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DENTAL TECHNIQUE

Anatomic and tripod landmark-based implant scanning workflows for fabricating complete arch implant-supported prostheses using extraoral and intraoral photogrammetry systems

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ABSTRACT

The accuracy of implant scanning techniques has been analyzed; however, the studies describing implant scanning workflows based on the conditions of the patient, design of the planned implant prosthesis, and implant scanning technique selected are scarce. This manuscript describes 2 implant workflows for fabricating complete arch implant-supported prostheses in which an extraoral and intraoral photogrammetry systems were used to record implant positions. A tripod landmark-based workflow composed of an existing tooth and 2 temporary anchorage devices and an anatomic landmark-based workflow are described in different treatment phases to register the scans of the implant workflows and fabricate the interim and definitive prostheses. (J Prosthet Dent xxxx;xxx:xxx-xxx)

Intraoral scanners (IOSs) can be used to fabricate crowns and short span implant-supported prostheses.[1–6] The accuracy of IOSs for fabricating complete arch implant-supported prostheses varies depending on the implant scanning technique.[1,7–12] The accuracy of IOSs has been reported to be significantly impacted by operator handling and patient conditions.[13–15]

Extraoral and intraoral photogrammetry (PG) systems provide a reliable acquisition method for recording the position of the implants.[16–21] Extraoral PG systems only record implant positions.[16–18] Intraoral PG devices provide the capability not only to record implant positions, but also to capture additional scans, similar to IOS systems.[19–21]

An implant scanning workflow involves the scans containing the different information needed to fabricate an implant prosthesis: tooth, soft tissue, and implant position information of the arch being restored, antagonist, and maxillomandibular relationship.[22] The accuracy of the IOSs and PG methods for capturing implant positions has been determined[1–12,16–21]; however, studies describing implant scanning workflows based on the patient's conditions, planned implant prosthesis, and implant scanning technique selected are scarce.[22–27]

This manuscript describes 2 implant scanning workflows for fabricating a maxillary and mandibular complete-arch implant-supported prostheses in which extraoral and intraoral PG systems are selected for recording implant positions. A tripod landmark-based workflow composed of an existing tooth and 2 temporary anchorage devices (TADs) and an anatomic

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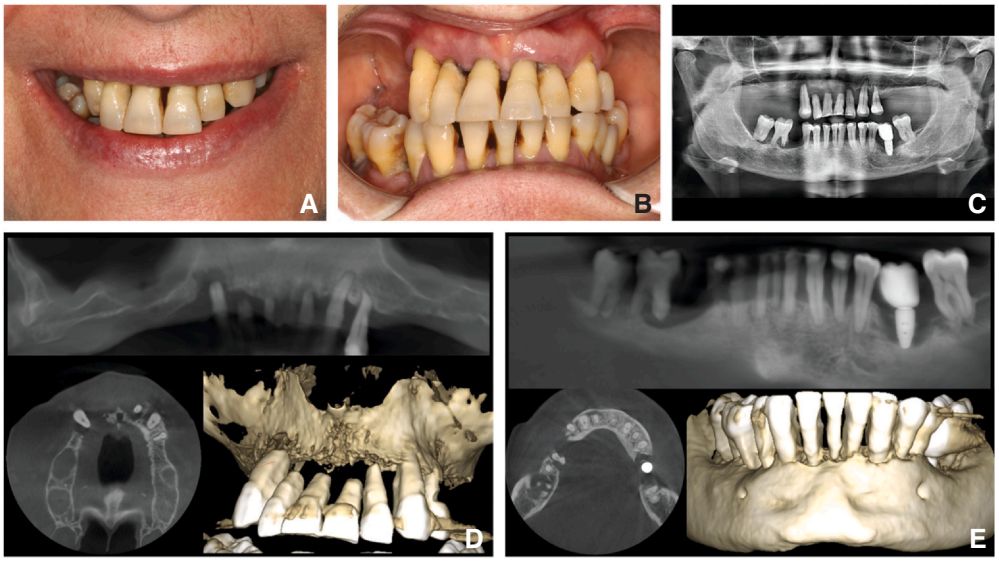

Figure 1. Initial evaluation. A, Smile. B, Maxillary and mandibular arches in MIP. C, Orthopantomography evaluation. D, Maxillary analysis using CBCT. E, Mandibular examination using CBCT. CBCT, cone beam computed tomography; MIP, maximum intercuspal position.

