LITERATURE REVIEW

Fundamentals of Stereolithography, an Useful Tool for Diagnosis in Dentistry

Fundamentos de estereolitografía, una herramienta útil para diagnóstico en odontología

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ABSTRACT

Advancements in digital technology and imaging over the last 25 years have permitted the implementation of three-dimensional (3D) modeling protocols in Dentistry. The use of stereolithographic models has progressively replaced traditional milled models and x-rays in the management of craniofacial anomalies and in implant rehabilitation. Diverse advantages can be mentioned, including better visualization of complex anatomical structures and more precise and sophisticated pre-surgical planning, through a simulated insight of the procedures of interest. The aim of this review is to provide essential information about the different applications and limitations of stereolithography, addressed to those general dentists and dental students interested in gaining experience in the reconstructive surgery and implant placement fields.

KEYWORDS

Stereolithography.

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RESUMEN

Los avances en la tecnología digital e imagenología en los pasados 25 años han permitido la implementación de protocolos de modelado en tercera dimensión (3D) en Odontología. El uso de modelos estereolitográficos han remplazado progresivamente a los modelos y rayos X en el manejo de anomalías craneofaciales y en la rehabilitación con implantes. Diversas ventajas pueden ser mencionadas, incluyendo mejor visualización de estructuras anatómicas complejas y más preciso y sofisticado plan prequirúrgico a través de una vista simulada del procedimiento de interés. El objetivo de esta revisión es brindar información básica sobre las aplicaciones y limitaciones de la estereolitografía, dirigida a aquellos dentistas generales y estudiantes de odontología interesados en obtener experiencia en las áreas de cirugía reconstructiva e implantología.

PALABRAS CLAVE

Estereolitografía.

INTRODUCTION

During recent years, advances in computer technology have aided the diagnostic and clinical process during the management of complex craniofacial anomalies, as in cases of orthognathic surgery or oral reconstruction with dental implants. The development of high-resolution computed imaging and modeling technologies, also known as rapid prototyping systems (RPS) is considered extremely useful when diagnosing and planning the treatment of these anomalies. Stereolithography, a relatively new technology, is a RPS designed to create solid and detailed, three-dimensional (3D) physical models that can accurately replicate complex anatomical structures directly from computer data (1, 2). Combining the scanned information of reconstructed Computed tomography (CT) images with an Ultraviolet (UV) laser beam sequentially passed over a photosensitive resin, it is possible to produce, from a two-dimensional (2D) image, a dimensionally accurate 3D anatomical model, as a complete replica of the external surface and internal structures (including soft tissues) in a layer-by-layer fashion (3). This process is accomplished with predictable results quickly, and cost effectively (4-6). Alternatively, the technique of color stereolithography, a recent, improved method, allows for the selective coloring of determined anatomical structures in solid 3D models (7, 8). Other important RPS currently employed in dentistry are: Three dimensional and PolyJet Photopolimerization printing, Fused Deposition Modeling, Digital Light Processing, and Selective Laser Sintering (8).

BRIEF HISTORY

Lithography is the art of reproduction of graphic objects. It comprises different methods, such as photographic reproduction, photosculpture, xerography, microlithography, and modern photolithographic systems (9).

Stereolithography, also denominated laser lithography, is one of the most popular groups of techniques called modern Additive Manufacturing (AM) systems; additive means that the systems build objects in a layer-by-layer manner. AM systems were initially developed and patented by Swainson in 1971 under the name of Photochemical Machining, which exhibited some major problems. One year later, the first commercial CT device was introduced. In 1981, Kodama described an automatic technique for fabricating 3D models in layered, stepped stages employing a photosensitive polymer. Afterward, Herbert designed the layer-by-layer method for replicating solid objects. However, the first investigators to devise modern stereolithography were Hull, in the U.S., and André, in France, who worked nearly simultaneously in the mid 1980s. Since that time, other investigators have contributed to the stereolithographic system with diverse improvements, which have increased its functionality and safe, including Murphy et al., Almquist and Smalley, Marutani, Dev et al., and Murakami, to mention a few (9). This technique was first used in oral and maxillofacial surgery by Brix and Lambrecht in 1985 and 1987 (10) and later by Mankovich et al (11).

