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Review Article

ESTABLISHING 3-D PRINTING IN RECONSTRUCTION SURGERY OF MAXILLOFACIAL DEFECTS AT A HOSPITAL SETTING: A REVIEW OF LITERATURE

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ABSTRACT

Background: Three-dimensional (3D) bioprinting, a technique derived from additive manufacturing technology, is a new and growing trend in the 3D volumetric structure design. Three-dimensional (3D) printing is based on additive technology, in which 3D objects are created by layering materials. This technology is still evolving, and the possibilities for its application are expanding. This article shows only some of the situations in which these methods have already been used. We review how these methods can be used in mandibular reconstruction, orthognathic surgery, maxillofacial trauma, temporomandibular joint reconstruction, facial prosthetics, and many other fields.

Methodology: PubMed was used to search the National Library of Medicine's MEDLINE database. We systematically reviewed the available literature using both the Medical Subject Heading's term "three-dimensional printing" and manual wildcard asterisked terms. Articles relating to various applications of 3D printing technology in maxillofacial surgery were selected using terms “surgery," "operation," "patient-specific implants," "maxillofacial surgery," and "reconstruction surgery." Only articles written in English were selected. After the findings were extracted (from 125 articles, only 23 were selected), they were categorized and analyzed in order to extract their content and core findings in order to clarify various aspects of 3D printing applications in the maxillofacial region.

Results: In maxillofacial surgery, additive 3D printing technologies are currently used to create personalized prostheses, surgical guides, dental and jaw models for training and preoperative planning, and patient-specific implants. Receiving data, processing it in a computer program, 3D printing, and post-processing are all steps in manufacturing any of the above items. The use of additive 3D printing technologies in maxillofacial surgery has a number of benefits, including improving student and doctor quality, reducing surgical intervention time, and increasing the number of satisfactory results.

Conclusion: The role of 3D printing in oral and maxillofacial surgery should be a focus of interest, as the technology has limitless development potential. A variety of implants, prostheses, bone fragments, tissues, and organs are now manufactured using 3D printers. With the increasing use of three-dimensional printing in dentistry and maxillofacial surgery, most organs and tissues can be produced in the near future, with their use in transplantation surgery. However, there are still issues with 3D printing to be addressed, such as the high cost of setting up 3D printing facilities. Long-term results from a larger sample size are often required to conclude 3D printing technology.

Keywords: 3D printing, maxillofacial surgery, reconstruction surgery, patient-specific implants

INTRODUCTION

Even experienced surgeons find reconstructing and augmenting congenital and acquired maxillofacial defects difficult. The precision molding and carving of autologous grafts and synthetic implants to adapt them to the native skeleton and soft tissue to restore normal facial form and function must accurately restore the face's complex three-dimensional (3D) shape. Suboptimal contour restoration can be caused by inaccurate molding of off-the-shelf implants, as well as the possibility of graft resorption. Recent advancements in computer-aided design/computer-aided manufacturing (CAD/ CAM) have created innovative alternatives for fabricating patient-specific implants (PSIs) with improved accuracy and better adaptation, resulting in better contour outcomes. Since its introduction to maxillofacial reconstruction surgery several decades ago, the technology for fabricating PSIs has advanced quickly. 3D images were created from computed tomography (CT) slices in the early 1980s. After that, the 3D images were converted into crude anatomic models for preoperative planning. CNC milling machines used 3D imaging data to cut out Styrofoam blocks or polyurethane into the final model to create these models. This method was also used to create the first PSIs. Subtractive manufacturing describes the process of creating implants and models from a block of material by removing parts of the material to create the final form. The ability of subtractive manufacturing to replicate the complex 3D contour of the facial skeleton is limited.