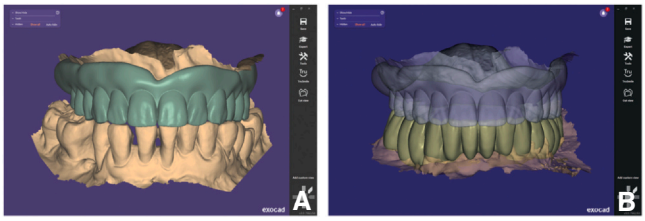

Figure 2. Treatment planning procedures phase 1. A, Evaluation of maxillary interim complete denture design and initial mandibular scan. B, Maxillary evaluation of interim complete denture design and mandibular diagnostic waxing.

landmark-based workflow are described in 3 different treatment phases to register the scans of the implant workflow and fabricate the interim and definitive implant-supported prostheses.

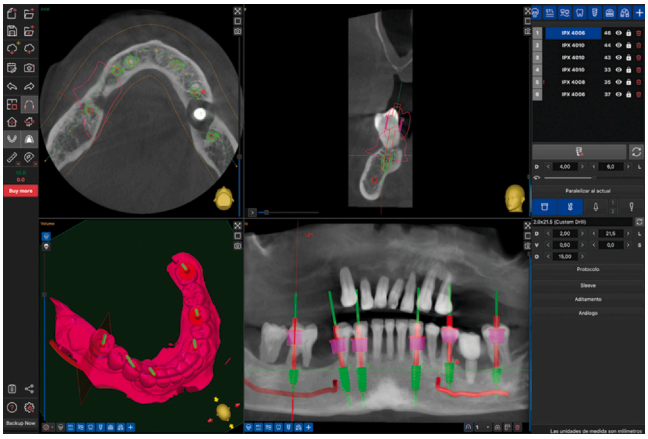

Figure 3. Computer-aided implant planning procedures of mandibular arch. Representative image prosthetically driven implant position.

TECHNIQUE

After extraoral and intraoral clinical and radiographic analysis (Fig. 1), treatment options were discussed with the patient. The patient elected a maxillary and mandibular screw-retained implant-supported prostheses.

Following conventional treatment planning procedures, initial scans were obtained by using a calibrated[28] IOS (Aoralscan Elite; Shining 3D). These scans were used to design a diagnostic waxing (DentalCAD; Exocad GmbH). Afterwards, the initial maxillary scan was duplicated, virtual extractions were performed, and an interim maxillary complete denture (CD) was fabricated (Fig. 2). Additionally, computer-aided implant planning procedures were completed to plan the mandibular implants based on the tooth position determined in the diagnostic waxing. The surgical implant guide was manufactured (Fig. 3).

During the first surgical and restorative phase, the maxillary teeth were extracted, and the interim CD was delivered (Fig. 4A). One month later, the first surgery was performed under intravenous conscious sedation. Guided bone regeneration and a direct sinus lift were performed on the right side of the maxilla and an implant was placed in the first right maxillary first molar position (Fig. 4B). This implant was placed aiming to facilitate the posterior restorative phase (second phase). Additionally, mandibular bone grafting and implant placement procedures were completed during this surgery. In the mandible, a tripod landmark-based scanning workflow was used to register the scans (Table 1). The tripod was composed of 2 TADs (Dual Top Anchor System; Jeil Medical Corporation) and 1 existing tooth. The following steps were completed:

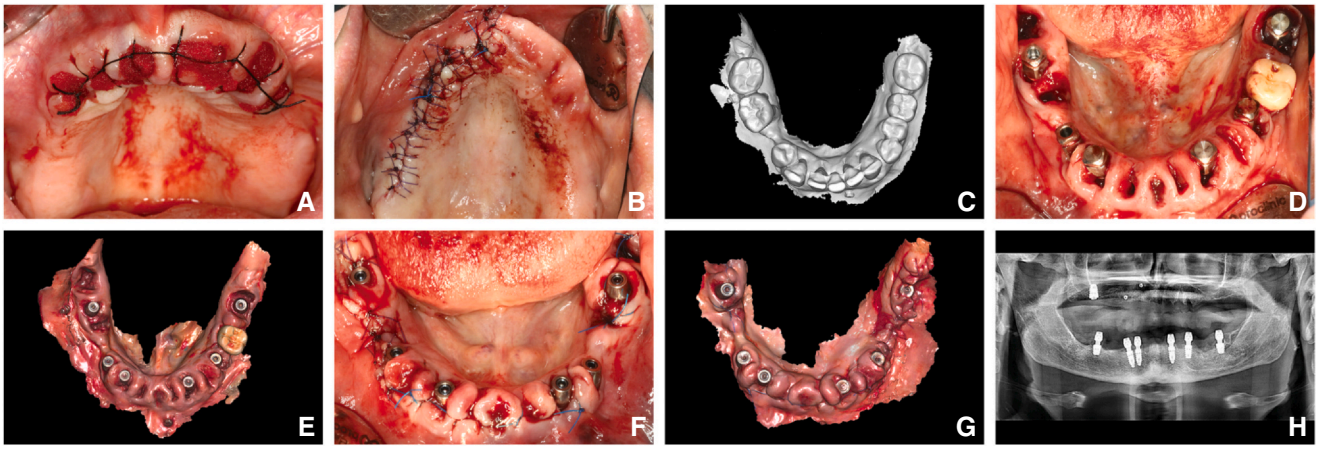

Figure 4. Surgical phase 1. A, Extraction of maxillary arch. B, Guided bone regeneration and direct sinus lift in right side of maxilla the first surgery after 1 month of maxillary teeth extraction. C, Mandibular intraoral presurgical scan involving 2 TADs positioned in buccal surface 3 mm apically to gingival margin in right first molar and midline between both central incisors. D, Mandibular implants placed, maintaining left first molar. E, First intraoral surgical scan. F, Surgical procedures completed. G, Second intraoral surgical scan. H, Orthopantomography. TAD, temporary anchorage device.

Table 1. Tripod reference-based implant scanning workflow used in mandibular first surgical and restorative treatment phase 1

Digital Scans	Information Contained	Reference Landmark/s
Presurgical scan	- Tripod landmark - Same teeth position as initial scans	- 2 TADs and left first molar for registration between presurgical and first surgical scan - Mandibular teeth for registration between presurgical scan and initial scans/diagnostic waxing
First surgical scan	- Tripod landmark - Healing abutment geometry of all placed implants (soft tissue information scan)	- 2 TADs and left first molar for registration between presurgical and first surgical scan - Implant healing abutment geometries for registration between first and second surgical scan
Extraoral PG scan	- Implant positions	- Implant healing abutment geometries for registration between extraoral PG and first/second surgical scans
Second surgical scan	- Healing abutment geometry of all placed implants (soft tissue information scan)	- Implant healing abutment geometries for registration between first and second surgical scan

