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CLINICAL RESEARCH

A digital approach integrating facial scanning in a CAD-CAM workflow for complete-mouth implant-supported rehabilitation of patients with edentulism: A pilot clinical study

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ABSTRACT

Statement of problem. Complete-mouth implant-supported rehabilitations are challenging because of the multiple surgical and prosthetic steps involved in clinical evaluations to assure passive prosthesis fit and optimal esthetic and functional outcomes. As a result, these rehabilitations are usually associated with substantial clinical time, patient discomfort, and high treatment cost.

Purpose. The purpose of this pilot clinical study was to evaluate a novel digital approach integrating digital intraoral dental and extraoral facial scanning information to design and mill a computer-aided design and computer-aided manufacturing (CAD-CAM) implant-retained prosthesis for patients with complete edentulism.

Material and methods. Ten patients in need of full-mouth rehabilitation were included in this pilot study. Digital intraoral records were obtained through optical scanning the duplicate interim prosthesis using a laboratory scanner, while digital extraoral records were obtained through facial scanning using an in-office scanner. The scanned impressions and occlusal records were used to create a virtual tooth arrangement, which was matched to the patient's 3-dimensional face scan to create a virtual clinical evaluation phase. After applying the necessary adjustments, the virtual arrangement was submitted to a CAM procedure where a 5-axis industrial milling machine was used to fabricate an interim prosthesis.

Results. Digital intraoral and extraoral records were integrated and used to fabricate CAD-CAM milled interim prostheses, which were inserted and assessed for clinical fit, occlusion/articulation, and esthetics. The prostheses remained in function for at least 6 months with no notable technical or biological complications except for 1 prosthesis that fractured.

Conclusions. A novel digital workflow incorporating facial scanning in a CAD-CAM workflow was used to fully digitally design and mill 10 implant-retained interim prostheses. More research is required to further develop and assess the accuracy and applicability of this approach. (J Prosthet Dent 2016;■:■-■)

Complete-mouth rehabilitation in patients with edentulism remains a clinical challenge since various prosthetic and surgical parameters need to be evaluated.[1] In particular, a maxillary rehabilitation is difficult because the prosthesis needs to satisfy the patient's esthetic requirements and also restore function.[2] Therefore, preoperative diagnostics and treatment planning are essential for long-term success, and the diagnostic evaluation should include comprehensive information regarding the dental, skeletal, and soft tissue facial profile of the patient. A conventional prosthodontic diagnostic evaluation consists of dental casts mounted in an articulator supplemented with photographs and radiographs. This evaluation provides a limited 2-dimensional representation of the maxillofacial region but fails to depict the patient in 3 dimensions (3D). In addition, no information is provided regarding the patient's external soft tissue profile, although this is essential for achieving optimal esthetics.[3]

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Clinical Implications

The proposed digital approach may increase the precision of a complete rehabilitation of patients with edentulism, improving patient comfort and esthetics while reducing chair time and treatment cost.

Contemporary computer-aided design and computer-aided manufacturing (CAD-CAM) technology has significantly improved the predictability of fabricating complete-mouth implant supported restorations.[4,5] The availability of guided implant surgery with the aid of cone-beam computed tomography, digital intraoral impression and laboratory scanning, computer-aided framework and prosthesis design, and high-precision computer-guided milling has ushered prosthodontics into a new era of clinical practice.[6-8] CAD-CAM technologies have been successfully applied to treat edentulous patients with implant-supported prostheses.[9,10]

Digital 3D facial scanning is a rapidly evolving technology with a wide range of applications in the fields of biomedical engineering, industrial design, and 3D animation.[11,12] The technology promises to complete the virtual prosthetic patient record by supplying information regarding the external patient profile. Recent technology developments include the realization of economic, compact, in-office systems with integrated software platforms geared toward prosthetic dentistry applications. This, coupled with the wide availability of CAD-CAM systems, has made it possible to virtually design and fabricate a complete-mouth implant-supported prosthesis using a completely digital approach.[13]

Advantages of the CAD-CAM procedure include the elimination of multiple clinical evaluation visits, thereby reducing chair time and treatment costs and allowing better communication with the dental laboratory regarding prosthesis design and increased ability to realize an individualized tooth arrangement. The purpose of this clinical study was to evaluate a novel clinical protocol incorporating facial scanning and virtual tooth arrangement in a CAD-CAM workflow to design and fabricate implant-supported prostheses for edentulous patients.