On the other hand, additive manufacturing creates 3D structures by layering material onto a platform in a computer-controlled sequence. This method allows for the fabrication of exact forms without wasting material. For decades, additive manufacturing has been used in other industries, and it is now gaining traction in medicine (Owusu and Boahene, 2015). The word "personalized medicine" has gained popularity in the twenty-first century. It refers to shifting away from a "one-size-fits-all" approach for the average patient towards tailored therapies to the individual. Several recent developments have allowed the application of personalized medicine to oral and maxillofacial surgery to improve outcomes due to the complexity of the facial skeleton and the development of computer-aided design and computer-aided manufacturing (CAD/ CAM) technology. As the cost of this technology has decreased, it has become more affordable and available to patients. Temporomandibular joint (TMJ) total joint replacement, reconstruction of the maxillofacial skeleton, orthognathic surgery, and other oral and maxillofacial surgery areas now use patient-specific implants. (Huang et al., 2019).

History of 3d-printing:

In the fifteenth century, a German blacksmith named Johannes Gutenberg invented the printing press, which is regarded as the most important invention of the second millennium and the catalyst for the printing revolution. Since then, we have come a long way. 3D printing, contrary to popular belief, is not a brand-new invention. Hideo Kodama of Nagoya Municipal Industrial Research Institute used photopolymers to create the first-ever 3D model in 1981 (Ghai et al., 2018). Charles Hull invented 3-D printing in 1984, ushering in a new era marked by a major leap from printing paper to printing objects (Schubert et al., 2014). Stereolithography, or the “printing” of materials on top of each other in successive layers to form a 3-D object, is how he described it. In 1987, he received a patent for stereolithography. However, Hideo Kodama of Nagoya Municipal Industrial Research Institute published the first account of a working photopolymer rapid prototyping system in 1981, a few years before this. Stratasys Limited created the world's first fused deposition modeling (FDM) machine in 1991. An extruder and plastic were used in this technology, and layers were deposited on a print bed. 3D printing – a mechanical process in which solid objects are created by ‘printing' successive layers of material to replicate a shape modeled in a computer – has been adopted in numerous industries in the 30 years since Charles Hull filed his patent(Ghantous et al., n.d.).

History of 3d printing in maxillofacial surgery:

Three-dimensional printing has been used to make everything from weapons, boats, and food to models of unborn babies in various industries. It is the process of turning digital layouts into physical models. This technology illustrates a method for manufacturing a product using a layer-by-layer system after it has been developed using a computer-aided scheme. This method is also known as additive manufacturing, solid freeform technology (SFF), or RP (AM). 3D printing is not a new concept; it has been around for over 30 years. The growing market for 3D desktop printers stimulates a wide range of experiments in a variety of fields. Treatment planning, prosthesis implant fabrication, medical training, and other medical applications are common uses for these printers. RP has gotten much attention in surgery in the last ten years after being used in the military, the food industry, and the arts. Brix and Lambrecht were the first to use SL in oral and maxillofacial surgery in 1985. They later used this method for treatment planning in craniofacial surgery. Mankovich et al. used SL to treat patients with craniofacial deformities in 1990. They used computed tomography (CT) with complete internal components to simulate the bony anatomy of the cranium. Today, additive manufacturing can help maxillofacial surgery in a variety of ways and a variety of clinical situations. Bending plates, manufacturing templates for bone grafts, tailoring implants, osteotomy guides, and intraoperative occlusal splints can all benefit from this technique. RP can reduce surgery time and make pre- and post-operative decisions easier. It has improved surgical effectiveness and precision (Keyhan et al., 2016).

- Uses of 3D models.
- Diagnosis and treatment planning
- Direct visualization of anatomic structures
- Surgical guides/templates
- Surgical practice/rehearsal
- Designing incisions Surgical resections
- Assessment of bony defects for grafting
- Adaptation/pre-bending of reconstruction plates
- Fabrication of custom prostheses TMJ prostheses, distraction devices, fixation devices
- Decreased surgical time, anesthesia time, wound exposure duration.
- An educational tool for students and patients (Keyhan et al., 2016)

Use of 3d-printing technologies in craniomaxillofacial surgery:

A variety of computer-assisted planning and manipulation techniques are used to generate the desired virtual 3-D object in craniomaxillofacial surgery. Mirroring is a frequently used technique that involves transferring the uninjured side of the body from the medical image, mirroring it, and then using it as a template for the injured side of the body. The new image is then 3-D printed and used for implant contouring, plate contouring, mesh contouring. Another type of virtual manipulation widely used in maxillofacial jaw surgery is to simulate the final position of the jaws after surgery and create a 3-D printed splint using this virtual movement. Most of the time, 3-D printing not only results in more accuracy in craniomaxillofacial surgery but also saves time in the operating room (Ghai et al., 2018).

