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CLINICAL ARTICLE

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Recommendations for successful virtual patient-assisted esthetic implant rehabilitation: A guide for optimal function and clinical efficiency

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Abstract

Objective: Complete arch implant rehabilitation necessitates meticulous treatment planning and high-level collaboration between surgical and prosthetic dental teams. Emerging virtual technologies hold considerable promise in streamlining this process. The aim of this article is to extend recommendations to clinicians venturing into the virtual patient-assisted esthetic implant rehabilitation workflow.

Overview: This article summarizes recommendations for virtual patient-assisted esthetic implant rehabilitation in the following five aspects: three-dimensional data handling and superimposition, occlusion and virtual articulator integration in creating virtual patients, streamlined face- and prosthetic-driven surgical planning, reuse of presurgical data ("Copy & Paste"), and final impression for passive fitting of final restoration. To illustrate these principles, a case with complete-mouth implant rehabilitation completed within six visits using this virtual patient workflow is presented.

Conclusion: The virtual patient workflow serves as an invaluable tool to perform treatment planning, enhance efficiency, and ensure predictable outcomes in esthetic complete arch implant rehabilitation.

Clinical Significance: Virtual workflows are increasingly prevalent in esthetic implant rehabilitation. Nevertheless, these workflows necessitate a distinct set of knowledge and tools divergent from conventional dentistry practices. This article offers guidelines and recommendations for dental clinicians who are new to this field.

KEYWORDS
complete arch implant rehabilitation, computer-assisted implant surgery, virtual articulator, virtual patient

1 | INTRODUCTION

Implant-supported fixed complete dental prostheses (IFCDP) are frequently used treatment options for edentulous or terminal dentition patients.[1] IFCDPs support the patient's chewing function, esthetics, and phonetics. However, it is one of the most challenging dental treatments. This treatment involves a complete-arch implant surgery phase and a following prosthetic phase. The surgical phase usually involves teeth extraction, ridge reduction, implant placement, and possible immediate loading of the prosthesis. The prosthetic phase includes implant impression, jaw relationship records, face-driven esthetic design, and fabrication of interim and definitive restorations. What adds more challenges to this process is that the implants must be placed in a prosthetically driven position. Hence, a thorough prosthetic plan is required before implant surgery.[2–4] Given the complex nature of the treatment, achieving optimal outcomes necessitates a high level of collaboration between surgeons, prosthodontists, and dental technicians; an overall experienced treatment team.[5]

In recent years, the emergence of virtual dental patients has offered a streamlined solution for IFCDP rehabilitation.[6] A virtual patient is a computer simulation generated by superimposing various three-dimensional (3D) images from a patient, which include facial scans, intraoral scans, and cone beam computed tomography (CBCT) images. This 3D representation depicts the actual patient and can be accessed through various dental computer-assisted design/computer-assisted manufacturing (CAD/CAM) software platforms. This comprehensive digital visualization provides essential information about the patient's bone structure, existing teeth, and facial profile, enabling dentists to perform detailed surgical treatment planning even without the presence of the patient.[6–8] Moreover, workflows of integrating occlusal information, such as centric relation, vertical dimension of occlusion, and facebow records into virtual patients, have been proposed recently. This allows the use of virtual patient for both surgical planning and the following prosthetic design.[9–11]

Fully digital workflow utilizing virtual patients may significantly improve treatment outcomes and the overall efficiency of complete-arch implant rehabilitation. During the process, a stackable guide can be fabricated to provide guidance for ridge reduction, implant placement, and the conversion of immediate implant-supported interim restorations. By reusing presurgical virtual patient data in the prosthetic phase, the need for acquiring new facebow records and new data for face-driven prosthetic design can be eliminated. So far, numerous techniques and case reports have been published.[12] To better understand and implement this workflow, clinic procedures should be based on sound surgical, prosthetic, and digital principles. Hence, this article outlines the key tenets of successful complete-arch implant rehabilitation treatment assisted by virtual patient integration.

1.1 | 3D data handling and superimposing

The virtual patient workflow relies on 3D images that provide face (face scan), dentition (arch scans or scan of existing dentures), and bone information (CBCT scan) (Table 1). Managing these 3D data differs significantly from handling of dental stone casts or wax-ups. Understanding the unique features of these 3D data sets is a prerequisite for effectively implementing a digital workflow. A clinician should be familiar with what these images are, how superimposition works, and how to store and transfer 3D virtual patient data through different software.

In contrast to intraoral scans and CBCT, facial scans (Figure 1) are a relatively new addition to dentistry, and many people are not yet

TABLE 1 3D images for virtual patient workflow.

	Device	Image type	File format	Resolution	Roles in digital workflow
Face scan	• Industrial scanner • Dedicated face scanner • Smart-phone	Mesh 3D image	.stl, .obj, .ply	Low to median	• Provide facial landmarks • Esthetic information, smile line, lip line, lip mobility • Lip-teeth relationship • Facebow record
Ridge scan (Partially edentulous patient)	• Intraoral scanner • Conventional impression with following digitalization	Mesh 3D image	.stl, .obj, .ply	High	• Provide teeth and ridge information • Data for digital implant surgical guide designing • Inter-arch relationship
Complete denture scan (Edentulous patient)	• CBCT machine (Dual scan protocol) • Intraoral scanner	1. Volume 3D image 2. Mesh 3D image	1. DICOM 2. .stl, .obj, .ply	1. Low 2. High	• Provide prosthesis information • Can be converted into mucosa-supported guide
CBCT scan	• CBCT machine	Volume 3D image	.dcm (DICOM)	Low	• Provide face, teeth, and bone information at the same time • Anchor of other 3D images • Bone volume for implant planning • Vital structural, such as IAN, sinus • Inter-arch relationship; Facebow record