PG, photogrammetry; TAD, temporary anchorage device

1. Place 2 TADs in the buccal surface 3 mm apically to the gingival margin on the right first molar and midline between both central incisors without damaging the roots of the teeth.
2. Obtain an IOS scan involving both TADs following the recommended pattern[29,30] and scanning distance[31] and without rescanning[32,33] methods (presurgical scan) (Fig. 4C).
3. Proceed with the mandibular surgical treatment. Extract the mandibular dentition, except 1 posterior tooth, on the contralateral side of the posterior TAD. In the present patient, the left first molar was maintained as it did not interfere with the implant placement. Then, place the mandibular implants (IPX; Nueva Galimplant S.L.) and tighten an implant abutment (Straight Transepithelial Abutment; Galimplant) to 30 Ncm on each one (Fig. 4D).
4. Hand tighten[34] a PG marker (PIC Marker; PIC Dental) into each implant abutment and obtain a photogrammetry scan (PIC Camera; PIC dental) by following the recommended scanning distance[35] (extraoral PG scan). Retrieve the PG markers.
5. Hand tighten a scannable healing abutment on each implant abutment (Transepithelial Healing Abutment; Galimplant) and record a complete-arch scan involving the 3 landmark references by using the same IOS (first surgical scan) (Fig. 4E).
6. Complete the surgical treatment by extracting the left first molar and grafting procedures (Fig. 4F). Remove the mandibular TADs.
7. Obtain a complete arch scan by using the same IOS (second surgical scan) (Fig. 4G, H).

The scans were registered in pairs by using the common information between 2 scans by using the same CAD program (Fig. 5).[22] The dental laboratory technician designed and fabricated the mandibular screw-retained implant-supported restoration, which was delivered the day after the implant placement surgery by following conventional methods (Fig. 6).

After 6 months of this first surgical phase, a new cone beam computed tomography (CBCT) scan was obtained and used to assess the bone grafting outcome and plan the maxillary implants. The maxillary implant surgical

