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Scientific Letters

Research Article

The Use of Artificial Intelligence to Create a Virtual Patient for Oral and Maxillofacial Surgical Planning

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Abstract: The advancement of digital image acquisition technologies in dentistry has facilitated the creation of virtual patients through the integration of two- and three-dimensional (2D and 3D) images within digital platforms. These images, sourced from technologies such as Cone Beam Computed Tomography (CBCT), intraoral scanners (IOS), and 3D facial scanners, can be aligned and merged to comprehensively assess the bone structure, gingival and soft tissues, and the dentition. Additionally, 2D clinical photographs are incorporated into the digital project, enhancing aesthetic analysis and planning. Artificial intelligence (AI) algorithms can also be used to enhance and facilitate 3D image alignment. However, detailed information on digital workflows to work with virtual patients for dental and maxillofacial treatment planning is lacking in the literature. The purpose of this article is to describe a technique to create a virtual patient to assess the relationship between the patient's soft and hard tissues with the optional use of AI to enhance the quality of 3D-reconstructed models from CBCT. Within the limitations of this study, the technique described herein is suggested to be useful for prosthetically-driven treatment planning of surgical procedures such as crown lengthening, bone grafts and dental implant placement.

Keywords: computer-aided design; computer-aided manufacturing; dental implant; dental prosthesis

Received: 12 March 2024; Accepted: 12 April 2024; Published: 18 April 2024

Introduction

The concept of a prosthetically-driven treatment plan is fundamental in the field of restorative dentistry. This is a reverse planning strategy that initiates by designing the final dental restoration, followed by planning any necessary surgical and clinical procedures. Such method is crucial to ensuring that the restorative outcomes are aligned with functional and aesthetic objectives, as well as with satisfactory biological and health conditions of oral and maxillofacial hard and soft tissues [1-4].

The integrity and functionality of soft tissues are particularly critical for the success and longevity of various dental interventions, including bone grafting, implant placement, as well as dental restorations and prostheses [5-7]. In this context, the consideration of the area with supracrestal tissue attachment in the treatment plan is essential to maintain periodontal health in restorative dentistry. This area, formerly known as biological width, comprehends the height of the connective tissue and epithelial attachment above the alveolar bone crest. Evidence suggests that violating the supracrestal tissue attachment can lead to inflammatory responses, resulting in bone loss and periodontal breakdown. Therefore, its assessment is a fundamental step of restorative treatment planning [8,9].

Dental treatment planning has undergone a transformation with the integration of new technologies using three-dimensional (3D) information from Intraoral Scans (IOS), along with volumetric data of hard tissues from Cone Beam Computed Tomography (CBCT) [10-12]. IOS employs digital devices to capture direct optical impressions of the intraoral anatomy, offering high-resolution details of teeth and soft tissue structures. The resulting scanning files are essential for precise prosthodontic and periodontal planning [3,13,14]. Facial scans and 2D clinical photographs can also be imported into the same computer-aided design (CAD) projects to enhance aesthetic analyses during treatment planning [15,16].

CBCT, a 3D radiographic imaging technique, delivers detailed volumetric data of hard tissues, such as the alveolar bone and the teeth, and has also been used to assess periodontal dimensions, such as the supracrestal tissue attachment [2,17-19]. The integration of data from clinical photographs, IOS, facial scans, and CBCT enables the creation of a virtual patient – a comprehensive 3D digital model that accurately mirrors the patient's oral anatomy [20,21]. This approach not only enhances diagnostics, but also the predictability of clinical outcomes in prosthodontics, oral surgery, and periodontal care [15,22]. Furthermore, this digital simulation facilitates clearer communication with patients by demonstrating potential outcomes, thus aligning expectations, and increasing patient engagement [21,22].

Despite the advantages of creating a virtual patient for dental treatment planning, the integration and alignment of 3D imaging, such as CBCT and IOS, present significant challenges, such as the presence of artifacts from 3D reconstructions and impaired accuracy during image superimposition [20-22]. The complexity in superimposing virtual files arises from the differing formats, resolutions, and perspectives provided by each imaging modality [20-22].

To address the challenges related to the integration and alignment of files of 3D images such as CBCT and IOS, several algorithms of artificial intelligence (AI) have been developed. In this context, AI allows for automatizing the superimposition of these files. This automation not only reduces time and effort in the creation of a virtual patient, but also enables the identification and measurement of the supracrestal tissue attachment space. Such capability could be key to developing treatment plans that consider periodontal health. However, information on techniques using AI to enhance accuracy of virtual patients in medicine and dentistry is lacking in the literature [23,24].

