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Review Article

From Scan to Smile: The Digital Evolution of Implant Dentistry – A Narrative Review

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Abstract

Digital planning in implant dentistry has transformed the design and placement of dental implants. This innovative approach utilizes cutting-edge technologies like computed tomography, intraoral scanning, and computer-aided design software to develop a detailed and customized treatment plan for each patient. By obtaining three-dimensional images of the patient›s oral cavity, dental professionals can accurately assess the bone structure and surrounding areas, allowing them to pinpoint potential challenges and advantages. This leads to safer and more efficient surgeries while reducing the risk of complications. Additionally, digital planning facilitates the creation of customized surgical guides, ensuring precise implant placement. This advancement also enhances patient experience by decreasing postoperative discomfort and accelerating the recovery process. In conclusion, digital planning in implant dentistry enhances the accuracy, efficiency, and safety of implant procedures, resulting in healthier, more satisfied smiles.

Keywords: Computed Tomography (CT), Computer-Aided Design (CAD), Digital Planning, Dental Implants, Implant dentistry and Intraoral scanning.

1. Introduction

Technological advancements in implant dentistry have transformed the planning and execution of dental implant procedures. The introduction of digital planning has brought numerous benefits that enhance the accuracy, efficiency, and predictability of outcomes. This study aims to examine digital planning in implant dentistry, focusing on its key applications, advantages, and challenges [1].

Digital planning for dental implants incorporates imaging technologies like computed tomography, digital radiography, and 3D printing, alongside specialized software, to conduct a thorough analysis of the patient's anatomy and accurately plan implant placement. This method has proven essential for achieving more predictable results and minimizing complications during surgery [2].

The implementation of digital planning in implant dentistry provides several clinical benefits. With three-dimensional visualization of the patient's anatomy, potential obstacles, such as critical anatomical structures, can be identified, allowing for optimal positioning and sizing of the implants [3].

Virtual simulations of the procedure enable anticipation of possible complications and facilitate prior adjustments, resulting in enhanced safety and effectiveness [4].

Additionally, digital planning improves communication among the professionals involved in the treatment process. By sharing digital resources like 3D models and treatment plans, better integration between surgeons, implantologists, and lab technicians is achieved, optimizing collaboration and ensuring more predictable and aesthetically pleasing results [5].

Nevertheless, it is important to recognize the challenges associated with implementing digital planning in implant dentistry. The acquisition of specialized equipment and software entails significant investment, as well as the need for proper training and qualification of professionals [6].

Furthermore, effectively integrating all stages of the digital workflow—from image acquisition to executing the treatment plan—remains a challenge that must be addressed [7].

In conclusion, digital planning in implant dentistry marks a major advancement in the field, allowing for improved precision, efficiency, and predictability in procedures. Utilizing imaging technologies and specialized software enables detailed analysis of patient anatomy, safer planning for implant placement, and enhanced communication among treatment professionals. Despite the challenges, digital planning is poised to become an essential practice in contemporary implant dentistry. The aim of this paper was to conduct a literature review on digital planning in this field.

2. Discussion

2.1. Introduction to Guided Implant Surgery

Guided implant surgery started to emerge globally around 1988, when Columbia Scientific introduced the scientific community to 3D dental software. This innovative technology utilized computed tomography images to convert axial slices into reconstructed cross-sectional images of the alveolar ridges for diagnostic purposes [8].

A few years later, in 1991, new software was developed that enabled the positioning of graphic images of implants within the cross-sectional images obtained from computed tomography scans. In 1993, Columbia Scientific launched Simplant, allowing for the precise placement of virtual implants with accurate dimensions in cross-sectional, axial, and panoramic views derived from computed tomography. Simplant 6 further enhanced this software by incorporating 3D rendering of the reconstructed images. In 2002, Materialise acquired Columbia Scientific and introduced technology for performing osteotomies with precise depth and directional perforations using a surgical guide. This breakthrough led various software, rapid prototyping, and implant companies to develop their own software and surgical guide protocols for guided implant placement [9].