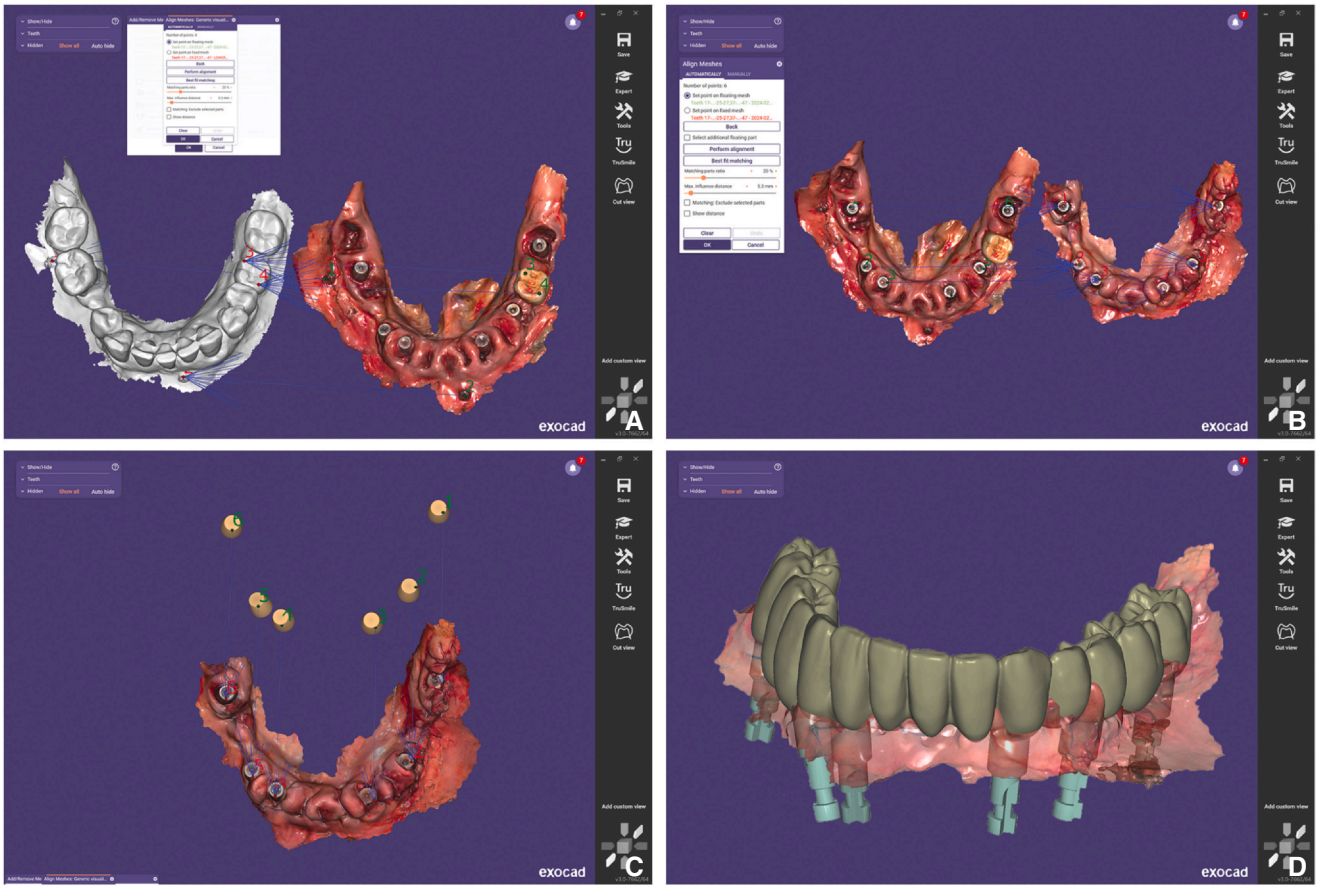

Figure 5. Registration procedures by using dental computer-aided design program. A, Aligning presurgical and first surgical scans using tripod landmark as common information. B, Alignment of first and second surgical scans using healing abutments as common information. C, Alignment of extraoral photogrammetry implant and second surgical scans. D, Mandibular interim restoration design on definitive virtual implant cast.

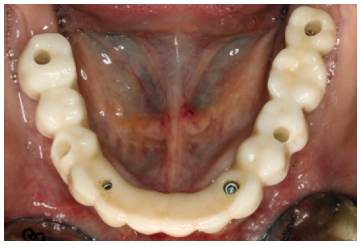

Figure 6. Restorative phase 1 in mandibular arch.

guide was fabricated. Additionally, the maxillary CD was relined by following conventional procedures without altering the vertical dimension of occlusion (VDO). New records were obtained by using the same IOS, including a 360-degree extraoral scan of the interim CD (digitized interim CD scan) and a mandibular scan, followed by occlusal records[36,37] to articulate the digitized interim CD and mandibular scans (Fig. 7).

During the second surgical and restorative phase, an anatomic landmark-based implant workflow was used to register the scans needed to fabricate the maxillary screw-retained interim prostheses (Table 2). The following steps were completed:

1. Start the surgical procedure and place the planned implants (IPX Implant; Nueva Galimplant) by using the surgical implant guide (Fig. 8). Tighten an implant abutment (Straight Transepithelial Abutment; Galimplant) to 30 Ncm on each implant.
2. Hand tighten[29] a PG marker into each implant abutment and obtain a photogrammetry scan (PIC Camera; PIC dental)[30] (extraoral PG scan). Retrieve the PG markers.
3. Hand tighten a healing abutment on each implant abutment (Transepithelial Healing Abutment; Galimplant) and obtain a scan by using the IOS (soft tissue scan).

The scans were registered in pairs by using the common information between 2 scans with a dental CAD program (Fig. 9A-C).[22] The dental laboratory technician designed and fabricated the mandibular