Because 3D printing can better differentiate between traumatic and pathologic defects, it has been shown to improve diagnosis and treatment in the maxillofacial region. As a result of this feature, accurate decision-making is possible. 3D printing should present spatial relationships to surrounding components in the case of pathologic lesions. These crucial visuals can help to reduce operative complications. Surgeons can visualize the process and anticipate problems with 3D printing, allowing them to achieve better results before they even begin. Three-dimensional printing can quickly produce models with reasonable accuracy and structural details, resulting in better results and shorter operation times (Keyhan et al., 2016). Other studies have found that preoperative planning enabled by physical or software manipulation of a 3D model boosts surgical team trust by providing a pre-surgery preview of the patient's anatomy, which improves clinical outcome predictability compared to similar treatments without it (Ciofu et al., 2020).

Takano et al. used a 3D custom-made, pre-bent titanium mesh plate fabricated from a 3D model created from CT data to successfully reconstruct the maxilla and teeth. For cases prone to postsurgical wound dehiscence, graft exposure and infection, and alveolar bone loss, the tunneling flap technique for titanium mesh insertion are ideal. The use of a pre-bent titanium mesh in conjunction with a tunneling flap incision shortens surgery time and increases patient safety (Fig 1)(Takano et al., 2019)

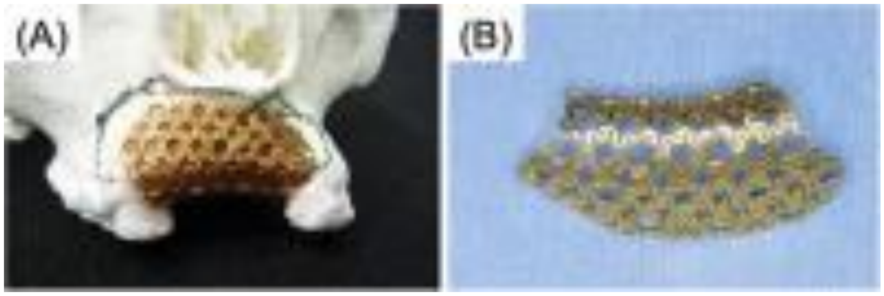

Figure 1: Pre-bent titanium mesh

VSP has the potential to become a mainstay, novel strategy in the treatment of oncologic head and neck reconstruction as its use grows and efforts to validate the technology (Rodby et al., 2014).

Maxillofacial reconstruction:

Whether acquired or developed, craniofacial deformities can have a negative psychological effect on those who are affected. The soft and hard tissues of the craniofacial complex are affected to varying degrees by such deformities (Salah et al., 2020).

The craniofacial skeleton has several functional and aesthetic properties. Total or subtotal resection of the maxilla or mandible may seriously impair one or both of these facets, affecting the patient's quality of life significantly. Hidalgo was the first to use microvascular fibula-free transfer for head and neck reconstruction. He uses the periosteal segmental blood supply of the fibula to allow various osteotomies to shape the bone and adds bi-cortical thick bone suitable for dental implants. This is the mainstay of mandibular reconstruction in many centers. The technique of bone modeling is one of the most important aspects of mandibulo-maxillary reconstruction. Dental occlusion, facial contour, and proper bone-to-bone contact are all affected (Smithers et al., 2018).

