Journal of Surgical Practice and Case Reports

Research Article

Open Access Full Text Article

Surgical Reconstruction and 3D Printing

Siniša Franjić*

[1]Independent Researcher

***Correspondence:**
Siniša Franjić, Independent Researcher, Europe.

Received: June 01, 2026; **Published:** June 19, 2026

How to cite this article:
Franjić S. Surgical Reconstruction and 3D Printing. *J Surg Pract Case Rep*. 2026;2(2):1-4.

Abstract

3D printing has changed the landscape of surgical reconstruction by making it possible to create custom implants, anatomical models, and surgical guides. This technology helps surgeons to meticulously plan procedures ahead of time, resulting in shorter operation times, fewer complications, and quicker recovery for patients.

Keywords: 3D Printing, Biofabrication, Surgery, Reconstruction, Health

Introduction

Key software features include segmenting anatomy, simulating osteotomy lines, and repositioning anatomical segments.[1] For patients experiencing distorted or absent anatomy due to trauma, cancer, or congenital issues, a normative template can aid in reconstructive planning. If a patient has unilateral defects, the healthy side is often mirrored around the mid-sagittal plane onto the image to assist with the design of autologous or alloplastic reconstructions. Alternatively, CT scans from before any medical issues can be imported as a reference. In cases of significant bilateral deformities, data can be taken from databases of normal patient anatomy and adjusted accordingly. The final shape can be smoothed and blended with surrounding anatomy to ensure it meets the patient's specific requirements.

Digital models of surgical instruments, implants, and osteosynthesis plates can be introduced into the 3D space and overlayed with patient data. This enhances visualization of the surgical process, assists in understanding spatial relationships, and helps with measurements. For instance, during mandibular distraction procedures, vendor-specific distraction devices can be imported and placed on the anatomical model, allowing for simulation of the distraction. This gives an idea of how the anatomy will appear after the procedure and enables necessary adjustments to the placement vector.

Moreover, the software may allow users to add geometric shapes or hand-drawn elements to the anatomical model, which is especially helpful when designing custom alloplastic implants. There is also the possibility to predict changes in functional aspects post-surgery, such as changes in bite forces from orthognathic movements, utilizing finite element analysis.

Biofabrication

Biofabrication is the automated creation of constructs that better replicate the intricate, diverse nature and shape of tissues and organs than current regenerative therapies currently achieve.[2] Recently, the community has refined the definition of biofabrication to describe it as "the automated generation of biologically functional items with structural organization from living cells, bioactive molecules, biomaterials, cell aggregates like microtissues, or hybrid cell-material constructs, utilizing bioprinting or bioassembly followed by tissue maturation processes." It's important to distinguish between bioprinting and bioassembly, as they are commonly confused. Bioprinting is defined as the use of computer-aided techniques to pattern and assemble living and nonliving materials into specific 2D and 3D arrangements to create bioengineered structures. In contrast, bioassembly is described as building hierarchical constructs in a defined 2D or 3D manner through automated assembly of preformed cell-containing units created via cell-driven self-organization or through hybrid cell-material components, aiming to closely mimic natural tissue structure and development.

The ability of the human body to regenerate damaged tissue or organs due to medical conditions is quite limited. However, 3D printing, a type of additive manufacturing, has made it possible to create complex, customized 3D structures. With these technological advancements in tissue engineering, it's clear that such methods can enhance the quality of life for many individuals suffering from illnesses. One day, we may be able to repair or replace various tissues and organs using engineered constructs that include therapeutic cells for reconstructive treatments. For instance, in the case of severe skin burns and scarring, 3D-printed skin grafts with differentiated stem cells could mimic natural skin closely and help prevent scar formation.

The technology behind 3D printing includes a series of tools that collaborate to produce the desired 3D print. This setup consists of a computer, 3D modeling software, which is computer-aided design created from clinical imaging data like CT or MRI scans, along with hardware and printing materials. To generate accurate tissue shapes, CT data is captured, processed by CAD software, and translated to the printer, resulting in the intended 3D construct.