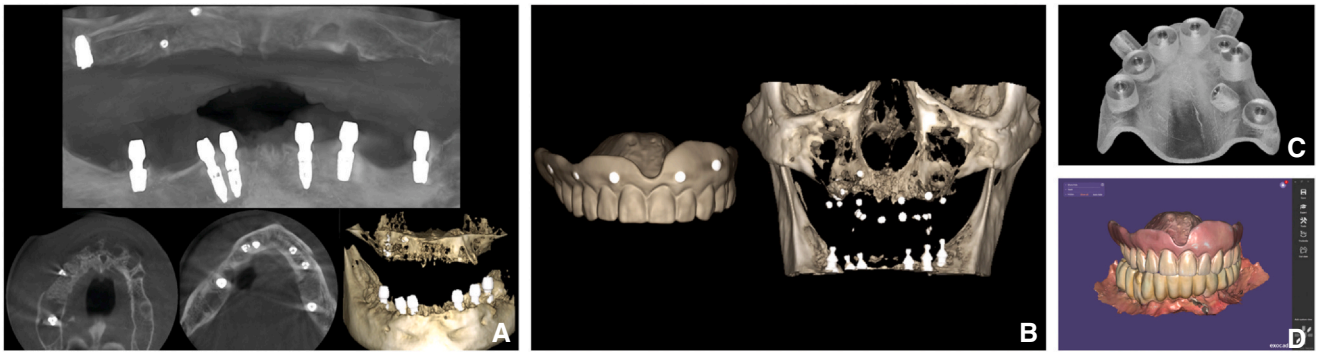

Figure 7. Treatment planning procedures phase 2. A, CBCT scan after sinus elevation and grafting procedures. B, Double CBCT scan method. C, Surgical implant guide. D, Intraoral scans after healing of first surgical and restorative phase 1: extraoral scan of maxillary interim CD and mandibular interim prosthesis. CBCT, cone beam computed tomography; CD, complete denture.

Table 2. Anatomic reference-based implant scanning workflow used in maxillary first surgical and restorative phase 2.

Digital Scans	Information Contained	Reference Landmark/s
Extraoral PG scan	- Implant positions	- Implant healing abutment geometries for registration between extraoral PG and soft tissue scan
Soft tissue scan	- Healing abutment geometry of all placed implants	- Implant healing abutment geometries for registration between extraoral PG and soft tissue scan
Digitized interim CD scan	- Healing abutment geometry of all placed implants in intaglio surface of interim CD	- Implant healing abutment geometries for registration between soft tissue and digitized interim CD scan - Teeth of interim CD for registration between digitized interim CD and diagnostic waxing/initial scans.
Antagonist scan	- Antagonist dentition for occlusal anatomy design of prosthesis being fabricated	- Teeth of occlusal records for registration between digitized interim CD and antagonist scan (This step is automatically completed by IOS program)
Maxillomandibular relationship	- Bilateral occlusal record for maxillomandibular relationship	- Teeth of occlusal records for registration between digitized interim CD and antagonist scan (This step is automatically completed by IOS program)
Extraoral PG scan	- Implant positions	- Implant healing abutment geometries for registration between extraoral PG and soft tissue scan

CD, complete denture; IOS, intraoral scanner; PG, photogrammetry

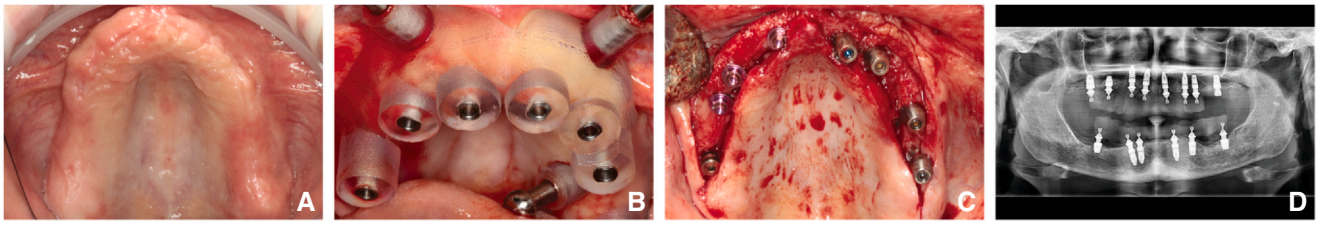

Figure 8. Surgical phase 3. A, Presurgical maxillary arch. B, Surgical implant guide placed in maxilla. C, Implants placed. D, Panoramic radiograph.

screw-retained implant-supported restoration, which was delivered the day after the implant placement surgery by following conventional methods (Fig. 10).

