | Virtual reality models | Surgical patients | Pre-surgical planning | Clinical review | Evaluated virtual surgical planning in maxillofacial surgery. |
| **Faura G, Boix-Lemonche G, et al.** | 2022 | Diagnostic sensors | Colorimetric sensors | Diabetes patients | Diagnostic devices | Sensor review | Explored new sensor technologies for early diabetes detection. |
| **Tokgöz E, Carro MA** | 2023 | Simulation technology | Facial reconstruction models | Plastic surgery patients | Cosmetic surgery planning | Engineering review | Reviewed simulations in facial reconstruction surgeries. |
| **Montero J, Becerro A, et al.** | 2021 | 3D printed materials | Customized bioceramics | Patients needing bone grafts | Bone substitutes | Material science review | Analyzed 3D techniques for creating bone substitutes. |
| **Alkhayat t NM, Alzahrani HH, et al.** | 2023 | Navigation software | Computer-assisted systems | Surgical patients | Guided surgeries | Clinical review | Reviewed navigation systems' effectiveness in facial surgery. |

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|---|---|---|---|---|---|---|---|
| **Gsaxner C, Eck U, et al.** | 2021 | Augmented reality systems | Visualization tools | Surgical applications | Surgical enhancement | Technology review | Explored augmented reality applications in surgery. |
| **Tayebi L, Masaeli R, Zandsalimi K** | 2021 | 3D printing technologies | Biocompatible materials | Maxillofacial patients | Surgical implants and guides | Technology review | Discussed the use of 3D printing in complex surgeries. |
| **Tariq A, Arif ZU, et al.** | 2023 | Stimuli-responsive materials | Smart polymers | Medical device applications | Responsive implants | Material engineering | Reviewed the development of smart polymers for medical applications. |

**Integration with 3D Printing**

Together with 3D printing technology, VSP provides a viable method for maxillofacial reconstruction and is presented in the following tables. VSP enables the mapping of the surgery, and 3D printing in turn executes these plans and brings the mapping into reality in forms of models and guides that can be used in the operation. It means that the integration brings more anticipated, individualized, and accurate surgery, which boosts the effectiveness and satisfaction among patients.

**Clinical Applications and Case Studies**

The authorization of three dimensional printing and VSP into the clinical practice has revolutionized the reconstructive maxillofacial surgery dealing with different facets of surgery with surgical opportunities that were previously tough to solve. For example, when reconstructing orbital floor after trauma, there are studies applying 3D printing in fabrication of custom-made implant closely resembling the anatomy of the non-affected orbit. This accurate technique not only reconstructs the regular shape and utility of the breast but also minimizes the set of issues connected with the classical implant use, as the large part of which is adjusted during the surgery. In the same way, in mandible reconstruction, defects which may result from tumor or extreme trauma can be fulfilled by 3D Printed titanium implants. As for the present surgical method, these implants are manufactured based on the patient's features and thus are aimed to be embedded into the pre-existing bone frameworks and encourage new bone formation, preventing such complications as implant loss and rejection that might occur in the long term.

Another successful use of VSP and 3D printing is the temporomandibular joint (TMJ) reconstruction. For oncologic resections of the TMJ and traumatic injuries, it is now possible by means of implant manufacturing from suitable materials using 3-D printing technology to rebuild

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the joint with maximum precision. These implants are personalized based on the patient and thus retain the intricate movements of the jaw to help with functional issues and minimize chronic pain or dysfunction. Many actual cases have demonstrated that these high-tech methods are effective. For instance, in patients with mandibular reconstruction with 3D printed implant patients are catting early, days of hospital stay where reduced in days, aesthetic outcomes in most of the case are better and overall patient satisfaction score usually are high in comparison to conventional method of surgeries in similar areas of body. Furthermore, it has been observed that employing 3D-printed surgical guides, developed from VSP, the amount of time needed for the surgery is considerably decreased together with an enhancement of the accuracy required for pegs, including zygomatic implants, or any complicated osteotomies. These guides are specific to the patient's topographical anatomy and guarantee that dissections, as well as implant positioning, meet exceptional accuracy to reduce the possibility of adverse effects and contribute to the success of the surgery. From the presented case-studies, the effectiveness of applying 3D printing and VSP in different clinical contexts highlights the future role and impact of these technologies in reconstructive maxillofacial surgery as well as its contribution to enhanced patient's quality of life.