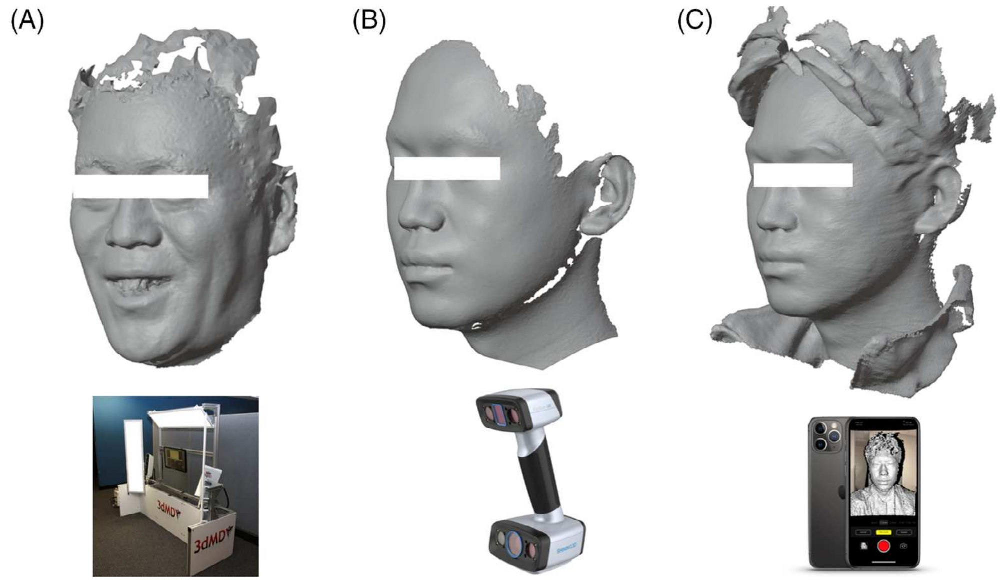

FIGURE 1 Facial scans produced by different scanners. (A) Stationary 3D scanner (3dMDtrio System; 3dMD), (B) Hand-hold industrial 3D scanner (EinScan HX, Shinning 3D), (C) Smartphone-based 3D scanner (iPhone 11; Apple, Inc.).

familiar with them. Therefore, it is advantageous for clinicians to acquire a greater understanding of facial scans in dental clinics. Similar to intraoral scanners, facial scanners generate 3D models via optical scanning. The primary distinction between the two lies in the facial scanner's considerably larger field of view, which consequently results in reduced detail capture.[13,14] Regarding the face scanning devices, industrial scanners like D100 (Imetric 3D, Courgenay, Switzerland) were assessed by early studies.[14,15] These scanners are trustworthy but are expensive and are not specifically designed for use in dental clinics. Recently, some dedicated dental–facial scanners like MetiSmile 3D (Shining 3D Tech. Co., Ltd. Hangzhou, China) and RAYface (Ray America Inc., Fort Lee, NJ) have emerged in the market. These specialized dental-facial scanners primarily utilize structured light or photogrammetry technology and require connection to a personal computer (PC) for operation. In comparison to these bulky scanners, smartphone-based 3D scans offer a more cost-effective and accessible option. While they may not produce 3D models with the same level of detail as their larger counterparts, smartphone-based face scans (iPhone, Apple, Inc., Cupertino, CA) can still provide adequate data for dental clinical use.[16] A recent publication demonstrated that smart-phone based face scan produced high-accuracy facebow record that is better than conventional facebow record in completely dentate conditions.[17]

The accuracy of the virtual patient integration is dependent on the accuracy of the digitizing methods used. The higher the accuracy of the digitizing process, the higher the accuracy of the virtual patient.[18,19] Therefore, the facial scanning method elected, as well as the method used to align patient's information, with or without the use of an extraoral scan body, will impact the accuracy of the virtual patient and, ultimately, the treatment planning or prostheses design methods.[18–20]

Both facial scanners and intraoral scanners generate mesh 3D images, which are digital representations of 3D objects created by connecting a series of vertices to form a network of polygons. These mesh 3D images can be stored in various formats, such as .stl, .obj, .ply, and others, and may or may not include color information. In contrast, CBCT images provide volumetric 3D data, presenting a digital depiction of 3D objects composed of voxels, which are small, cubic units that define spatial dimensions.[21] CBCT images are stored in the Digital Imaging and Communications in Medicine (DICOM) format, which also includes patient information. Therefore, it is crucial to store and transfer DICOM files in compliance with the Health Insurance Portability and Accountability Act (HIPAA) to ensure data privacy and security.[21]

Superimposing 3D images is the initial step of digital design. Upon initial import of a patient's facial, intraoral, and CBCT 3D images into software, these images are not aligned with each other (Figure 2). The process of creating a virtual patient involves the sequential overlaying or merging of these images. It is known as superimposition and its accuracy is critical for achieving optimal clinical outcomes.[22] For instance, when fabricating a surgical guide, any discrepancies in the superimposition between the DICOM file and the intraoral scan will directly impact the implant surgery accuracy.[23] During the superimposition process, one of the 3D images is established as a fixed 3D model, while the others are aligned to it. It is recommended to use the CBCT scan as the fixed model, as its 3D coordinates are more difficult to alter compared to mesh images. Additionally, CBCT scans encompass both facial and teeth structures, making them suitable anchors for facial and intraoral scans.

