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Review Article

Dentistry Section

Three-dimensional Computer-aided Design System used in Orthodontics and Orthognathic Surgery for Diagnosis and Treatment Planning- A Narrative Review

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ABSTRACT

Three dimensional advancements in technology have made a profound impact on various fields, and dentistry, particularly the branch of orthodontics and orthognathic surgeries, which has not been exempt from this transformative influence. Among the cutting-edge technologies that have gained significant traction is Three-Dimensional (3D) printing, which has found its initial applications in orthodontics for producing dental casts. By integrating intraoral scanners, dentists now possess the remarkable ability to obtain dental impressions without subjecting patients to the discomfort associated with traditional methods. Furthermore, 3D planning techniques have emerged as a pivotal element in orthodontics, especially when striving for optimal aesthetic and occlusal outcomes. Precise treatment planning plays a vital role in ensuring successful orthognathic surgeries and other orthodontic interventions. The utilisation of 3D planning techniques facilitates the gathering of comprehensive data, thereby achieving two main objectives: an accurate diagnosis of the dentoskeletal deformity and the formulation of a treatment plan that can be faithfully replicated during the clinical procedure. Even 3D imaging technology, such as Computed Tomography (CT) and Cone Beam Computed Tomography (CBCT), has become an indispensable tool in dentistry. These imaging techniques provide volumetric images of a patient's facial anatomy, enabling the transformation of intricate details into precise 3D representations of the craniofacial skeleton and soft tissue layers. Consequently, this progress has led to the development of computerised resources dedicated to preoperative planning and the fabrication of surgical splints. The integration of advanced technologies, including 3D printing, 3D planning techniques, and 3D imaging technology, has revolutionised orthodontics, providing dentists with precise tools for accurate diagnosis, treatment planning, and ultimately, enhanced patient care. As this field continues to progress, the potential for further advancements and innovative applications utilising artificial intelligence becomes an exciting prospect in the ever-evolving landscape of modern dentistry.

Keywords: Computer-assisted surgeries, Computer-generated, Imaging, Printing

INTRODUCTION

Advanced technology has significantly impacted in dentistry, branch of orthodontics. In the dynamic landscape of the manufacturing industry, one cutting-edge technology that truly stands out is 3D printing. One of its initial applications in orthodontics was for producing dental casts. By incorporating intraoral scanners, dentists gained the ability to take dental impressions without subjecting patients to the discomfort caused by traditional methods. The utilisation of intraoral scanners led to the creation of 3D images, which could then be printed [1-4].

To meet the expectations of successful orthognathic surgery, precise treatment planning is a crucial element, especially when employing 3D planning techniques. It a significant role in achieving optimal aesthetic and occlusal outcomes [5]. Preoperative planning involves gathering data to achieve two main objectives: making an accurate diagnosis of the dentoskeletal deformity and devising a treatment plan that can be replicated accurately in the clinical procedure [6]. Conventionally, preoperative information has been gathered from various sources, including physical examinations, lateral teleradiography, dental casts, face bow, articulators, and photographs. Computed Tomography (CT) and Cone Beam Computed Tomography (CBCT) have been utilised to generate volumetric images of a patient's facial anatomy. By employing a series of computerised mathematical algorithms, the aforementioned details could be transformed to 3D representations of a patient's craniofacial skeleton and the accompanying soft tissue layers [7,8]. The progression of 3D imaging technology has facilitated the emergence of projects dedicated to offering novel computerised resources for preoperative planning and the fabrication of surgical splints [9]. Furthermore, these 3D images can now be interacted with, allowing for simulations of the proposed surgery and predictions concerning postoperative results for both soft and hard tissues.

Taking advantage of Computer-aided Design/Computer-aided Manufacturing (CAD/CAM) systems in dentistry, specifically in prosthodontics, has closely followed the emergence of CAD/CAM systems that employ multiple 3D measuring techniques in the industrial sector. Notably, laser scanning technology has been utilised in dentistry to create a 3D dental model analysis system that has been explored for its clinical viability in orthodontics [10]. However, during the clinical application of this system, certain issues have come to light. The initial issue concerns the system's incapacity to precisely measure areas beneath overhangs, particularly the anterior oral vestibule in dental models with significant labio-lingual tipping of anterior teeth. The second issue involves the need for software capable of automatically aligning single tooth for computer to simulate the diagnostic cast [10]. The primary objective of the present review was to assess the value of 3D printing in dentistry and to identify the factors that drive the development of applications utilising 3D printing technology.