To achieve an optimum anatomical and functional result, composite maxillofacial reconstruction requires high accuracy in all dimensions and stages. Computer-aided design and manufacture (CAD-CAM) technologies actively encourage the development of new surgical and prosthodontic approaches to help achieve these goals. Preoperative surgical planning allows for surgical simulation of the resection and reconstruction stages and creating three-dimensional (3D) stereolithographic models, prebent reconstruction plates, surgical guides and templates, and prosthetic rehabilitation. Previous studies of virtual surgical simulation in head and neck reconstruction have found significant benefits over conventional techniques, such as increased accuracy and shorter operation times. Even in the hands of experienced surgeons, the clinical precision of virtually scheduled free fibular flaps in mandibular reconstruction has confirmed a high level of accuracy difficult to achieve through the manual placement of the graft. (Rohner et al., 2013).

Mandibular reconstruction:

Head and neck surgeons face a difficult task in mandibular reconstruction after ablative tumor removal, which seeks to achieve the best possible functional and esthetic outcomes. In 1989, Hidalgo published a paper on the use of vascularized fibula flaps for mandibular reconstruction. Since then, the fibular free flap has become the standard for mandible reconstruction. This flap has many benefits, including high-quality long bi-cortical bone grafts, a long pedicle, a wide vessel, and the ability to combine skin and muscle for mandibular reconstruction. However, since the mandible is mobile, determining the proper position of the fibula flap to achieve the best functional and aesthetic results becomes more difficult. (Ren et al., 2018).

Insertion of a reconstructive plate supporting a microvascular fibular free flap is the current gold standard for mandibular reconstruction after surgical ablation. When compared to conventional reconstruction methods, the computer-aided design/computer-aided manufacturing (CAD/CAM) approach for mandibular reconstruction has been shown to produce better results in terms of morphology and function, with an excellent improvement of the results. Because preoperative simulation of fibular removal and mandibular reconstruction was possible, these results were obtained. Preoperative planning is replicated intraoperatively using a personalized reconstructive plate that can be additively laser-sintered and a mandibular and a fibular osteotomy cutting guide. Furthermore, as virtual planning has progressed, it is now possible to accurately simulate both skin paddle resection and reconstruction when a composite fibular free flap is needed (Tarsitano et al., 2018)

Trauma surgery:

Trauma patients with recent or delayed fractures and defects may benefit from 3D printing. 3D printing can help with various maxillofacial fractures, but orbital wall fractures are the best candidates for these techniques. These patients can be treated with a 3D personalized orbital wall defect reconstruction using titanium mesh or sheet. Before the surgery, a 3D printed replica of the titanium mesh or plate is precisely adapted to help shorten the duration of general anesthesia. Reconstructing orbital defects is difficult due to the complex and detailed anatomy of the orbit. (Figures 2)(Keyhan et al., 2016)