MATERIAL AND METHODS

The local medical ethical review board approved the study protocol (registration 2014.154), and 10 participants in

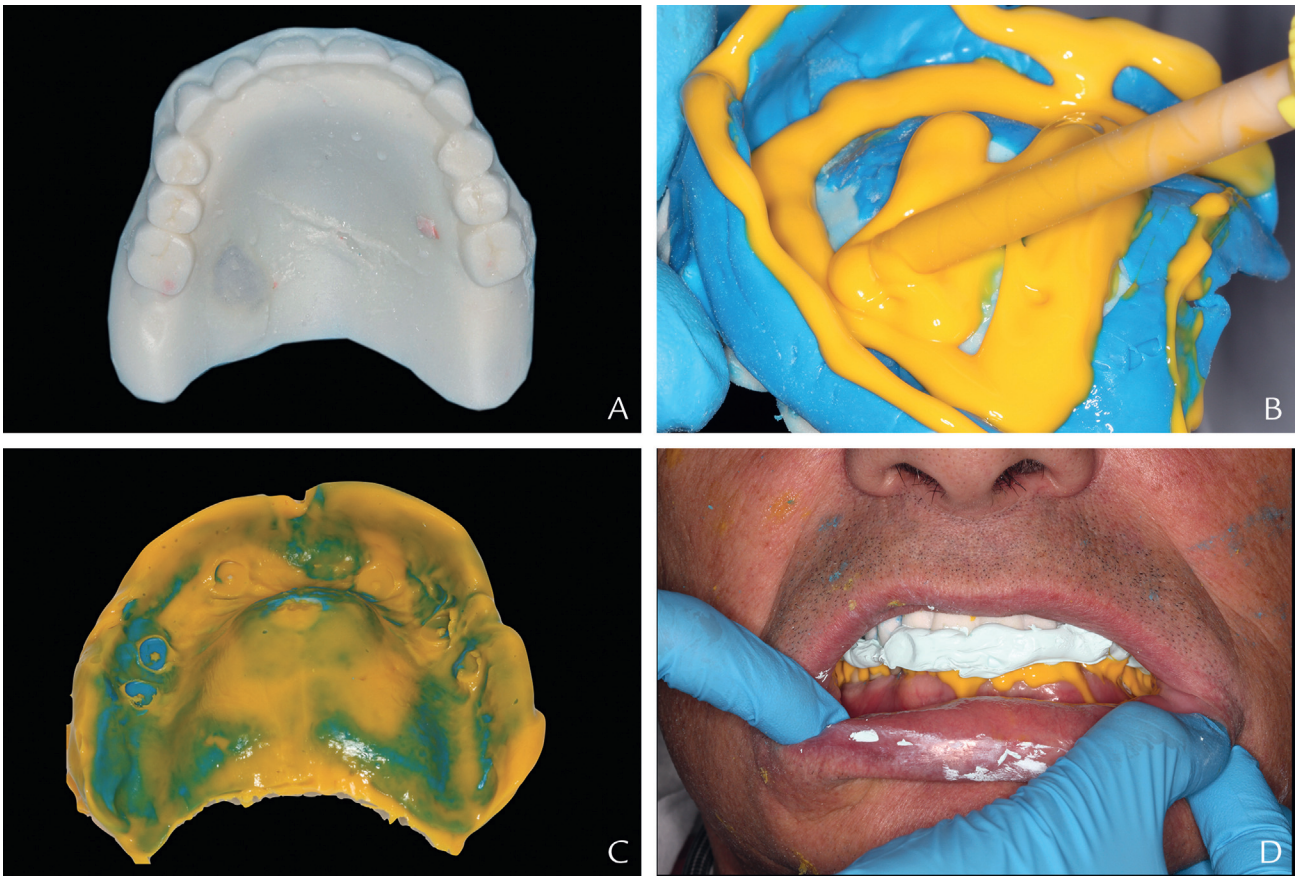

Figure 1. A, Acrylic resin duplicate of existing denture. B, Duplicate realigned using 2-stage (medium and light body) silicone impression material. C, Impression seated on healing abutments. D, Occlusal record obtained in maximum occlusion position.