During the implant rehabilitation treatment process, various software applications are typically utilized, including implant planning, prosthetic design, and 3D image processing. To streamline the treatment process, it is crucial to ensure seamless data transfer and communication between these applications. One unique feature of 3D images is that they greatly facilitate this process. Once all 3D images are superimposed within a software, they can be exported as a single file or as separate files. Upon importing these files into a second software, the 3D images would remain in their aligned positions.

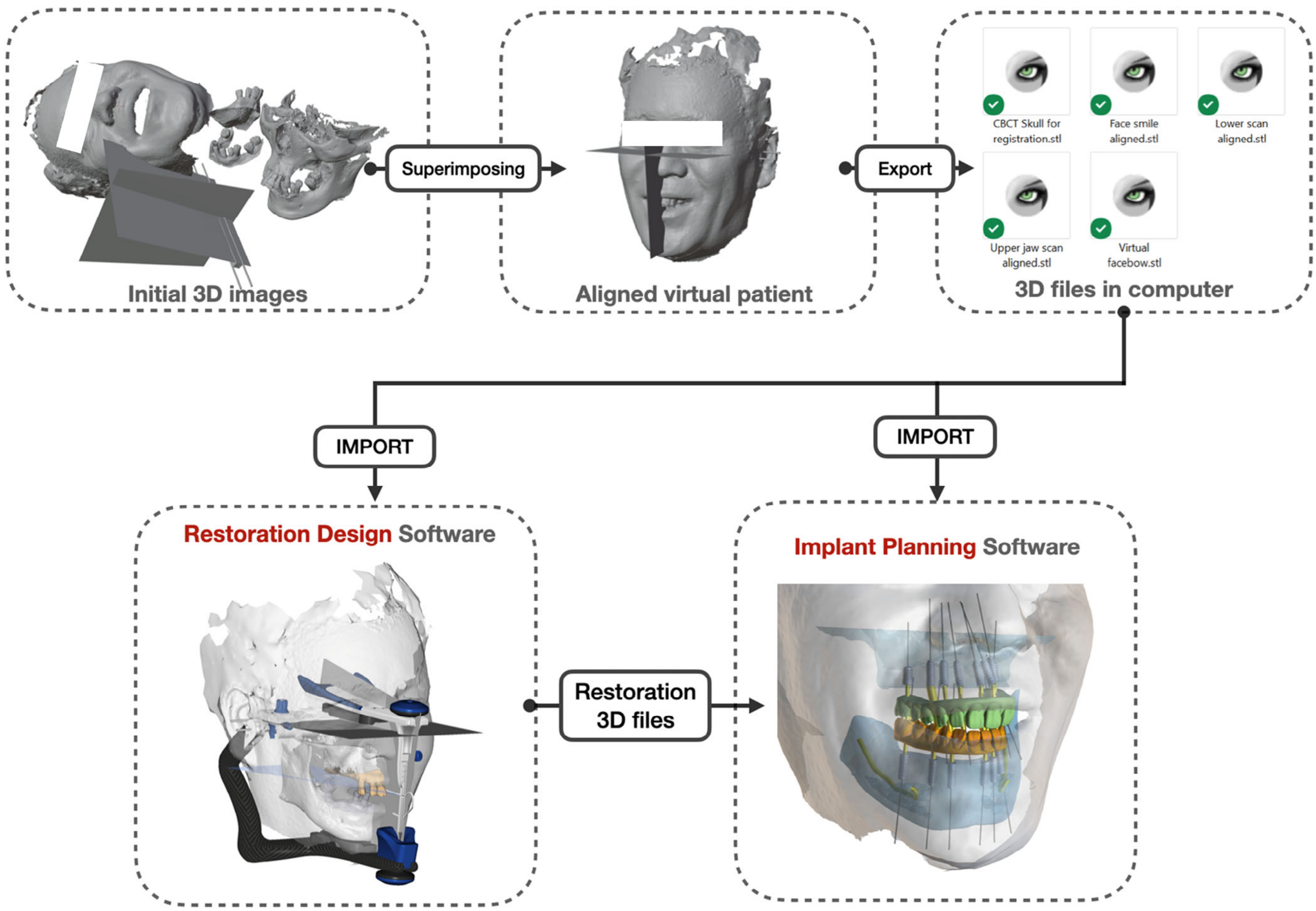

FIGURE 2 Handling of 3D data in virtual patient workflow. Once 3D files are aligned to create the virtual patient, they are exported and stored as separate 3D files in the computer. These 3D files can be used in both restoration design and implant planning software without the need for further superimposing. The 3D files exported from restoration design software also can be imported to implant planning software without the need for alignment.

This is because, once aligned, the images share the same 3D coordinates, and exporting or importing them between different applications does not alter these coordinates. This feature makes it possible to design a complete-arch restoration in a dental CAD program, such as exocad, based on an intraoral scan and then transfer it to the implant planning software while retaining the correct alignment with the CBCT image. This enables a prosthetic-driven implant position design.

1.2 | Occlusion and virtual articulator integration in creating virtual patient

In the context of implant-supported full arch restoration, occlusion design plays a crucial role in its success.[24] The virtual patient could incorporate relevant information and facilitate dynamic occlusion simulation allowing for the design of the complete arch restoration to be completed prior to the surgical planning of the implant-supported prosthetics.