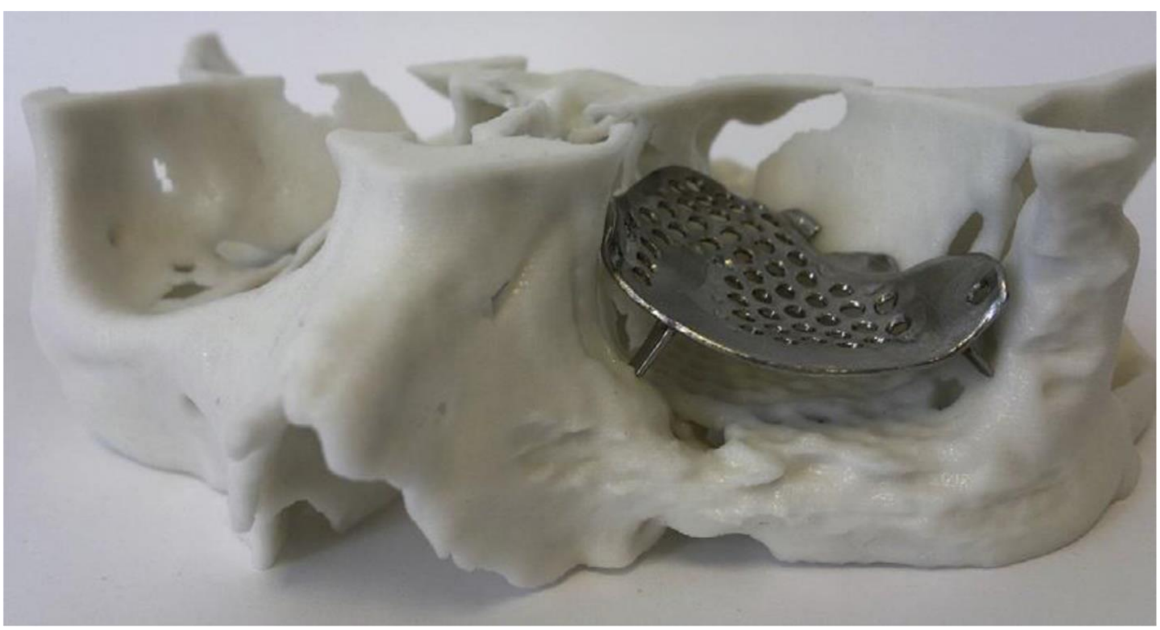

Figure 2: The rapid prototype metal orbital floor reconstruction in the orbit of the stereolithic skull reconstructed from the original CT scans (Keyhan et al., 2016)

Orthognathic surgery:

The success of orthognathic surgeries depends on precise planning and decision-making based on a precise diagnosis. (Keyhan et al., 2016)

The 3D models improved cooperation between orthodontists and surgeons and served as an excellent patient education tool. It also assisted in predicting the size and shape of the bony defect to be grafted, reducing the amount of graft material harvested and donor site morbidity. The 3D model assisted the surgeon and the patient in visualizing the better postoperative outcome and allow the surgeon to plan the procedure's minute details. The use of 3D-printed models in orthognathic surgery has increased surgical planning and smoothed the transition of the surgical plan into the operating room, resulting in a better surgical outcome with improved intraoperative orientation and miniplate bending (Park et al., 2019).

Facial prosthetics:

In the last ten years, there have been reports of prosthetic noses, ears, eyes, and faces being made. According to the literature, 3D printing produces better esthetic and functional results than traditional prosthetics.

Facial prosthetics made with RP techniques have proven to be effective. In 500 B.C., the Egyptians were the first to use facial prosthetics. With the use of 3D printing technology, facial prosthetics have advanced significantly. This approach allows for creating facial structure replicas in just a few hours (Subburaj et al., 2007). The most common method of producing facial prosthetics is through impression processes. Longer duration of the preferred manufacturing method for facial prosthetics. Hard tissue reconstruction is a common application for additive manufacturing. However, it is useful in soft tissue production; however, the primary drawbacks of this process are soft tissue distortion and patient discomfort. 3D printing has recently been used to make facial prosthetics to overcome the limitations of conventional procedures. By eliminating impression procedures and model wax-ups, additive manufacturing technology can simplify the process and shorten laboratory procedures. Without a doubt, 3D printing will become the standard for contouring procedures such as auricular reconstruction in patients who use the opposite ear (Figure 3) (Matsuoka et al., 2019).

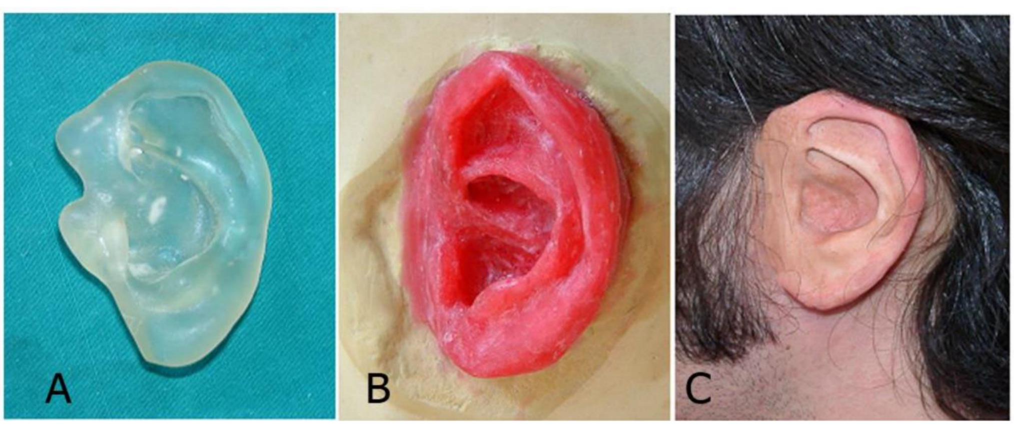

Figure 3: (a) 3D model obtained by stereolithography; (b) stereolithographic model turned into wax; (c) finished auricular prosthesis(Matsuoka et al., 2019)