TECHNICAL PRINCIPLES

The stereolithographic apparatus consists of a container or bath with a liquid photo-sensitive resin, a model-building platform, and a curing ultraviolet laser. The laser beam moves in sequential cross-sectional increments of 1 mm or less, corresponding to the slice intervals previously specified during the CT formatting procedure. The model is initially designed through a CAD (Computer Assisted Design) software; the CAD data file is converted into slices of known dimensions and transferred to the stereolithographic apparatus for building. The laser beam is computer controlled and directed to the resin and, on contact, polymerizes the surface layer; when this layer is completed, a mechanical platform moves down 1 mm (or less) into the resin bath, carrying and exposing a new layer of resin, and this second layer is then cured and bonded on the previous one, in a sequential fashion. This process is repeated, layer-by- layer, as necessary, until completing the stereolithographic model of the anatomical structures-of-interest (3, 9). About 80% of the total polymerization takes place in the device's container and the remaining 20% is completed by means of a conventional UV curing unit. Stereolithography is considered to provide the greatest accuracy and best surface finish of any RP system (3). Some examples are illustrated in Figures 1 and 2.

Figure 1. Three-dimensional (3D) Computerized axial tomography (CAT) of a pediatric patient (**A**), stereolithography models of the same patient made with C. Acrylic (**B, C**).

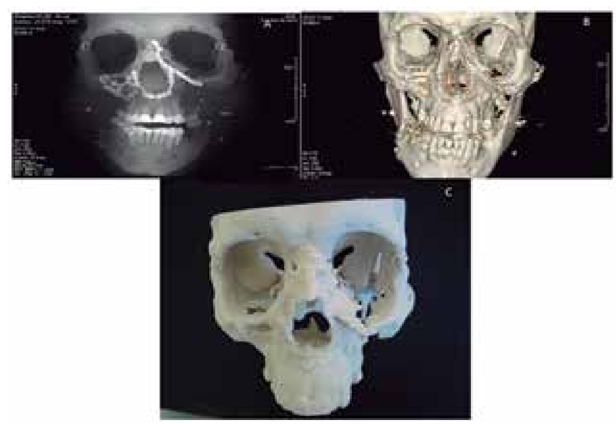

Figure 2. Three-dimensional (3D) Computerized axial tomography (CAT) of a patient and his stereolithography (**A, B**), model made with C. Acrylic (**C**).

PRACTICAL APPLICATIONS OF STEREOLITHOGRAPHY IN DENTISTRY

The use of stereolithographic 3D modeling in dentistry is a valuable support tool when designing a surgical or rehabilitation treatment in two main clinical fields: craniomaxillofacial surgery and prosthetic implantology, although, in recent years, this RP technology has become popular in the orthodontics field (8, 12, 13).

CRANIOMAXILLOFACIAL SURGERY

In the craniomaxillofacial area, stereolithography has become a well-known technique in the processes of diagnosis, pre-operative planning, and surgery (8) simulation, primarily in cases of reconstructive and orthognathic surgery (8, 11).

A. RECONSTRUCTIVE SURGERY

The aims for reconstructive surgery in maxillofacial defects are the maintenance of esthetic, proper functionality, protection of intracranial structures, and facial symmetry, preserving the form and strength of the mandible and maxilla to allow for future dental rehabilitation (2, 11, 13, 14). Trauma, head and neck tumors, and external decompression comprise the main reasons for cranial defects. Surgery simulation is helpful when grafts are positioned from a predetermined donor area, such as scapular bone, fibula, or iliac crest. The length and shape of the graft are estimated through a surgery model, and special plates can be pre-produced to hold the future bone graft, thus facilitating the surgical procedure and saving operating time (11).

Likewise, by coloring tumors with stereolithography, it is possible to visually establish their extension and clarify their relationship to the alveolar nerve in the mandible and hard surrounding structures, such as paranasal sinuses, orbit, infratemporal fossa, and cranial base; thus, the surgical team may estimate the extent of the tumor resection in complex areas (8, 10).

Other applications of stereolithography in reconstructive surgery include management of craniosynostoses –the premature fusion of one or more cranial sutures in newborns and infants, and the subsequent increase in intracranial pressure–, in which the different remodeling surgical techniques can be simulated in the 3D model, thereby reducing operating time substantially (8).

B. ORTHOGNATHIC SURGERY

Facial soft tissues, bone and cartilage skeleton and dentition are three important anatomical groups which play a decisive role in planning orthodontic therapy and orthognathic surgery (12, 15). Furthermore, it is essential to develop accurate recording and replication of the correct maxilla-mandibular position and orientation in relation to the skull (5). Traditionally, these diagnostic issues have been approached by manual or digital tracings based on cephalometric radiographs, in combination with photograph-assisted systems (1, 15, 16).