Centric relationship (CR), vertical dimension of occlusion (VDO), and facebow records are the prerequisites for designing and fabricating a complete-arch prosthesis. In the virtual patient workflow, a possibility for carrying occlusal information is the CBCT scan. If the proper field of view is chosen, a single CBCT scan can capture the maxilla, mandible, infraorbital rim, and temporomandibular joint (TMJ) and can be used as facebow record to locate arbitrary hinge axis and mount the virtual patient to a virtual articulator.[11] Additionally, the CBCT scan should be made while securing the patient's jaw in CR and VDO so that when intraoral scans are superimposed onto the CBCT 3D reconstruction, the designing of restorations can be initiated.[9]

Strategies for capturing occlusion information in CBCT scans vary on the patient type and a decision tree is shown in Figure 3. The principle is recording CR and VDO information when performing the CBCT scan. This process can be simple when an edentulous patient has an existing denture with an acceptable inter-arch relationship, or a dentate patient has good occlusion in maximum intercuspation (MIP). However, in edentulous patients without tooth position information, an occlusal device is recommended to obtain and secure interocclusal relationships, and then the CBCT scan is made.[23] Since the virtual patient includes all facial landmarks, it is straightforward to locate all three articulator reference points. As described by Li et al, a

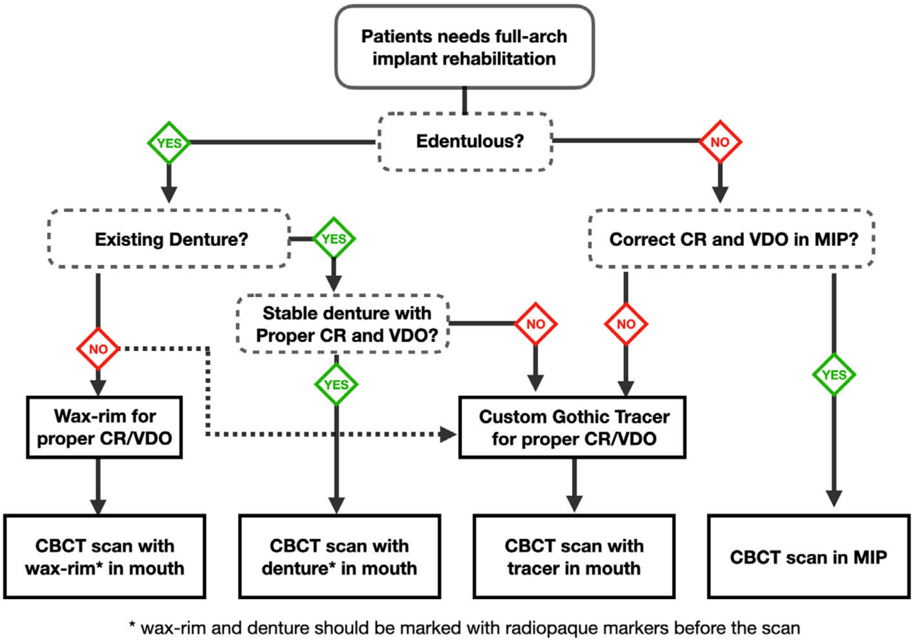

FIGURE 3 Decision tree for capturing correct occlusal records in CBCT scan.

3D facebow with reference planes and hinge axis can be aligned to the virtual patient. This 3D facebow helps to mount the virtual patient on a virtual articulator, allowing for the simulation of jaw movement when designing the implant-supported restoration.[9]

1.3 | Streamlined face- and prosthetic-driven surgical planning

Once the virtual patient is integrated, it can be imported into dental CAD software to design the wax-up of the implant prosthesis, which would be used for driving digital implant planning and possibly be used as the interim IFCDP. The restoration design process begins with determining the position of the maxillary incisor edge. The face scans provide valuable reference in this step, including lip support, incisor edge exposure, and the smile line.[25] Subsequently, the occlusal plan can be established using Camper's plane (Figure 4A,B).[9,26]

Another critical thing that needs to be determined at the beginning of the virtual planning is the height of implant restoration, since it directly influences the esthetics, phonetics, function, need for ridge reduction, and the cleanability of final restoration. The decision process starts from choosing prosthesis type (FP1, FP2, and FP3).[27] For FP1 type restoration, the restoration bottom will be at the gingival margin level of the crowns. This type of restoration requires a good height of existing alveolar bone and meticulous soft tissue molding during the interim restoration phase. Moreover, due to limited restoration space, it puts more challenges to the implant position and mechanical strength of the restoration. For FP3 type restoration, the restoration bottom position is largely decided by esthetics because the interface between restoration and gum should be hidden while the patient is smiling. In other words, the bottom of the prosthesis must be higher than the smiling lip line. The smiling face scan helps a lot during this designing process (Figure 4B). In an FP3 implant restoration, ridge reduction is usually necessary, with a 4 mm space for soft tissue and multiunit abutments designed between the restoration bottom and reduced ridge. Implant placement should aim to align the screw channel with the cingulum position of anterior teeth or the occlusal table of posterior teeth. When bone volume limits implant placement options, angulated abutments can help achieve this alignment. These factors can all be simulated in the digital planning software, allowing for precise implant planning. To realize the virtual planning, stackable guides can be designed and fabricated to assist surgery on ridge reduction, implant placement, and immediate loading of restorations (Figure 5).

1.4 | Reuse of presurgical data ("Copy & Paste")

After completing the computer-assisted implant surgery, the treatment progress to the prosthetic phase. Three key elements are crucial for a successful definitive implant-supported complete-arch rehabilitation: (1) a facially driven esthetic design, (2) facebow transfer and articulator mounting, and (3) precise definitive implant impressions. Since the virtual patient-generated during the presurgical stage already incorporates the first two elements, "copying and pasting" this presurgical data in the restorative phase can significantly reduce time and the number of patient appointments. This is one of the advantages of the digital workflow compared with conventional methods.