After 6 months of healing time and clinical evaluation of the implants and interim prostheses, the definitive prostheses were fabricated. An anatomic reference-based

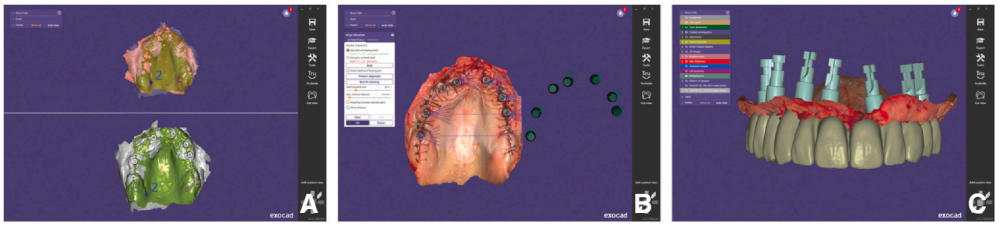

Figure 9. A, Registration between intaglio surface of digitized interim CD and soft tissue scans. B, Registration between extraoral PG and soft tissue scans. C, Maxillary screw-retained interim prosthesis design. CD, complete denture; PG, photogrammetry.

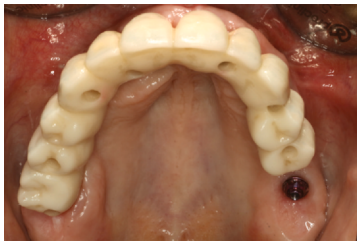

Figure 10. Maxillary screw-retained interim implant-supported restoration.

implant scanning workflow was selected. An intraoral PG (AoralScan Elite; Shining 3D) was used to capture implant positions (Fig. 11). The scan of the maxillary and mandibular screw-interim prostheses recorded the tooth position information of the prosthesis being fabricated, a bilateral occlusal record captured the maxillomandibular relationship, and the soft tissue scans recorded by using implant healing abutments provided the information for designing the intaglio surfaces of the definitive prostheses (Figs. 12, 13). Esthetic improvements related to minor tooth positions were implemented in the design of the definitive prostheses. The definitive prostheses were delivered, and the patient was integrated into a regular maintenance protocol.

DISCUSSION

Two implant scanning workflows have been described. The different treatment phases and interventions completed throughout the surgical and prosthodontic care represent different clinical conditions of the patient, varying prostheses designs, and registration procedures. The understanding of all the different scans needed to fabricate an implant prosthesis and how these scans are registered is critical to the successful integration of digital technologies in prosthodontic care. While the accuracy of implant scans has been broadly analyzed, the accuracy of the registration procedures of all the scans of an implant scanning workflow remains uncertain. The standardization of implant workflows is needed to obtain predictable outcomes.

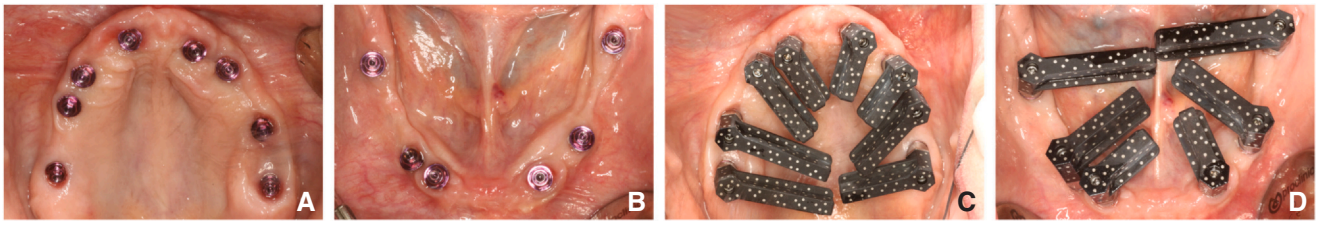

Figure 11. Restorative phase 3 after healing procedures. A, Maxillary arch. B, Mandibular arch. C, Intraoral PG implant scan bodies placed into maxillary implant abutments. D, Intraoral PG implant scan bodies placed into mandibular implant abutments. PG, photogrammetry.