Thus, this study aims to introduce a technique for creating a virtual patient for periodontal assessment, with the possibility of using AI to integrate CBCT and IOS into a comprehensive 3D virtual patient model. This would facilitate the analysis of various critical measurements, including the supracrestal tissue attachment, enabling the prediction of essential outcomes, such as the maintenance of periodontal health.

Materials and Methods

Clinical case

A clinical case of oral rehabilitation was used retrospectively to illustrate the present technique. An informed consent was signed by the patient to allow the authors to use the files previously obtained during treatment planning in this article. The study of this case was previously approved by the ethical committee of the University of São Paulo, São Paulo, Brazil (protocol number: 33337420.0.0000.0075).

Technique for alignment and superimposition of CBCT and IOS datasets

First, intraoral scans (TRIOS 5, 3Shape A/S) of maxillary and mandibular dental arches, as well as of the bite registration of the patient, should be performed. Save the resulting images as to the standard tessellation language (STL) files. If the teeth to be rehabilitated are in the aesthetic region, take clinical photographs of the facial frontal view at rest, facial frontal view smile and facial frontal view with retractors of the patient.

Take a cone beam computed tomography of the patient (ProMax, Planmeca) with the following imaging protocol: 0.2 mm slice thickness; 79 KvP; 10 mA; FOV 8×8 cm. Export the resulting digital imaging and communications in medicine (DICOM) files to 3D-reconstructed models in the STL format [25], using a DICOM viewer software (Horos v3.3.6, The Horos Project). An implant planning software (CoDiagnostix, Dental Wings GmbH) with AI algorithm to correct the threshold of the 3D-reconstructed models can also be used to obtain a better quality of 3D images.

Import both maxillary and mandibular STL files from IOS into a CAD software (Modellier, Zirkonzahn). In the expert mode of the software, import the STL files from CBCT as "situ" or "generic visualization mesh". Match both images, either automatically or manually, by selecting common occlusal points throughout the dental arch of both CBCT and IOS meshes (Fig. 1).

A colormap of 3D deviations between both meshes can be used to check for possible discrepancies, if needed (Fig. 2). Click on the "extra" menu and select the "cut-view" tool to obtain a 2D cross-sectional image of the aligned 3D-reconstructed models. Use the linear measurement tool available in the "cut-view" window to measure the distance between the level of the marginal gingival tissue and the top of the alveolar bone crest (Fig. 3).

Results

The technique described was used to perform a periodontal evaluation and surgical planning using the CBCT and IOS of a 49-year-old female patient and tested by two different operators: a professor with expertise in dental computer-aided design-computer-aided manufacturing (CAD-CAM) and a PhD student with basic CAD-CAM training. Both operators were able to import all files and perform a periodontal analysis of the patient by using the steps described above (Fig. 1).

The technique could also be tested with different STL files from 3D CBCT reconstructed models exported from the same DICOM dataset with different threshold levels (Fig. 2). Even adjusting the threshold to prevent artifacts, the alignment of the STL files exported using the Horos software required manual alignment by selecting common occlusal points in both meshes before using the “cut-view” tool to perform the linear measurements for biological width estimation (Fig. 3).

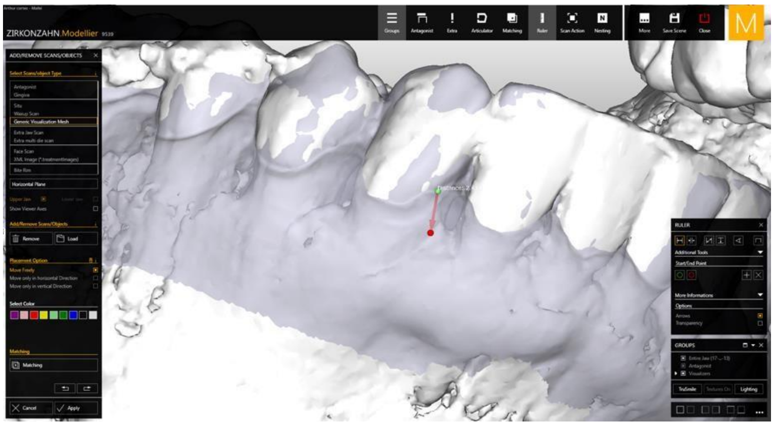

Figure 1. Screenshot of the CAD software after superimposing and aligning CBCT (white) and IOS (grey) meshes. A 3D linear measurement of the space between soft and bone tissue limits is shown in red color.