Historical Aspects

In 1986, Hull C made a groundbreaking contribution by introducing the first 3D printing technology, which revolutionised the manufacturing sector and gave rise to a variety of production methods utilised across various industries [11,12]. Hull's pioneering work helped in the creation and development of a 3D printing method known as Stereolithography (SLA), for which he obtained a patent in the same year. Additionally, in 1990, Scott Crump was granted a patent for "Fused Deposition Modelling (FDM)", another significant 3D printing technology. Since then, 3D printing has made remarkable strides and is now recognised as an advanced manufacturing technology, often referred to as additive manufacturing [13]. It employs standardised materials and specified automatic processes to create customised 3D objects that depend on digital CAD models. Rapid prototyping can be done, and it has become popular in the manufacturing, engineering, design, and industrial sectors for about thirty years. The innovation of new materials, printing technology, and equipment related to 3D printing is expected to significantly transform conventional approaches to experimentation and instruction.

In the medical branch, 3D printing is often used in specialities including traumatology, cardiology, neurology, plastic surgery, and Craniomaxillofacial (CMF) surgery for surgical planning, personalised surgical equipment, and patient-physician communication [14].

Revolutionising Dentistry: The Unseen Dimension-Unleashing the Power of 3D Imaging in Oral and Maxillofacial Surgery

Numerous software programmes are now accessible for 3D planning and the production of surgical splints utilising CAD/CAM technology [15]. The adoption of CAD/CAM surgical splints established a distinct clinical methodology, setting it apart from ordinary dental practices. This article focuses on the concept of 3D planning, made possible by the capability to practice in a computerised 3D environment. Shifting from 2D to 3D imaging brings additional information to surgeons and patients that cannot be obtained solely from lateral teleradiography. The interactive nature of the software programme allows surgeons to engage with 3D images, and all data can be conveniently secured as computer files, streamlining data management. Sharing preoperative information with colleagues worldwide is made quick and effortless through internet connectivity.

Though various software programmes have undergone scrutiny in research studies, each of them cannot store preoperative data efficiently in a centralised location and allowing the approach to images that facilitate simulated surgery, the drawing of osteotomy lines, 3D treatment planning with postoperative outcome predictions and construction of surgical splints by CAD/CAM technology [16].

Digital Orthodontics

In orthodontics, patient information can be collected through intraoral, lab, or even CBCT optical scanning for digital treatment planning. Subsequently, wires can be robotically bent or appliances can be fabricated [17]. This technology digitally realigns the patient's teeth, creating a sequence of 3D printed models used to produce "aligners," that gradually straighten the teeth over a period of several months to years. For example, utilising different materials for printing involves orthodontic CAD software to create 3D printed indirect bracket bonding splints, ensuring precise bracket implantation [18]. When data is transferred via a network and software is employed for smile planning, significant time-saving opportunities arise. Patient information can be secured digitally and printed solely whenever necessary, thus reducing the need for physical storage space [19].

Unraveling the Boundless Possibilities of 3D Printing in Orthodontic Dentistry and Oral and Maxillofacial Surgery