2.2. Digital Workflow

The digital workflow in implant dentistry can be broken down into six stages: 1. patient evaluation; 2. data collection; 3. data manipulation; 4. virtual implant planning; 5. guide and prosthesis fabrication; 6. surgery execution and immediate provisional prosthesis installation. It is important to note that different virtual implant planning software may exhibit variations in their digital workflows [10].

2.3. Computed Tomography (CT)

Recent technological advancements in radiology have highlighted the significance of computed tomography for various applications. This examination method has evolved substantially, allowing for enhanced certainty in results and producing high-quality images without overlap or distortion of structures. Recently, there has been a marked increase in using techniques that utilize X-ray tubes as radiation sources, which emit lower doses compared to traditional tomography, along with television monitoring systems and image digitization equipment [11].

Cone Beam Computed Tomography (CBCT) operates on a technology that employs a cone-shaped X-ray beam paired with a two-dimensional image receptor, rotating between 180º to 360º around the area of interest. This method provides practical advantages and excellent image clarity [12].

Analyzing the use of CBCT in dentistry reveals that it allows for the acquisition of highly accurate 3D images of hard tissue structures, making it one of the most vital diagnostic imaging techniques to emerge in recent years. This technique captures the necessary information for image formation in a single rotation around the area of interest, enabling extensive data collection from smaller areas or the entire skull. After imaging, the software can reproduce images with outstanding spatial resolution of all structures at a proportional scale (1:1), maintaining near-real size in axial, paraxial, coronal, and sagittal planes [13].

In implant dentistry, CBCT is crucial for analyzing craniofacial anatomy, planning implant size and thickness, verifying maxillary transverse dimensions, assessing the feasibility of immediate implant placement, and visualizing bone wall morphology. It also plays a fundamental role in evaluating the density of mineralized bone tissue, fabricating placement guides for mini-implant positioning, and creating static surgical guides. Additionally, CBCT is recommended to prevent complications with previously placed implants, measure vertical, horizontal, and oblique alveolar bone loss, assess the necessity of sinus grafting, and analyze potential autogenous bone donor sites [14].

A literature review indicates that CBCT is highly effective for advanced planning and achieving improved diagnoses. As understanding of tomography has progressed, dental care and its applications have expanded, benefiting both professionals and patients. Silva et al. assert that implant dentistry is one of the fields that most requires CBCT, as it demands precise anatomical diagnosis. This technique has significantly improved the assessment of patients and facilitated the development of more accurate procedural plans. With CBCT, clearer images can be obtained of specific areas for dental implant placement, providing operators with a comprehensive three-dimensional view of the alveolar ridges [15].

2.4. Scanning Techniques

Scanning is a method for digitizing real objects using images generated by light or, originally, by contact. Images can be captured from intraoral or bench scanners by reflecting light or through physical contact [16].

Intraoral scanning of individual teeth has been possible for some time, although it initially required the application of titanium dioxide powder due to the translucency of enamel and dentin, which enhances opacity for effective scanning. However, modern scanners can produce complete digital arches by "stitching" images together without the need for powder [17].

When scanning metallic components, such as mini-implants, a spray is necessary to opacify them and prevent the metal's shine from causing scanning inaccuracies. The decision to use specific scanners generally depends on the quality of the generated image, scanning duration, sample preparation requirements, scanner size, internal volume, scanning methodology, and the optical technology employed, as well as the method of capturing the patient's data, whether from a plaster model, molding, or intraoral impression [18].

Each scanner comprises three primary components: a wireless mobile workstation for data input, a computer monitor for entering prescriptions, approving scans, and reviewing digital files, and a handheld wand to gather digitized data from the patient's mouth. Surface data points are collected as laser light or white light energy is projected from the wand onto the object and reflected back to a sensor or camera within the wand. Utilizing 17 algorithms, the scanner takes tens or hundreds of thousands of measurements per inch, resulting in a 3D representation of the object's shape. The technology in the wand for capturing surface data influences the scanning speed, resolution, and accuracy [19].