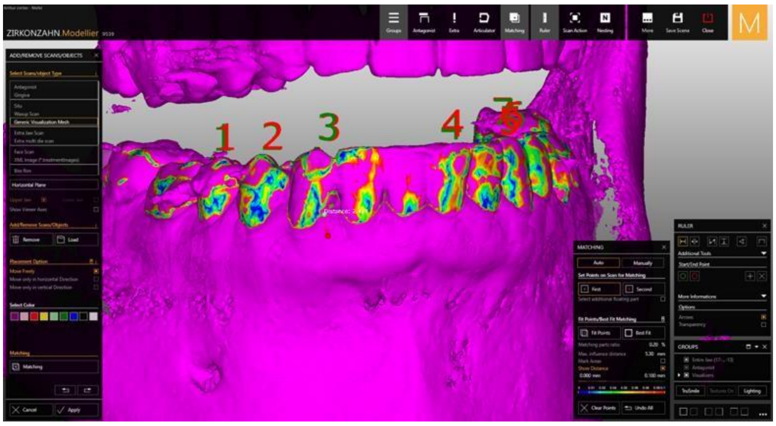

Figure 2. Colormap used to analyze the 3D alignment between STL files from CBCT and IOS. A satisfactory alignment can be obtained to superimpose CBCT and IOS meshes, although manual alignment may be required.

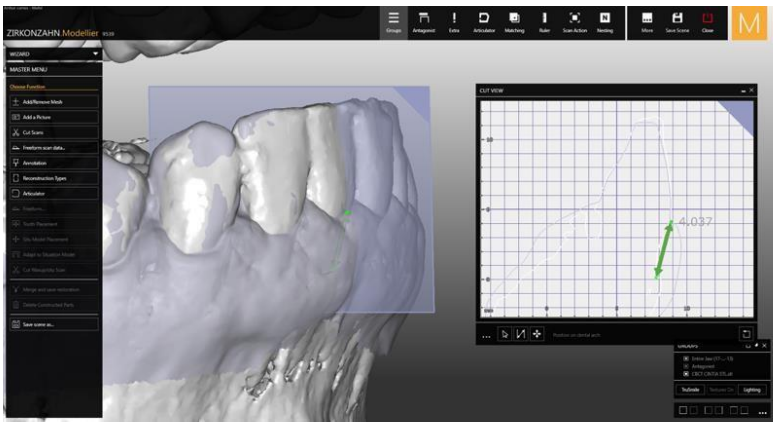

Figure 3. Screenshot of the “cut-view” tool used to perform linear measurements to estimate the supracrestal tissue attachment. Note the presence of minor discrepancies at the occlusal surface between STL files from IOS (gray) and CBCT (white).

Furthermore, the same DICOM dataset was also exported using the AI algorithm of the abovementioned implant planning software (CoDiagnostix, Dental Wings GmbH). The quality and accuracy of the resulting 3D-reconstructed model was higher, as confirmed by checking the limits of the anatomical structures on the original 2D cross-sectional DICOM images. As a result, the alignment of STL files from IOS and CBCT could be done automatically and had a higher accuracy, as confirmed with the "cut-view" tool of the Modellier software (Fig. 4). Adequate alignment trueness was further confirmed quantitatively (Fig. 5) with a 3D inspection and metrology software program (Geomagic Control X 2024, 1.0, Oqton).