The most basic implementation of 3D printing in surgery was the creation of a "study model" anatomically, known as medical modelling [20]. In last few years, dentistry has revealed a significant development in accessibility to this technology, with CBCT becoming more prevalent in dental offices, revolutionising diagnosis and treatment in endodontic and implant dentistry [21,22]. Prior to surgery, precise replication of patient's jaws can be created using volumetric data transmitted to a 3D printer through CT scans, which are readily available and offer comparable data, making them popular in a hospital setting [23-25]. While the concept of "surgery first" may save time in some cases, it may lead to a loss of stability in the long run, which cannot be compensated for. The idea of the "surgery-first approach" was initially presented by Nagasaka H et al., [26]. A decade ago, making it less novel than commonly believed. Although, speculative fiction might be considered innovative or new in certain regions, especially in the Asian region, the surgery-first approach is promoted and employed selectively. However, a comprehensive review and meta-analysis have demonstrated that following extensive clinical observation, the orthognathic-first approach can offer greater long-term postsurgical stability compared to the surgery-first approach. This allows for a surgical strategy to be planned or practiced before the actual surgery, especially in cases involving complicated, unique, or unfamiliar anatomy [27,28]. As a result, significant progress has been made in developing new surgical methods and techniques, leading to quicker, less invasive, and more predictable surgeries. Additionally, the utilisation of traditional laboratory techniques or 3D printing technology has enabled the creation of drilling or cutting guides [29,30]. While in many surgical applications, the margin of error is unlikely to have clinical significance, the accuracy of medical modelling is often affected by the original imaging technology and like the artifacts caused by existence of metal objects like teeth, restorations, or implants. Therefore, printing medical models with sterile materials like nylon becomes essential for their usage in operating rooms. Various 3D printers and printing materials can be employed to create these medical models [31]. In parallel with advancements in 3D scanning technologies like CBCT, intraoral, and extraoral scanning, as well as other CAD/CAM technologies, 3D printing has quickly progressed in the branch of maxillofacial surgery [32,33]. The application of 3D printing technology has contributed to the improvement of symmetry and functional outcomes in Craniomaxillofacial (CMF) plastic surgery procedures [34]. Detailed descriptions of applications in the CMF region, involving implants, occlusal splints, and surgical guidance, have been provided by Jacobs CA and Lin AY [35].

The occlusal splint, a reversible therapeutic tool, is an intraoral appliance utilised to address various temporomandibular joint issues by modifying the occlusal connection within the maxillary and mandibular dental arches [36]. The conventional manufacturing approach for creating occlusal splints involves costly interocclusal wax recording and alginate imprints for study models' upper and lower dentitions. This method carries a risk of errors during casting or imprint procedures [37]. Furthermore, machining occlusal splints requires a significant amount of materials and time, and their form prevents efficient nesting within a resin blank, resulting in considerable waste. Milling equipment, particularly those made of hard materials, is significantly worn down due to this technique [38]. However, when occlusal splints are produced using 3D printing, the need for framework support is eliminated. This offers the advantage of simultaneous production of multiple splints, leading to improved manufacturing efficiency and cost savings [39]. To sum up, occlusal splints serve as an intraoral device with clinical benefits that can be regained, effectively addressing temporomandibular joint issues by altering the occlusal connection within the maxilla and mandible [39]. Nonetheless, it should be noted that the antistress and antiaging properties of 3D printing materials are inferior to those of conventional or milling resin materials, potentially affecting their long-term use [38-40]. In a study by Lutz AM et al., occlusal splints created through 3D printing were compared to those machined or traditionally made. The 3D-printed occlusal splints exhibited lesser wearing and bending resistance than the other two techniques [38]. The standard manufacturing process for producing occlusal splints involves interocclusal wax occlusal registration and alginate impressions of maxillary and the mandibular dentitions of study models [41].

Clinical Implications

A relatively new development in dentistry has witnessed significant advancements with the introduction of various digital methods in orthodontics. These digital techniques have gradually transformed the conventional orthodontic practices. A growing trend in orthodontics involves the adoption of virtual technology to replace electronic records from hard-copies, leading to the emergence of a "digital" patient approach. This digital approach is utilised for diagnosis, treatment planning, observing treatment progress and evaluating outcomes [42-44]. Within orthodontics, digital scanning has found a multitude of applications [45-48]. Among the crucial and time-consuming procedures in dental practice is making accurate dental impressions. During this process, achieving precise reproduction of the intraoral condition is of utmost importance. The practice of intraoral scanners to achieve digital models has shown promising results in terms of validity, reliability, and reproducibility. These digital models allow for accurate dental measurements, particularly for orthodontic purposes [49].