Customized TMJ reconstruction:

The temporomandibular joint (TMJ) is a bilateral synovial articulation between the mandible and the temporal bone that allows for speech, chewing, swallowing, and emotional expression. Jaw pain and dysfunction are prevalent, with prevalence ranging from 33 to 86 percent.

When conservative treatment fails, prosthetic total joint replacement surgery is the standard of care for degenerative severe joint conditions of the TMJ.

When stock prosthetic components cannot be used after a large tumor resection that results in bone loss, patients may be left with gross deformities and poor mandibular function. Three-dimensional (3D) printing, also known as fast prototyping or additive manufacturing, is a manufacturing method that involves melting, fusing, or depositing materials in layers to create a three-dimensional object. Implantable devices like prostheses can be made in nearly any shape, but they can also be 'personalized' by using x-ray, MRI, or CT scans to guide implant design and the subsequent creation of a patient-specific digital 3D print file. The ability to rapidly create personalized components solves a critical problem in orthopedics and maxillofacial surgery, where standard implants are anatomically inadequate; however, despite recent advances in 3D printing, transformative medical applications are still in their infancy. Prior to commercialization and industry manufacturing, medical implants often require biomechanical assessment and standardized testing for scientific and regulatory requirements (Driemel et al., 2009).

Dental implants:

3D printing has aided in the development of new dental implants. Dental implants with complex geometries can be created using 3D printing. Drilling guides are handy for moving implants from their intended positions. Creating a drilling guide using traditional techniques takes time and necessitates numerous patient visits and extensive laboratory work. RP makes this possible by requiring only a single consultation before the operation. Data is collected during this session, and the guide is practically constructed before being manufactured by the 3D device (Dawood et al., 2015)

Establishing 3d printing technology at a hospital setting:

From highly specialized clinical, educational simulators to minimally invasive robotic surgery, there have been significant advancements in medical technology, as well as a slew of new computer-aided design and manufacturing developments, capped by the introduction of three-dimensional printing (3DP). They have a wide range of applications, including virtual reconstruction of cross-sectional imaging data into 3D objects and the design and manufacturing of patient-specific implants (PSIs) and intraoperative guidance devices. 3DP technology reduces operating room time and provides accurate 3D models while also improving medical outcomes. The primary drawback of this technology is its higher cost when compared to traditional methods (Tack et al., 2016). Despite this, their popularity continues to increase, with new applications being published regularly. There are a plethora of businesses that provide 3D services, as technological advancements have made it possible to transfer this information more easily. These businesses will then use this information to create the final product (e.g., 3D model, PSI, guiding splint, cutting guide, etc.) while keeping the treatment plan in mind. These services are often web-based, time-consuming, and necessitate special conference call arrangements.

Furthermore, they are costly, and any transaction that involves the transfer of sensitive patient information risks breaching patient confidentiality. The establishment of in-house specialized hospital-based 3D services, on the other hand, reduces the risk of personal information being compromised while also encouraging the growth of local expertise in this technology. (Hatamleh et al., 2018)

Increased preoperative counseling, operative accuracy, reduced operating room time, lower reoperation rates, and improved resident training are among the reported benefits

According to a recent systematic review, the main drawbacks of 3-dimensional printing applications in maxillofacial surgery were the costs and delays associated with remote printing. (Honigmann et al., 2018) Compared to other methods, 3D printed replicas are thought to be more accurate and cost-effective for patient and trainee education. In the twenty-first century, 3D printing technology would improve our lifestyle and health care. (Mathew et al., 2020)