To transform the presurgical virtual patient into the prosthetic phase virtual patient, the definitive implant digital scan needs to be aligned with the presurgical patient. A workflow to achieve this is illustrated in Figure 6. First, the implant-supported screw-retained interim restorations are placed on the definitive implant cast and scanned. These scans act as an intermediate cast to align the cast scan

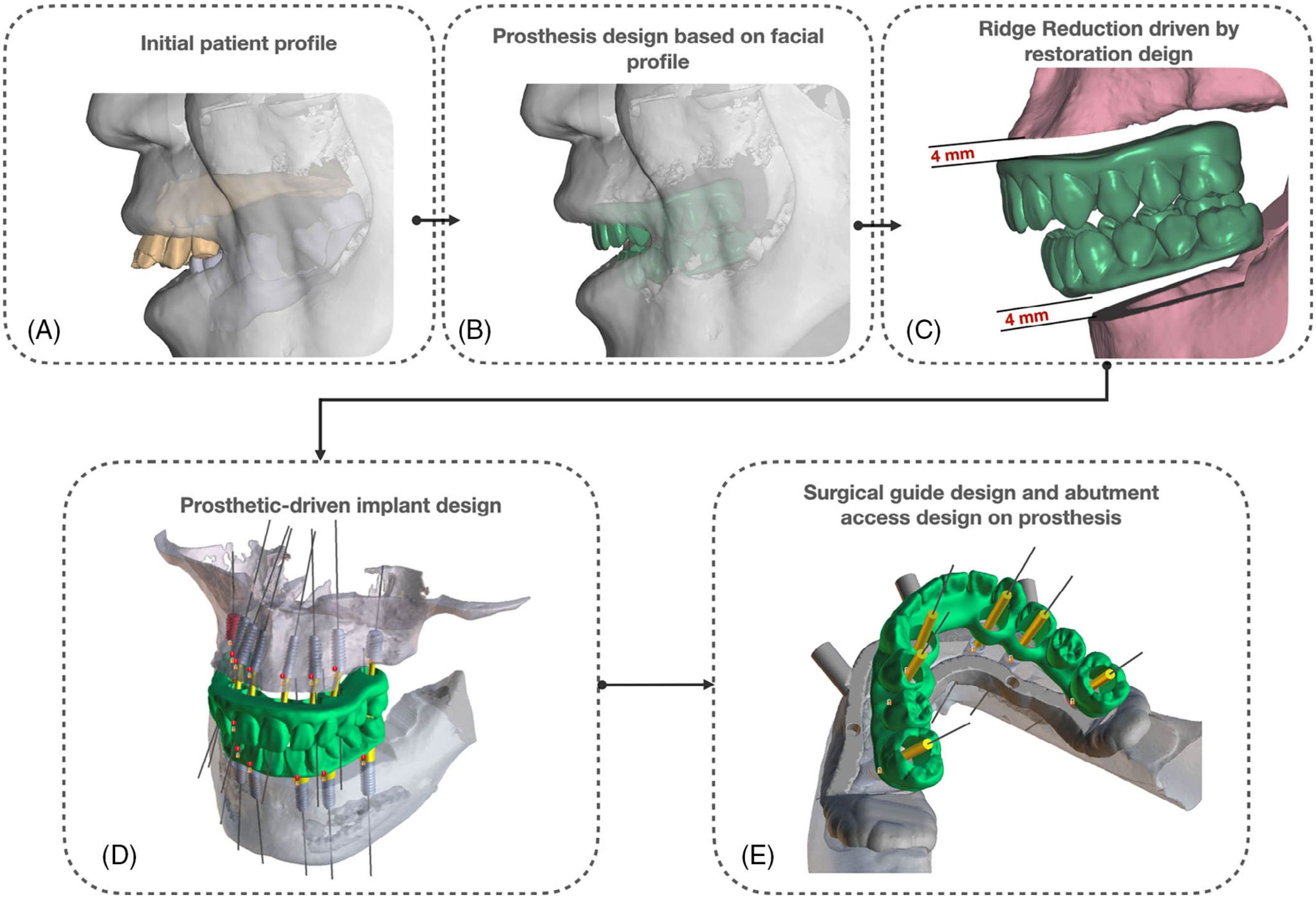

FIGURE 4 FP-3 draft prostheses were designed according to patient's face references. Maxillary incisor edge and camper's plan were used to determine occlusal plan. Restoration bottom was designed in a way that it can be hiding behind lips while patient is smiling. Following, ridge reduction was designed by leaving 4 mm between restoration bottoms. The draft prostheses were imported into implant planning software to design a prosthetic-driven implant plan.