The scanning process typically starts in the lower left quadrant, with the operator moving the wand from posterior to anterior. The operator then moves to the upper arch, bite, and palate. Scanning can be paused and resumed at any time, allowing for retracing steps to recapture areas with missing data [20].

The scanner requires approximately 1.5 minutes to process and stitch together all individual images. Following this "View" process, any void larger than 1.25 mm is highlighted by the software with red circles, prompting additional captures to fill in the missing data. Another "View" round is necessary to integrate the new captures, repeated as needed [21].

The pioneering work and development of scanners are noted in the lessons of Kravitz et al [22].

2.5. 3D Printing

Digital models can be utilized to create resin prototypes for various applications. The most prevalent rapid prototyping techniques include Stereolithography (SLA), Selective Laser Sintering (SLS), 3D Printing, Fused Deposition Modeling (FDM), and Thermojet. All of these techniques are based on the principle of layer-by-layer material addition, corresponding to the axial "slices" of the examined anatomical structure [23].

Intraoral scanners generate digital files of objects in the standard tessellation language (STL), allowing for the transfer of a 3D model from a computer screen to a global format compatible with 3D printing. The STL file format was developed in 1987 by Charles Hall to support his 3D stereolithography printer [24].

Computer-Aided Design and Manufacturing (CAD/CAM) software is employed to process the file and prepare it for printing. It divides the object into small layers, ranging from 16 to 300 microns, known as "build layers." The time needed to produce 3D models depends on the vertical height and the number of layers printed, rather than the number of models being produced [25].

The printing process involves preparatory steps such as removing excess data. The operator must repair all holes and polygons (comprising hundreds of thousands of triangles, some of which need to be eliminated or fixed), adjust the base height, hollow out the interior, and print with patient identification. As the software provided with the 3D printer may not handle all these manipulations, CAD/CAM technology is utilized for designing and producing prosthetic components using 3D printers or milling machines. The process begins with mapping the patient's arch and capturing all details using an intraoral scanner. Subsequently, CAD is used to design the 3D digital structure of the part, and CAM generates the digital language that the printer or milling machine uses to manufacture the component. This integration allows for the rapid creation of various models, such as crowns, bridges, and restorations, with superior quality compared to traditionally produced models [26].

3. Conclusion

The integration of virtual planning and guided surgery in implantology represents a dynamic and continually evolving approach that unites dental professionals in pursuit of more predictable and optimized solutions for rehabilitating patients with tooth loss. In this context, radiology plays a crucial role, providing a solid foundation for a comprehensive multidisciplinary perspective. It aids in the selection of the most appropriate digital and imaging resources tailored to the specific needs of each clinical case.

The application of digital technologies and the utilization of surgical guides have revolutionized implantology, enabling more precise and less invasive procedures. These advanced tools allow professionals to plan with greater detail, thoroughly analyze the patient's anatomy, and ultimately enhance the quality of life for patients undergoing rehabilitation with dental implants.

As technology continues to advance and research in this field expands, implantology is poised to reap further benefits from these developments, leading to increasingly predictable and satisfactory outcomes for patients. This progression ensures the quality and effectiveness of treatments. Consequently, the integration of virtual planning, guided surgery, and radiology in implantology represents a promising trend that is shaping the future of this dental specialty and enhancing

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As technology continues to advance and research in this field expands, implantology is poised to reap further benefits from these developments, leading to increasingly predictable and satisfactory outcomes for patients. This progression ensures the quality and effectiveness of treatments. Consequently, the integration of virtual planning, guided surgery, and radiology in implantology represents a promising trend that is shaping the future of this dental specialty and enhancing clinical practice as a whole.

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