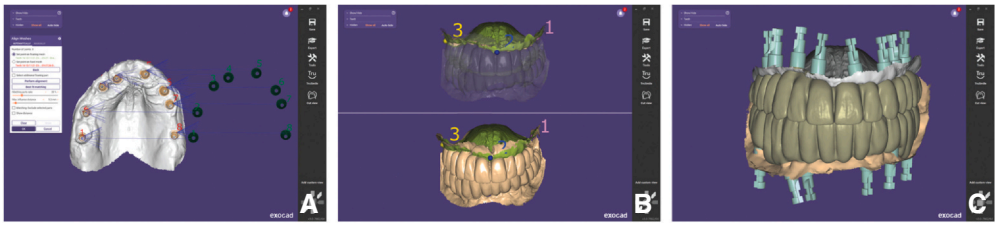

Figure 12. Registration procedures using dental computer-aided design program. A, Alignment of maxillary soft tissue and implant scans. B, Alignment of maxillary soft tissue and tooth position information scans. C, Virtual design of maxillary and mandibular definitive screw-retained implant-supported prostheses.

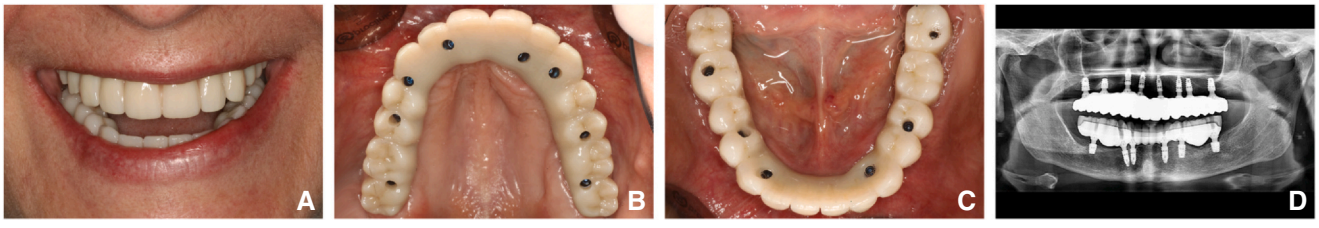

Figure 13. Definitive prostheses. A, Smile view. B, Maxillary screw-retained implant-supported prosthesis. C, Mandibular screw-retrained implant-supported prosthesis D, Panoramic radiograph.

A tripod reference-based implant scanning workflow was implemented during the first surgical phase. The location and disposition of the 3 landmarks eased the registration procedures. Clinical complications include the mobility of any of these landmarks, which could introduce registration discrepancies into the procedure. The anatomic reference-based implant workflow represents an easier procedure when compared with the tripod reference-based protocol, as it does not require placing artificial landmarks. However, the amount of attached mucosa may significantly impact the reliability of this workflow. When limited attached mucosa is present, especially in the mandibular arch, using fixation screws as artificial landmarks may be recommended. Moreover, the anatomic- and tripod-reference based landmarks can be implemented independently of the implant scanning technique used to capture implant positions. Studies are needed to assess the accuracy of the implant workflows guided by different reference landmarks and their impact on the prosthesis being fabricated.

SUMMARY

This manuscript describes 2 implant scanning workflows for fabricating complete arch implant-supported prostheses. A tripod landmark-based workflow composed of an existing tooth and 2 temporary anchorage devices and an anatomic landmark-based workflow are described in 3 different treatment phases to align the scans of the implant scanning workflows.

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