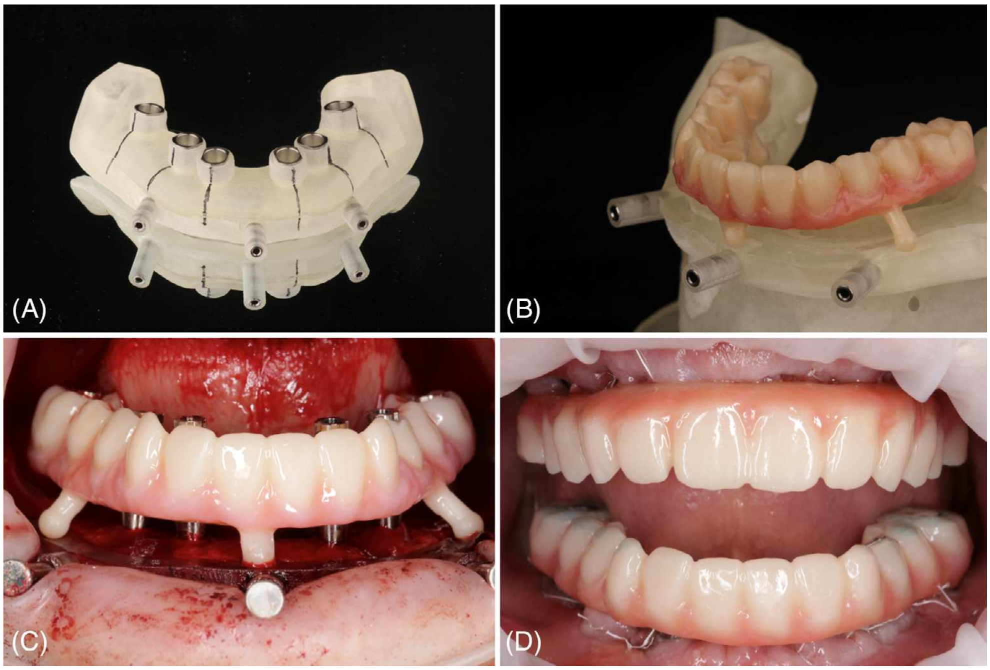

FIGURE 5 (A–D) Prosthetic-driven implant planning and immediate loading of CAD/CAM prostheses.

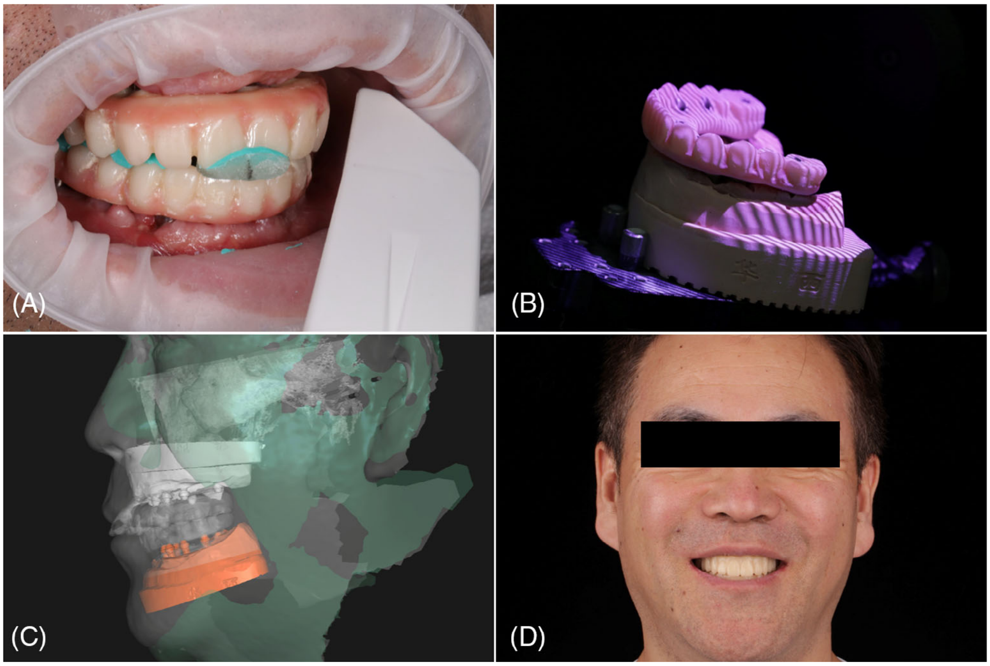

FIGURE 6 (A) Intraoral scanning of inter-arch relationship, (B) Scanning of master cast, (C) Master case scan were superimposed to presurgical virtual patient, (D) Try-in of 3D printed definitive restoration prototype.

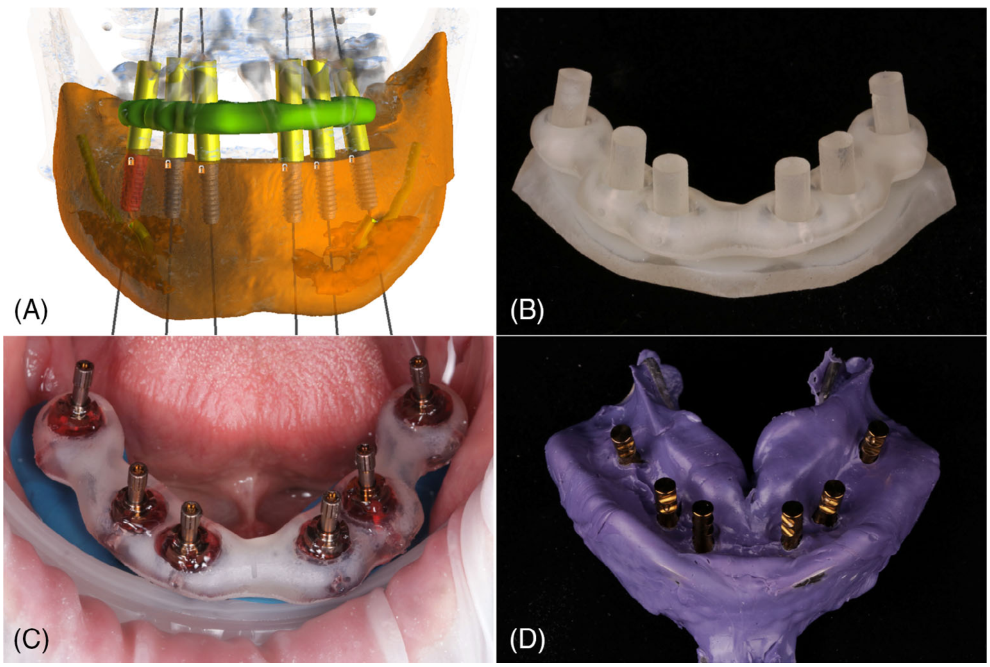

FIGURE 7 Presurgical implant planning data was used to fabricating splinting framework for definitive impression. (A) Digital design of splinting framework in implant planning software, (B) 3D-printed splinting framework, (C) Impression copings were splinted, (D) Definitive impression.

to the presurgical virtual patient. In addition, the inter-arch relationship can be captured by intraoral scan, which helps to align the mandibular scan to the maxilla in the CR.