In complex cases of orthognathic surgery, careful pre-operative assessment of tissue interdependence is necessary, and stereolithographic methods that integrate digital dental casts are available to display the facial skeleton and dentition, rendering improved visualization of these structures (5, 8). 3D Physical models are accurate and predicative anatomical replicas for documentation, analysis, treatment planning, and long-term follow up; furthermore, these models are useful for developing and teaching surgical and orthodontics protocols (15); additionally, the following different purposes may be achieved primarily (16):

- Guiding the treatment to the desired result.
- Giving the patient a reasonable preview of the outcome.
- Serving as a communication tool among the Orthodontist, Surgeon, Pediatric Dentist, and other specialists, and the patient.

PROSTHETIC IMPLANTS

Implant placement has become a routine dental care modality. Dental implant rehabilitation originally required a two-stage process: implant placement itself and, weeks later, abutment connection (7). Currently, due to their osseointegration success rates, implants can be placed immediately at a sole appointment, avoiding additional time, procedures, and costs. Detailed diagnosis and pre-surgical planning are always necessary and must include anatomical as well as prosthetic considerations in order to precisely position the implants that will enable the fabrication of esthetic and functional restorations (17, 18).

Computer-aided designing and fabrication techniques, employing any available implant simulation software, provide a pre-operative view of anatomical structures and restorative information for achieving the ideal implant position. Subsequently, this clinical evidence can be accurately transferred to the patient and guide the pre-prosthetic surgical procedure (17).

In the clinical setting, guided implant surgery applies these digital techniques using drill guides processed by stereolithographic rapid prototyping, on which implants are positioned, with minimal surgical exposure of bone, or even with a flapless approach (6, 19). The advantages of the less invasive flapless surgical procedure include the following (1, 17, 19):

- Shorter duration and facilitation of the surgical procedure.
- Faster and less complicated recovery.
- Enhanced esthetic results.
- Bone grafting procedures are unnecessary.

On the other hand, its main inconveniences comprise the following (1, 17, 19):

- Lack of visibility of anatomic landmarks and vital structures.
- Increased risk for malposed angle or depth of implant placement.
- Decreased ability to contour osseous topography, when needed.
- Inappropriate in cases of insufficient mouth opening.

A guided surgery system essentially consists of a stereolithographic guide with implant mounts for fixture installation, additional guide sleeves for fixation screw installation, drill keys of different heights, and depth-calibrated drills to prepare osteotomies (4). Once the surgical procedure has been planned and after virtual implant placement on the computer, the next step consists of the construction of the stereolithographic surgical guide, which can be positioned predictably. Surgical guides are seated onto the surface anatomy of the physical model and connected to it by a series of small triangles, which are later removed during the finishing process (3). After completion, the guides are sterilized utilizing conventional techniques while preserving their physical properties. In this manner, the guide can be surgically placed directly onto the bone, with a precise fit, without the need for external fixation; then, the osteotomies are performed and the implants are put in place, following a protocol according to the chosen implant system (1, 4).

DISCUSSION

Stereolithography offers the clinician a 3D solid model for analyzing diverse maxillofacial anomalies from numerous observation angles. The spatial realism and tactile abilities of the model afford a multisensorial approach with regard to the surgical procedure or the implant placement, without the surgeon even having meet the patient (13). Combined with the selective coloring of some structures, this digital system provides a clearer panoramic view by delimiting the anatomical site-of-interest and the surrounding tissues (7, 8); therefore, it is very useful for surgical simulation in order to facilitate anatomic reduction and diminish operation invasiveness and time, for example, in instances such as tumor ablation reconstruction (11). Stereolithography is also used to determine the dimensions, location, and form of osteotomies, implants, grafts, fixation devices, etc (8, 11). In conjunction with conventional periapical and panoramic imaging techniques, visual inspection, and clinical palpation, this novel approach offers many significant benefits over traditional procedures, providing more accurate and consistent results (1, 3, 6).

In cases of craniofacial deformities such as hemifacial microsomia and Crouzon syndrome, stereolithographic models are beneficial tools overall in areas of complex anatomy. With a model, the area of greatest bone stock can be visualized prior to the surgery, and the device implanted in the area of maximal bone (10).

Some disadvantages of stereolithography are the increased radiation exposure from the CT scan and the high cost of manufacturing the physical model. However, this technology has proven to be an effective adjunct for diagnosing, planning, and treating craniofacial anomalies, as well as for placing and restoring implants, through the use of surgical guides (6, 17).