The printability of biomaterials relies on the manufacturing method and the rheological and mechanical characteristics of the raw material. Depending on the printing technique chosen, both the composition and the final shape of the material can vary significantly. Historically, various traditional fabrication methods like gas foaming, phase separation, fiber bonding, molding, particulate leaching, and membrane lamination were employed to create porous scaffolds. Over the last two decades, advancements in technology have paved the way for new applications in 3D printing. Some of the most frequently used 3D printing techniques for producing scaffolds in tissue engineering are stereolithography, selective laser sintering, fused deposition modeling, and 3D plotting/bioprinting.

Tissue engineering is a new area within biomedical engineering that involves creating biological tissues either outside the body (ex vivo) or inside the body (in vivo) by using new technologies to help repair and grow existing tissues.[3] In ex vivo methods, bioartificial tissues, which blend synthetic and natural materials, serve as alternatives for organ transplants or are used for in vitro studies on how tissues behave. Key challenges in this field include isolating cells, managing how they organize and function, scaling up to larger bioartificial tissues, and making biomaterials.

While the most publicized achievements in tissue engineering have focused on epithelial tissues, there are ongoing clinical trials aimed at rebuilding cartilage, bone, neural, and liver tissues. Grafts are utilized to treat all sorts of skin injuries, including burns, pressure sores, venous stasis ulcers, and diabetic ulcers. Polymeric tubes are used to help regrow nerves that have been damaged due to issues in the central or peripheral nervous system. Additionally, tissue engineering includes joint replacements, creation of connective tissues, and bone grafting. Artificial heart valves incorporate tissues from cows and pigs along with bioartificial materials. Innovations in this area also address organ failure, providing solutions for conditions like liver cancer and breast reconstruction. Advancements in dental surgery and blood transfusions reflect just a couple of the many applications of tissue engineering technologies.

Bone marrow transplants aim to restore the most active organ in the body. Bone marrow produces blood cells and often gets damaged from treatments like chemotherapy and radiation. Modern techniques involve collecting a patient's marrow samples before these treatments and then reinjecting them afterward. This process allows the body to replenish its marrow supply, but it can lead to temporary immune system weakness.

3D Printing

3D printing has grown to complement CAD by being the only means for creating Patient Specific Realizations that can be physically used in surgeries.1 It's now an essential part of pre-surgical planning, making it easier and more dependable to turn the visual surgical plan into the actual actions needed for the procedure. Data on measurements and coordinates can be extracted from the software and utilized to design accurate custom guides for marking, cutting, segment positioning, or splints, effectively bringing the virtual plan into the operating room. Various technologies, including Vat Polymerization machines like Stereolithographic Apparatus (SLA) and Power Bed Fusion methods like Selective Laser Sintering (SLS), have been employed. These techniques allow for the quick creation of accurate and stable plastic models tailored to patient specifications.

Computer-Numerically Controlled (CNC) milling machines have traditionally been used to carve material from solid blocks, like Styrofoam, to create the intended surface shapes. Initially, the models produced were of low fidelity, but they steadily improved as technology advanced, leading to more precise representations of both preoperative and anticipated postoperative anatomy. As 3D printing methods gained traction, CNC milling started to be replaced for making these reference models. The layer-by-layer printing process allows for intricate internal details and additional anatomical features to be included more easily and cost-effectively than milling can achieve. Consequently, models of patient skulls or jaws created through SLA or SLS printing are far more common these days.

Osteotomy

To faithfully reproduce the virtual osteotomies, it is crucial to replicate the direction of the saw blade accurately and to restrict the instrument's movement to the intended path.[1] The best way to achieve this is by using a cutting guide with a narrow slot that accommodates the saw blade without unnecessary looseness. In 3D-printed cutting guides, this slot can either be integrated into the printed model or made as a separate metal insert that fits into the guide. The side of the cutting guide that faces the patient can be designed to match the patient's anatomical surface, ensuring that the guide is placed correctly in the right position and orientation. Standard bone screws can be used to secure the guide to the bone before performing the osteotomies.

Understanding 'Predictive Holes' in patient-specific cutting guides is important. These holes are a vital part of the cutting guide design, positioned accurately concerning the osteotomy lines. When the surgeon drills these holes using the same settings as during osteotomies, they create an additional reference point for later use in reconstructive surgery. These predictive holes may serve as spots for placing a positioning guide or can be designed to precisely align with the holes in a patient-specific osteosynthesis plate. This surgical method helps facilitate the accurate positioning of the plate.