Recent studies have shown that digital implant planning data can be used to fabricate customized trays and 3D printed splinting frameworks (Figure 7A,B), which facilitate definitive full-arch implant impressions.[28] Traditionally, a primary implant impression is required for this process. However, these innovative digital workflows enable the production of trays and splinting frameworks before the implant surgery, thereby streamlining the overall procedure.

1.5 | Final impression for passive fitting of final restoration

Clinicians must identify reliable and efficient impression techniques for IFCDP. The analog technique for complete-arch implant impressions has been well-established, in which a splinting framework that connects impression copings generates a dependable master cast (Figure 7C,D). Recent advancements in digital implant scans have garnered significant attention in the field of dentistry due to their potential to enhance clinical efficiency. Digital implant scans can be categorized into three distinct methodologies, depending on the device utilized: (1) digitization of a conventional definitive implant cast using a desktop scanner, (2) intraoral scanning, and (3) photogrammetry. The first method has been established as a reliable gold standard in the field. Although some studies have reported lower scanning precision for one photogrammetry method,[29] the majority of research and recent systematic reviews have validated the accuracy of this technology as a dependable tool for acquiring the 3D position of dental implants.[30–35] However, desktop scanning of conventional definitive implant cast does not enhance clinical efficiency, and the photogrammetry method requires costly equipment exclusively used for implant impressions. Additionally, photogrammetry systems do not capture soft tissue or teeth information. Consequently, if intraoral scanners can produce accurate complete-arch impressions, they would offer the greatest benefit to clinicians. Nonetheless, research in this area has yielded conflicting results, and further investigation is needed.

In contrast to desktop scanners and photogrammetry devices, which capture the 3D implant position within a single 3D image, intraoral scanners possess a much smaller field of view. These scanners capture fragments of the arch and require stitching these fragments together to create a complete 3D model of the complete arch. The stitching, or superimposing process, introduces deviations, with longer arch spans correlating to larger deviations.[36] Moreover, intraoral scanners are primarily designed for scanning dentate arches, posing challenges when scanning edentulous arches. Recent evidence indicates that intraoral scanners (IOS) can be recommended as a suitable alternative to conventional impression methods for fixed implant restorations with a short span of less than four units.[37,38]

TABLE 2 Summary of treatment workflow of example case.

	Treatment sequence	Goals	Objectives
Surgical phase	Appointment 1	• Consulting and confirm treatment plan	• Clinical exams • Consents • Intraoral scan
	Lab process	• Preparation for appointment 2	• Design and fabrication of 3D printed custom Gothic tracer for jaw relations
	Appointment 2	• Collecting data to create PAIR virtual patient	• Gothic tracing for CR a VDO • CBCT scan • Face scans (3dMDtrio System; 3dMD)
	Lab process	• Fabrication of surgical guides; CAD/CAM interim complete-arch restorations; Preparation for definitive implant impression	• Creating of the PAIR virtual patient with occlusion integration • Digital design of complete mouth restorations • Prosthetic-driven implant planning • Fabrication of stackable guides • Fabrication of milled PMMA complete-arch restorations • Fabrication of splinting framework and custom trays for definitive implant impression
	Appointment 3	• Immediate implant placement • Immediate loading of fixed complete mouth restorations	• Teeth extraction. • Guided ridge reduction. • Full-guided implants placement. • Intraoral conversion of complete-arch interim restorations
Restorative phase	Appointment 4	• 2 weeks follow-up and definitive implant impression	• Suture removal • Conventional full-arch implant impressions • Intraoral scan of interim restorations
	Lab process	• Design of definitive restoration	• Align definitive impression to presurgical virtual patient • Design of definitive restoration • 3D printing of try-in restoration
	Appointment 5	• Restoration try-in; impression of healed soft tissue	• Try-in printed trial restoration • Check esthetics • Check occlusion and phonetics • VPS impression to capture healed soft tissue
	Lab process	• Fabrication of definitive restoration	• Modification of restoration design according to appointment 5 • Fabrication of definitive implant restoration
	Appointment 6	• Definitive restoration delivery	• Definitive restoration delivery • Hygiene instruction; maintenance plan

Abbreviations: CBCT, cone-bean computed tomography; CR, centric relation; PAIR virtual patient, prosthetic articulator-based implant rehabilitation virtual patient; VDO, vertical dimension of occlusion; VPS, vinyl polysiloxane.

However, for complete-arch implant restorations, IOS remains a less favorable option. Recently, a few novel techniques, including scan aid and specially designed scan bodies, have been proposed to improve the accuracy of IOS.[39] However, further studies are still needed to determine their reliability before systematically recommending complete-arch intraoral digital scans for complete-arch rehabilitations.

In conclusion, the conventional impression method using a splinting framework is still the recommended approach for complete arch implant-supported fixed restoration if a photogrammetry device is unavailable.