CONCLUSIONS

As part of their upgrade process, general dentists must possess a basic knowledge about the applications and advantages of new 3D modeling technologies used in dentistry, such as those of stereolithography, an exceptional support tool for designing surgical treatment and implant placement. Because stereolithography evolutes and becomes more accessible in terms of cost, it should comprise a more common technology among general dentists for obtaining better surgical and restorative results, and, obviously, in favor of their patients.

REFERENCES

1. D'Haese J, Van De Velde T, Komiyama A, Hultin M, De Bruyn H. Accuracy and Complications Using Computer-Designed Stereolithographic Surgical Guides for Oral Rehabilitation by Means of Dental Implants: A Review of the Literature. Clin Implant Dent Relat Res. 2012; 14(3):321-35.
2. Chia HN, Wu BM. Recent advances in 3D printing of biomaterials. J Biol Eng. 2015; 9:4.
3. Dandekeri SS, Sowmya MK, Bhandary S. Stereolithographic surgical template: a review. J Clin Diagn Res. 2013; 7(9):2093-5.
4. Sammartino G, Della Valle A, Marenzi G, Gerbino S, Martorelli M, di Lauro AE, et al. Stereolithography in oral implantology: a comparison of surgical guides. Implant Dent. 2004; 13(2):133-9.
5. Terajima M, Yanagita N, Ozeki K, Hoshino Y, Mori N, Goto TK, et al. Three-dimensional analysis system for orthognathic surgery patients with jaw deformities. Am J Orthod Dentofacial Orthop. 2008; 134(1):100-11.
6. Farley NE, Kennedy K, McGlumphy EA, Clelland NL. Split-mouth comparison of the accuracy of computer-generated and conventional surgical guides. Int J Oral Maxillofac Implants. 2013; 28(2):563-72.
7. Balshi SF, Wolfinger GJ, Balshi TJ. Surgical planning and prosthesis construction using computed tomography, CAD/CAM

technology, and the Internet for immediate loading of dental implants. J Esthet Restor Dent. 2006; 18(6):312-23.
8. Torabi K, Farjood E, Hamedani S. Rapid Prototyping Technologies and their Applications in Prosthodontics, a Review of Literature. J Dent. 2015;16(1):1-9.
9. Bártolo P. Stereolithography United States: Springer; 2011.
10. Winder J, Bibb R. Medical rapid prototyping technologies: state of the art and current limitations for application in oral and maxillofacial surgery. J Oral Maxillofac Surg. 2005; 63(7):1006-15.
11. Hidalgo HM, Romo GW, Estolano RT. Stereolithography: a method for planning the surgical correction of the hypertelorism. J Craniofac Surg. 2009; 20(5):1473-7.
12. Plooij JM, Maal TJJ, Haers P, Borstlap WA, Kuijpers-Jagtman AM, Bergé SJ. Digital three-dimensional image fusion processes for planning and evaluating orthodontics and orthognathic surgery. A systematic review. Int J Oral Maxillofac Surg. 2011; 40(4):341-52.
13. Groth C, Kravitz ND, Jones PE, Graham JW, Redmond WR. Three-dimensional printing technology. J Clin Orthod. 2014; 48(8):475-85.
14. Cohen A, Laviv A, Berman P, Nashef R, Abu-Tair J. Mandibular reconstruction using stereolithographic 3-dimensional printing modeling technology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009; 108(5):661-6.
15. Ayoub AF, Rehab M, O'Neil M, Khambay B, Ju X, Barbenel J, et al. A novel approach for planning orthognathic surgery: the integration of dental casts into three-dimensional printed mandibular models. Int J Oral Maxillofac Surg. 2014; 43(4):454-9.
16. Schendel SA, Lane C. 3D Orthognathic Surgery Simulation Using Image Fusion. Semin Orthod. 2009; 15(1):48-56.
17. Turbush SK, Turkyilmaz I. Accuracy of three different types of stereolithographic surgical guide in implant placement: an in vitro study. J Prosthet Dent. 2012; 108(3):181-8.
18. Cassetta M, Giansanti M, Di Mambro A, Calasso S, Barbato E. Accuracy of two stereolithographic surgical templates: a retrospective study. Clin Implant Dent Relat Res. 2013; 15(3):448-59.
19. Ersoy AE, Turkyilmaz I, Ozan O, McGlumphy EA. Reliability of implant placement with stereolithographic surgical guides generated from computed tomography: clinical data from 94 implants. J Periodontol. 2008; 79(8):1339-45.