In areas with limited access where a full cutting slot might be too cumbersome, a slimmer marking guide can provide a helpful alternative by allowing the osteotomy's location to be marked with ink or pencil. However, this method may compromise the accuracy of the vector.

Surgery

The widespread use of CBCT (Cone-Beam CT) machines in dental and orthodontic practices has led to more frequent presurgical planning for orthognathic surgery.1 Generally, a few weeks before the operation, the patient is given either conventional CT or CBCT imaging of the facial structure. During the same appointment, dental impressions for creating stone models or modern intraoral scans are taken, and the occlusion is set either manually or digitally based on what the surgeon prefers.

The occlusion data, usually obtained from the intraoral scanner, is combined with the CT images using specialized software. This combined information forms the Final Anatomic Representation, which is essential for planning the surgery. In the 3D modeling software, surgeons can simulate the osteotomies, adjusting the segments of the jaw (maxilla, mandible, genioplasty, or a combination) to the required positions. The facial skeleton can be examined from various angles to ensure everything is positioned correctly, and the individual segments can be compared to numerical measurements from chosen cephalometric analyses. After determining the final position, the surgical sequence is confirmed for double-jaw surgeries (whether to tackle the maxilla or mandible first), and attention turns to creating the occlusal guides, both intermediate and final. If needed, guides for marking or cutting the osteotomy can be designed with predictive holes. The choice of using standard, pre-adapted, or custom-made osteosynthesis plates is up to the surgeon's preference. Our experience shows that pre-adapted fixation plates work well, are easy to use, and are suitable for most standard orthognathic situations. Predictive hole placement, as well as occlusal or skeletal-based guides, and custom titanium plates, are likely most beneficial for patients experiencing severe complex asymmetries, significant osteopenia limiting screw placement, or in cases where large gaps from the osteotomy are expected.

One of the key advantages of planning jaw movements in a digital 3D setting is the simultaneous preparation for surgical corrections at both the skeletal and occlusal levels. This is especially useful for patients with severe skeletal asymmetry, like those with craniofacial microsomia, where the deformity often appears much less severe when viewed through a lateral cephalogram. By rotating the 3D model, yaw and cant discrepancies are easier to visualize and adjustments can be readily made. Many potential errors and inaccuracies that arise with traditional model surgeries can be avoided through this digital approach. The success of CAD and 3D printing-assisted orthognathic surgeries has been assessed by comparing postoperative CT-scan results with the predicted positions after surgery, revealing promising outcomes with insignificant linear and angular errors of about 1 millimeter and 1.5 degrees, respectively.

PSI

An alternative to computer navigation during surgery is called Patient-Specific Instrument (PSI).[4] After being utilized in total knee and hip replacement surgeries, as well as for pedicle screw placement and corrective osteotomy, PSI has recently been adapted for use in bone tumor surgeries. This instrument is tailored specifically for each patient, featuring surfaces that match the contours of their bones, which helps guide a saw or drill to the correct areas for resection. The design of these cutting guides is based on 3D images of the patient and Computer-Aided Design (CAD) software. This lets surgeons plan operations according to the unique anatomical details of their patients. The PSI includes three key elements: (1) a contact surface that fits the pre-determined contours made by the surgeons, ensuring the blocks can be placed precisely near the intended resection site without movement; (2) three-planar cutting slots aligned with the specific resection angles set during virtual simulation; and (3) cylindrical guides for inserting Kirschner wires to secure the PSI to the pelvic bone after proper placement. Moreover, PSI features calibration marks that help control the cutting depth, reducing the risk of soft tissue damage by the saw. These marks indicate the distance from the outer edge of the PSI to the deepest bone layer to be cut. Based on the surgeon's instructions regarding the surgical approach, soft tissue nearby, and the planned position and direction for placing the PSI, engineers merge the various PSI components to create a tailored contact interface with the host bone.

Orthopedic surgeons can also practice and become familiar with placing the PSI on 3D-printed bone models before they finalize the design. The end product is manufactured from a thermoplastic material that offers high chemical resistance and tensile strength, making it stable at temperatures up to 130 °C, thus making it suitable for sterilization in the operating room.