1.6 | Example clinic case

To illustrate the above recommendations, a case of a patient with terminal dentition who underwent complete-mouth implant-fixed restoration treatment is presented. The treatment comprised two phases: an implant surgery phase, which aimed to accomplish immediate implant placement and loading of both maxillary and mandibular interim implant restorations, and a restorative phase, during which the definitive implant restoration was fabricated. The utilization of a virtual patient model and digital workflow facilitated the completion of the entire process in only six appointments, demonstrating the efficiency of this approach.

The treatment process is summarized in Table 2. Creating a virtual patient that can be used for both surgical and restorative phases is key to the entire treatment process. It was planned to gather all scans during the patient's second visits (Figure 2). Since the patient had a collapsed bite, custom Gothic arch tracer was fabricated from intraoral scans obtained during the first visits. These tracers helped to obtain the CR and VDO and maintained the patient's jaw relationship during the CBCT scan performed during the second visit. The CBCT scan included patient's maxilla, mandible, and TMJ joints. Face scans and intraoral scans were superimposed onto the CBCT to create the PAIR virtual patient. The PAIR virtual patient was then used to design a face-driven full-mouth restorations, and a prosthetic-driven implant surgical plan was made (Figure 4). Using 3D printed stackable guide, immediate implant placement and loading was achieved during the patient's third visit (Figure 5).

By using the digital implant planning data, splinting frameworks were fabricated by 3D printing even before the implant surgery (Figure 7A,B). They were used to made definitive implant impressions at the 4th visit, which was 2 weeks after the implant surgery (Figure 7C,D). At the same visit, sutures were removed, and an intraoral scan of the interim restoration was made. This scan helped to align the definitive impression scan onto the PAIR virtual patient (Figure 6C). Following this, definitive restorations were designed. To test the design, prototype restorations were 3D printed and tested at the 5th patient visits (Figure 5D). Since the previous impression did not capture healed soft tissue, another set of impressions was made to obtain the healed soft tissue contour, which assisted in designing of the intaglio surface of the full-arch restoration.

The definitive restoration was fabricated using a CAD/CAM metal framework, full-contour zirconia crowns, and composite gingiva. The framework exhibited good passive fitting (Figure 8A). To improve hygiene, the intaglio surface of the restorations was designed with a convex contour, and access for dental floss were incorporated (Figure 8B). The delivered restorations demonstrated favorable esthetics, phonetics, and occlusion (Figure 8C). A 3-year follow-up revealed stable bone levels around the implants (Figure 8D).

2 | SUMMARY

Virtual patient has emerged as a valuable tool in full-arch esthetic implant rehabilitation. It offers a streamlined approach integrating

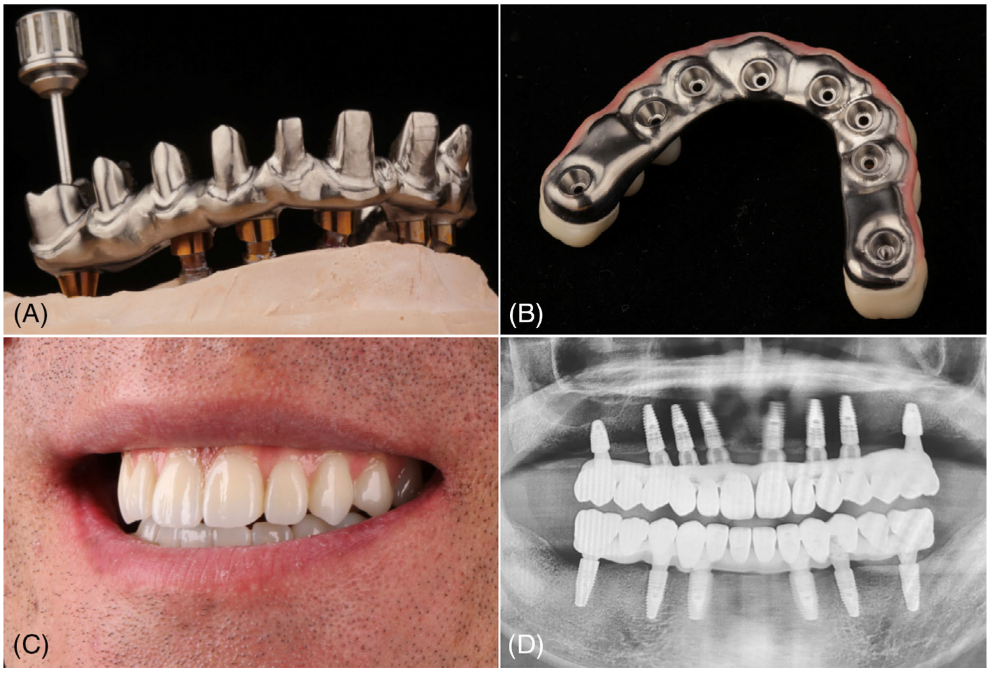

FIGURE 8 (A) Milled framework showed passive fitting, (B) Intaglio surface design for hygiene access, (C) Delivered final restorations, and (D) 3 years follow up.

face- and prosthetic-driven implant planning, effectively bridging the surgical and prosthetic phases. By adopting this workflow, clinicians can achieve predictable outcomes while reducing chairside time and the number of patient visits. To effectively implement this approach, it is recommended to consider the following aspect as illustrated in this article: (1) 3D data superimposing and handling, (2) occlusion and virtual articulator integration in creating virtual patient, (3) streamlined face- and prosthetic-driven surgical planning, (4) reuse of presurgical data ("Copy & Paste"), and (5) accurate final impression for passive fitting of prostheses.

CONFLICT OF INTEREST STATEMENT

The authors do not have any financial interest in the companies whose materials are included in this article.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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