CONCLUSION

All aspects of dentistry are being influenced by 3D imaging and modeling, as well as CAD technologies. 3D printing allows one-off, complex geometrical forms to be accurately created from digital data in a variety of materials, locally or in industrial centers. Even though a 3D printer can now make almost everything we make for our patients, no single technology can meet all of their needs. The technology is already widely used in orthodontics, where high-resolution resin printing is already a viable option. Similar technology is being used to print models for restorative dentistry and patterns for the lost-wax process, becoming more critical as intraoral scanning systems get popular. Anatomical models created using any number of different 3D printing techniques are becoming commonplace and required in maxillofacial and implant surgery to aid in planning complex treatments. Surgical guides printed in resins (commonly) or autoclavable nylon are widely accepted as making surgery less invasive and more predictable. (Dawood et al., 2015)

InterestofConflict: None

REFERENCES

1. Ciofu, M.L., Rosu, A., Drochioi, C.I., Doscas, A., Boisteanu, O., Costan, V.-V., 2020. Enhancing outcomes of mandibular reconstruction by introducing three-dimensional printing. Romanian Journal of Stomatology 66, 35–39. https://doi.org/10.37897/RJS.2020.1.6
2. Dawood, A., Marti, B.M., Sauret-Jackson, V., Darwood, A., 2015. 3D printing in dentistry. British Dental Journal 219, 521–529. https://doi.org/10.1038/sj.bdj.2015.914
3. Driemel, O., Braun, S., Müller-Richter, U.D.A., Behr, M., Reichert, T.E., Kunkel, M., Reich, R., 2009. Historical development of alloplastic temporomandibular joint replacement after 1945 and state of the art. International Journal of Oral and Maxillofacial Surgery. https://doi.org/10.1016/j.ijom.2009.01.022

4. Ghai, S., Sharma, Y., Jain, N., Satpathy, M., Pillai, A.K., 2018. Use of 3-D printing technologies in craniomaxillofacial surgery: a review. Oral and Maxillofacial Surgery. https://doi.org/10.1007/s10006-018-0704-z
5. Ghantous, Y., Nashef, A., Mohanna, A., Abu-El-Naaj, I., n.d. Three-Dimensional Technology Applications in Maxillofacial Reconstructive Surgery: Current Surgical Implications. https://doi.org/10.3390/nano10122523
6. Hatamleh, M.M., Ong, J., Hatamleh, Z.M., Watson, J., Huppa, C., 2018. Developing an in-house interdisciplinary three-dimensional service: Challenges, benefits, and innovative health care solutions. Journal of Craniofacial Surgery 29, 1870–1875. https://doi.org/10.1097/SCS.0000000000004743
7. Honigmann, P., Sharma, N., Okolo, B., Popp, U., Msallem, B., Thieringer, F.M., 2018. Patient-specific surgical implants made of 3D printed PEEK: Material, technology, and scope of surgical application. BioMed Research International 2018. https://doi.org/10.1155/2018/4520636
8. Huang, M.F., Alfi, D., Alfi, J., Huang, A.T., 2019. The Use of Patient-Specific Implants in Oral and Maxillofacial Surgery. Oral and Maxillofacial Surgery Clinics of North America. https://doi.org/10.1016/j.coms.2019.07.010
9. Keyhan, S.O., Ghanean, S., Navabazam, A., Khojasteh, A., Iranaq, M.H.A., 2016. Three-Dimensional Printing: A Novel Technology for Use in Oral and Maxillofacial Operations, in: A Textbook of Advanced Oral and Maxillofacial Surgery Volume 3. InTech. https://doi.org/10.5772/63315
10. Mathew, N., Gandhi, S., Singh, I., Solanki, M., Bedi, N.S., 2020. 3D Models Revolutionizing Surgical Outcomes in Oral and Maxillofacial Surgery: Experience at Our Center. Journal of Maxillofacial and Oral Surgery 19, 208–216. https://doi.org/10.1007/s12663-019-01275-0
11. Matsuoka, A., Yoshioka, F., Ozawa, S., Takebe, J., 2019. Development of three-dimensional facial expression models using morphing methods for fabricating facial prostheses. Journal of Prosthodontic Research 63, 66–72. https://doi.org/10.1016/j.jpor.2018.08.003
12. Owusu, J.A., Boahene, K., 2015. Update of patient-specific maxillofacial implant. Current Opinion in Otolaryngology and Head and Neck Surgery. https://doi.org/10.1097/MOO.0000000000000175
13. Park, S.-Y., Hwang, D.-S., Song, J.-M., Kim, U.-K., 2019. Comparison of time and cost between conventional surgical planning and virtual surgical planning in orthognathic surgery in Korea. Maxillofacial Plastic and Reconstructive Surgery 41. https://doi.org/10.1186/s40902-019-0220-6
14. Ren, W., Gao, L., Li, S., Chen, C., Li, F., Wang, Q., Zhi, Y., Song, J., Dou, Z., Xue, L., Zhi, K., 2018. Virtual planning and 3D printing modeling for mandibular reconstruction with fibula free flap. Medicina Oral Patologia Oral y Cirugia Bucal 23, e359–e366. https://doi.org/10.4317/medoral.22295
15. Rodby, K.A., Turin, S., Jacobs, R.J., Cruz, J.F., Hassid, V.J., Kolokythas, A., Antony, A.K., 2014. Advances in oncologic head and neck reconstruction: Systematic review and future considerations of virtual surgical planning and computer aided design/computer aided modeling. Journal of Plastic, Reconstructive and Aesthetic Surgery. https://doi.org/10.1016/j.bjps.2014.04.038