During surgery, standard surgical techniques and soft tissue dissection can generally be employed. However, a potential limitation of this method is the necessity for adequate exposure of the bone surface, so the PSI fits correctly without disturbing surrounding soft tissues or vital structures like nerves and blood vessels.

Modern Technology

It is a medical specialty focused on replacing absent body parts to restore normal functions, helping individuals live more comfortably.[5] Essentially, it involves creating and developing artificial body parts and represents a growing area of biomedical engineering that employs engineering concepts to improve the lives of those with disabilities. Prosthetic limbs are designed as dynamic devices controlled by the body's sensations and movements. They can either be bioelectrically powered or operate as static or manually operated mechanical tools for individuals with disabilities. Although our bodies can often fix minor issues, there are situations where self-repair falls short, necessitating external support to manage day-to-day activities. This assistance might come in the form of prosthetics or assistive technologies born from advancements in tech. From the perspective of prosthetics, every cutting-edge design aims to aid individuals by enhancing their capabilities beyond the limitations posed by missing or dysfunctional body parts. Technical designs serve to replace, extend, and rebuild functionalities, complementing the natural abilities we have.

The goal of modern technology is to enable individuals to lead independent lives with minimal reliance on others. While this seems straightforward, restoring functional activities using artificial devices is quite complex, requiring extensive research and thoughtful analysis. When a person loses a limb due to an accident, the process of creating and fitting a customized artificial alternative involves numerous considerations. The external design is not only applied but also requires the individual to undergo training to effectively use it in their daily routines. Achieving functional recovery may involve surgical amputation, followed by healing and rehabilitation. This is accompanied by evaluations and prescriptions to ensure safety and effectiveness. Throughout this journey, patients encounter numerous challenges; however, they often find ways to adapt to these changes, making them secondary to their main concerns. These challenges encompass physical, emotional, and psychological hurdles encountered during the restoration and rehabilitation process.

Bionic hands featuring individually movable fingers are a recent innovation in the market. They represent a significant advancement in the field of prosthetics, both in terms of appearance and functionality, when compared to existing models.

Conclusion

In recent times, the medical field has experienced a groundbreaking shift in how surgical planning is done, largely due to the influence of 3D printing. This technology is changing the way medical experts handle intricate surgeries, much like how X-rays, CT scans, and MRIs revolutionized imaging when they were introduced. By enabling doctors to visualize and engage with patient information in previously unimaginable ways, 3D printing has expanded the horizons of surgical planning. Now, physicians and patients can explore complicated or uncommon cases in three dimensions, enhancing their grasp of the patient's anatomy and the details of their condition. These advancements have resulted in notable improvements such as reduced surgery duration, better outcomes, and a clearer understanding of the situation for patients and their families.

References

1. Alkureishi LWT, Patel PK. Patient-specific planning in head and neck reconstruction including virtual reality. In: Rybicki FJ, Morris JM, Grat GT, eds. *3D Printing at Hospitals and Medical Centers: A Practical Guide for Medical Professionals*. 2nd ed. Cham, Switzerland: Springer Nature Switzerland AG; 2024:188-197.
2. Abdelgaber R, Kilian D, Fiehn H. Bioscaffolding: a new innovative fabrication process. In: Maniruzzaman M, ed. *3D and 4D Printing in Biomedical Applications: Process Engineering and Additive Manufacturing*. Weinheim, Germany: Wiley-VCH Verlag GmbH & Co.; 2019:113-114.
3. Bronzino JD. Biomedical engineering: a historical perspective. In: Enderle JD, Bronzino JD, eds. *Introduction to Biomedical Engineering*. 3rd ed. Burlington, USA: Academic Press, Elsevier; 2012:26-27.
4. Boffano M, Aprato A, Piana R. Indications: didactical use of 3D printing, surgical didactical use, surgical planning, patient information, custom-made prosthesis, spacer and template, external prosthesis, cast. In: Zoccali C, Ruggieri P, Benazzo F, eds. *3D Printing in Bone Surgery*. Cham, Switzerland: Springer Nature Switzerland AG; 2022:1-2.
5. Pandey VK, Paul S. Overview of medical electronics for physically disabled. In: Paul S, ed. *Biomedical Engineering and Its Applications in Healthcare*. Singapore, Singapore: Springer Nature Singapore Pte Ltd; 2019:97-98.