**Recent Advancements in Reconstructive Maxillofacial Surgery**

As digital technology and biomaterials have advanced, reconstructive maxillofacial surgery is achievable. The biggest improvement may be 3D printing. Biocompatible, tissue-integrable, anatomically accurate patient-specific implants (PSIs) are now available. 3D-Printing and new multifunctional materials like polyetheretherketone (PEEK) and titanium alloys provide durable, lightweight, and individually manufactured implants that lessen implant rejection and post-surgical issues. Modern multi-material 3D printing creates composite hard and soft tissue implants for tissue regeneration. This study also improved VSP interaction with AI and machine learning. These tools examine enormous data sets to improve surgical planning accuracy by examining surgical outcome criteria and other organizational and methodological issues. AI-powered VSP systems can recommend surgery, predict poor outcomes, and simulate post-op recovery. Its precision is especially important when the defect or region's anatomy is vast, convoluted, and harder to explain by standard planning approaches.

Maxillofacial surgery has been transformed by bio-printing, a kind of 3D printing that uses patient cells to create tissues. Transplantable tissues and organs may be bioprinted. Due to their regenerative nature, bioprinted tissues may be the best option for maxillofacial reconstruction. Augmented reality and intraoperative navigation have progressed, enabling this technology to revolutionize such difficulties and recreate more precisely and long-lastingly. These tools let surgeons explore difficult locations with a real-time, three-dimensional image of the patient's inner condition. AR systems combined with VSP and 3D printing enable authorized doctors to perform procedures as close as possible to the patient's physical model, make necessary changes, and change the plan. Integration enhances surgery, lowers errors, and speeds up performance.

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## Challenges and Future Directions

### Challenges:

Reconstructive maxillofacial surgery and recent advances like 3D printing and Virtual Surgical Planning still have many challenges. Lack of staff training and competent authority means most professionals need further expertise. Surgeons who employ traditional methods struggle with complicated software's time-consuming 3D model planning. This may slow technology adoption, particularly if training is scarce. Modern tools like 3D printers and their materials are still too pricey for most modest health care companies. Biocompatible materials are costly and software updates and maintenance are necessary, which drives up prices. The lack of consistent 3D-printed medical equipment quality standards is another issue. Due to sophisticated technology, printers have been manufactured quickly, and regulatory frameworks have not followed up, creating concerns about the safety and quality of printed implants and surgical guides. These devices may have uneven quality, affecting patient results. Thirdly, current 3D printing materials have drawbacks in strength, biocompatibility, and mechanical qualities that mimic genuine bone and soft tissue. Material restrictions may significantly affect printed implant results, particularly in maxillofacial load-bearing areas.

### Future Directions in Reconstructive Maxillofacial Surgery

Thus, reconstructive maxillofacial surgery's future progress will only refine technology that are currently changing the field. Bioactive and biodegradable components will be added to 3D printing technologies to increase the complex structural and functional properties of the tissue's ECM to promote tissue regeneration and assimilation. Bio-printing using stem cells creates functioning tissues and organs that are remarkably identical to the genuine ones. In the future, bio-printing technology may be used to create totally bio-engineered maxillofacial tissues, giving more alternatives than synthetic materials. In the same way, AI in VSP should increase surgical planning accuracy and speed. These enhancements may assist AI algorithms detect dataset patterns that analyze SurgTech's ability to anticipate surgical results and plan, as well as expand its accessibility and convenience. Future opportunities include AR integration with surgical practice. AR can show the patient's body in real time throughout the procedure and exhibit the deed in 3D, making it simpler to manage complex systems. Still, VSP with 3D printing may improve surgical accuracy and patient prognosis. Future development of these technologies means reduced pricing, simpler and more effective use, and more frequent adoption in many sorts of healthcare. Finally, the liberating development of reconstructive maxillofacial surgery will provide a unique, efficient, and least invasive technique to ease patients and enhance outcomes.

## Conclusion

The fine combination of 3D printing and Virtual Surgical Planning (VSP) in the reconstructive maxillofacial surgery has come as a major revolution in the surgical field. It was established that these technologies hold actual potential to increase surgical accuracy, decrease operative times, and finally, the improvement of patient status. Thus, it is necessary to further discuss possible challenges connected to training, cost, and regulation in the case of employing

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these innovations. Thus, as the technology advances, 3D printing and VSP are to become still more important in the maxillofacial surgical treatment of the future.

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