In all fields of dentistry, including orthodontics, the success and comfort of clinical procedures largely depend on their duration. Shorter procedure times are key to ensuring a positive experience for both patients and dentists. However, when examining scanning times in published studies, it becomes evident that there is significant variation among them. To maintain objectivity, it is essential to correlate the similar malocclusions in patients with comparable degrees of tolerance. The duration of the scanning procedure in intraoral situations can be influenced by various factors, including rotations of teeth and varying behaviour patterns of the patients. Additionally, age is frequently correlated with a patient's level of tolerance as children and adolescents display lower levels of tolerance in this type of assessment. As a result it is crucial to carry out studies with people from various age groups, consistently including adults in the research. Intraoral scanners seem to offer a higher level of comfort to patients. Most studies analyse the feeling of comfort using Visual Analogue Scale (VAS). The VAS serves as a valuable tool for evaluating patients' perspectives, particularly with computerised versions like Visual Analogue Scale for Anxiety (VAS-A), offering additional benefits such as streamlined and precise data collection and analysis [50].

The 3D CT, the jaw abnormalities on models have the capacity to be very useful in prosthodontics. It has been established that optical scanner that create 3D computer models provide enough system accuracy for therapeutic use. In order to create models of an edentulous maxilla, Boldt F et al., employed photo-optical, laser-optical, CT-based, and tactile techniques [51]. Outcomes were then contrasted with those of a typical plaster cast. According to Barone S et al., the optical scanner's accuracy and resolution provide for the best reconstruction of oral soft tissues and tooth crown surfaces as compared to CBCT scanning [52]. There has been published research about precision of intraoral scans and digital impressions. These studies present scans of individual restorations, groups of teeth in a series, quadrants, and complete arches. Motohashi N and Kuroda T used scanning dental research models along a slit-ray laser and established a 3D computer-aided system, and Lu P et al., established a dental model 3D digitisation system using laser scanning [53,54]. Hirogaki Y et al., compared the measurements recorded on actual castings to those taken on computer-reconstructed models after scanning dental casts with a line laser scanner [55]. The difference was 0.3 mm or less, which was consistent with the authors' findings. Dental volumetric analysis using CBCT equipment and software has been the subject of several quantitative research studies. A prior study demonstrated good agreement between outcomes that were similar to the present study when the extraction socket volumes were computed using numbers obtained from the CBCT image segmentation process and the Archimedes method. One of the few clinical uses of 3D surface models gained from CBCT is the creation from actual study models of the jaws with the help of SLA technology. Other uses include preoperative implant planning, jaw evaluation, and estimation of the amount of bone required for orthognathic surgery [56,57]. The precision about dental impression and cast, which may deteriorate over time and become inconsistent depending on a number of circumstances, limits the accuracy of a digital model. In actuality, a number of patient scanning and data reconstruction factors have an arbitrary impact on the CBCT image quality. All of these variables could have an impact on the 3D surface models, which are created from CBCT pictures [58,59]. In comparison to the maxilla, the mandible's threshold value fluctuated less. Bone dehiscence and fenestration appear in the 3D model as a result of the maxilla's variably thin cortical bone, specifically inside the region of a palate and tuberosity. The cortical bone of jaw, is adequately thick to maintain a consistent resorption profile across the entire bone surface.

CONCLUSION(S)

Every clinician is concerned about the outcome and long-term stability of post-treatment patients. For the effectiveness and long-term retentivity of combined orthodontic and orthognathic treatment, CMF surgery precision is also necessary in addition to excellent pre and postsurgical orthodontic treatment. Computer-aided surgical simulation may be used to produce a 3D composite skull model that precisely represents patient's facial soft tissue, dentition, and CMF skeleton. The aforementioned details are all used to reconstruct an anatomical orientation frame in order to execute orthognathic surgical stimulation. Therefore, computer-aided surgical simulation is a reliable way for linking combined orthodontic and orthognathic treatment surgery and orthodontic treatment. As a result, combined orthodontic and orthognathic treatment will be having substantial results on the appearance of patients, as well as their craniofacial function and quality of life over the course of their lifespan. The need for combined orthodontic and orthognathic treatment selection is critical, especially when considering the trend in the approach.

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