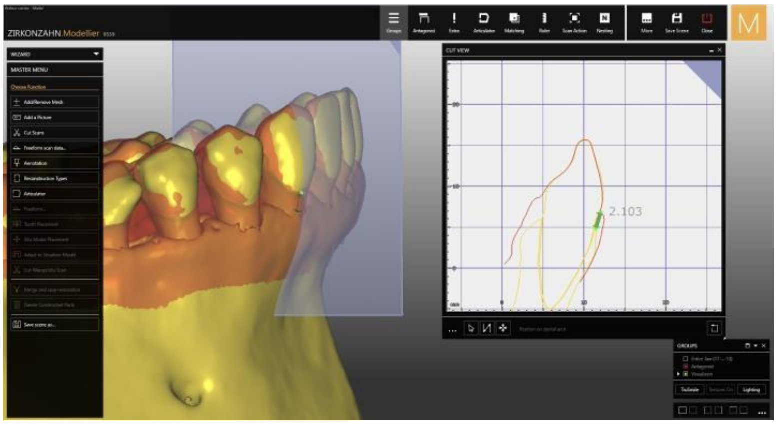

Figure 4. Screenshot of the "cut-view" tool used to perform the same type of linear measurements of the previous figure but using the STL file from the AI-enhanced 3D-reconstructed model. Note the accuracy of the alignment between the STL files from IOS (red) and CBCT (yellow).

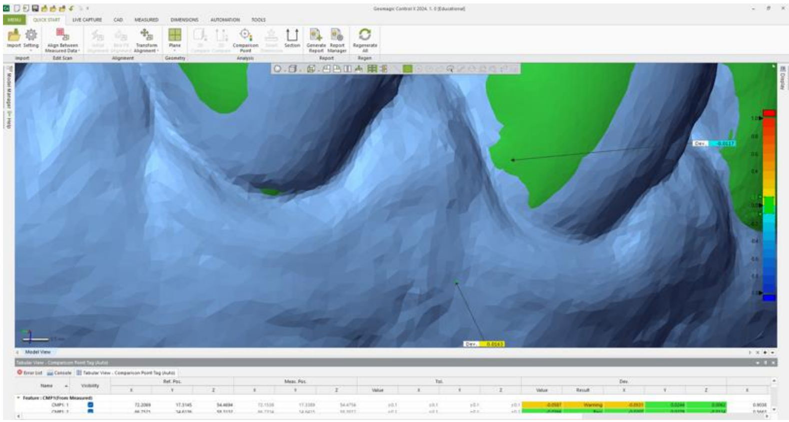

Figure 5. Screenshot of the Geomagic Control X software (Oqton), showing 3D mesh deviations of less than 15 µm between the CBCT 3D reconstructed model and the IOS of the patient. The discrepancy between the two 3D meshes from STL files is calculated in 3D and depicted using a color map.

Discussion

In this study, we introduced a technique of working with virtual patients for periodontal assessment, including the possibility of using AI to merge and superimpose CBCT and IOS into a cohesive 3D virtual patient model. This model focuses on accurately measuring the supracrestal tissue attachment, which is crucial for planning treatments that prioritize periodontal health [8,9]. This approach aligns with existing literature emphasizing the advantages of digital workflows in periodontics, notably in enhancing treatment precision and efficiency [19,26]. Our findings support the integration of digital technologies as essential for advancing diagnostic accuracy and treatment outcomes in periodontal care.

The present study utilized a commercial CAD software program (Modellier, Zirkonzahn) for CBCT and IOS data integration. This software offers a high level of automation and a user-friendly interface. In contrast, employing a free open-source CAD software might require more manual interventions due to its limited automated features, alongside a more pronounced learning curve. Despite these challenges, open-source platforms remain viable options for data integration, though they may demand more time and effort from the user [27].

In our methodology, we used an open-source DICOM viewer and an implant planning software to convert CBCT scans into the STL format. The software incorporates AI algorithms for artifact filtering and mandibular canal detection, aiding in canal mapping. Such capabilities enhance 3D reconstructions and ensure precise alignment with IOS STL files, crucial for accurately measuring biological dimensions like the supracrestal tissue attachment [28,29]. This precision supports safer and more accurate implant and maxillofacial surgery planning.

The limitations of the present study include employing only one software platform (Modellier, Zirkonzahn), a single CBCT device (ProMax, Planmeca), and illustrating the technique with a single clinical case. Additionally, this study did not include evaluations of bone graft assessments, which have also been described as possible with the use of the virtual patient, representing a significant area for future exploration [30]. Future prospective clinical studies are essential to explore the applicability and effectiveness of the present technique in routine dental practice. Additionally, future research should prioritize investigating how differences in image quality and the performance of AI algorithms affect the accuracy of 3D reconstructions and precise measurements.

Acknowledgments

The authors would like to thank the Zirkonzahn company for encouraging this study.

Author Contributions

APA conceived and designed the work, ARGC performed the experiments, APA and ARGC drafted the manuscript. All authors read and approved the final manuscript.

Conflicts of interest

The authors declare no competing interests.

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