16. Rohner, D., Guijarro-Martínez, R., Bucher, P., Hammer, B., 2013. Importance of patient-specific intraoperative guides in complex maxillofacial reconstruction. Journal of Cranio-Maxillofacial Surgery 41, 382–390. https://doi.org/10.1016/j.jcms.2012.10.021
17. Salah, M., Tayebi, L., Moharamzadeh, K., Naini, F.B., 2020. Three-dimensional bio-printing and bone tissue engineering: technical innovations and potential applications in maxillofacial reconstructive surgery. Maxillofacial Plastic and Reconstructive Surgery 42. https://doi.org/10.1186/s40902-020-00263-6
18. Schubert, C., van Langeveld, M.C., Donoso, L.A., 2014. Innovations in 3D printing: A 3D overview from optics to organs. British Journal of Ophthalmology 98, 159–161. https://doi.org/10.1136/bjophthalmol-2013-304446
19. Smithers, F.A.E., Cheng, K., Jayaram, R., Mukherjee, P., Clark, J.R., 2018. Maxillofacial reconstruction using in-house virtual surgical planning. ANZ Journal of Surgery 88, 907–912. https://doi.org/10.1111/ans.14353
20. Subburaj, K., Nair, C., Rajesh, S., Meshram, S.M., Ravi, B., 2007. Rapid development of auricular prosthesis using CAD and rapid prototyping technologies. International Journal of Oral and Maxillofacial Surgery 36, 938–943. https://doi.org/10.1016/j.ijom.2007.07.013
21. Tack, P., Victor, J., Gemmel, P., Annemans, L., 2016. 3D-printing techniques in a medical setting: A systematic literature review. BioMedical Engineering Online. https://doi.org/10.1186/s12938-016-0236-4
22. Takano, M., Sugahara, K., Koyachi, M., Odaka, K., Matsunaga, S., Homma, S., Abe, S., Katakura, A., Shibahara, T., 2019. Maxillary reconstruction using tunneling flap technique with 3D custom-made titanium mesh plate and particulate cancellous bone and marrow graft: a case report. Maxillofacial Plastic and Reconstructive Surgery 41. https://doi.org/10.1186/s40902-019-0228-y
23. Tarsitano, A., Battaglia, S., Ricotta, F., Bortolani, B., Cercenelli, L., Marcelli, E., Cipriani, R., Marchetti, C., 2018. Accuracy of CAD/CAM mandibular reconstruction: A three-dimensional, fully virtual outcome evaluation method. Journal of Cranio-Maxillofacial Surgery 46, 1121–1125. https://doi.org/10.1016/j.jcms.2018.05.010