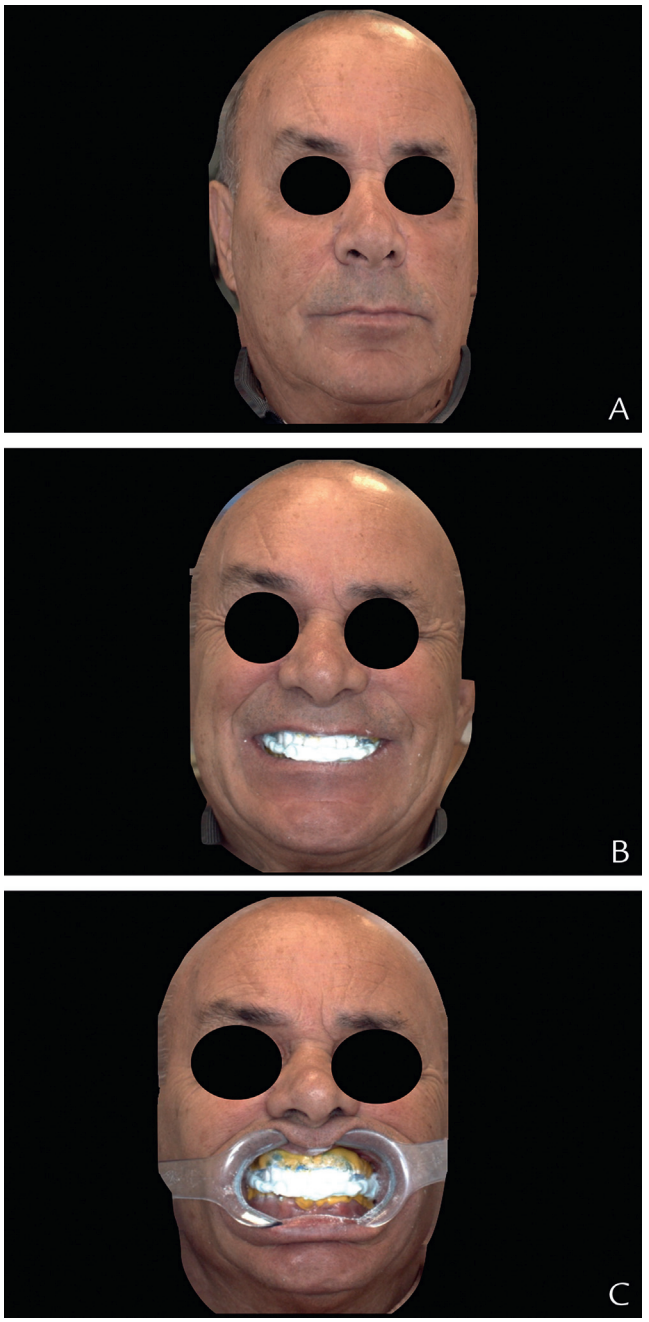

Figure 2. A, Facial scan in neutral head position. B, Facial scan in maximum smile position. C, Facial scan with cheek retractors in place to expose anterior teeth.

need of complete-mouth prostheses after implant placement were recruited. The study objective was explained to all participants, and signed informed consent was obtained. The participants were treated with the Straumann AG and Nobel Biocare AG implant systems. After clinical and radiographic examinations, the digital preoperative planning phase began. The existing prosthesis was duplicated and used as a basis for obtaining the digital intraoral record. The tissue-bearing area was relined with a silicone impression material (AvaDent Impression Material; Global Dental Sciences), and occlusal records were obtained with an occlusal registration material (Fig. 1). This technique has been previously described for obtaining intraoral records for fabricating CAD-CAM complete dentures.[14]

Each participant was subsequently scanned with an extraoral facial scanning system (Pritimirror; Pritidenta GmbH) to obtain 3D facial scans with the duplicate and the occlusal record in situ. The scanning technology consists of a camera system able to capture the 3D geometry of the face and to overlay a photorealistic skin texture photograph using a single exposure, thus permitting accurate acquisition of the soft tissue profile in 3D.[15]

Three facial scans were obtained with the patient seated. The first scan was of a head position with the Frankfort plane parallel to the floor with the lips in light contact (Fig. 2A). The second facial scan was in an exaggerated smile to establish the level of the lip line (Fig. 2B), and the third scan was obtained using cheek retractors to expose the dental arches and the anterior teeth (Fig. 2C). This was necessary to provide a reference for matching with the intraoral record (the duplicate of the maxillary denture, opposing arch impression, and the occlusal registration).

After the facial scanning procedure, the model casts and occlusal records were scanned with a laboratory scanner (iSeries DWOS; Dental Wings). The scanned casts were transferred to CAD software for creating a virtual tooth arrangement (Fig. 3). The prosthetic parameters of this arrangement included tooth form, gingiva shape, vertical dimension of occlusion, and compensation curves of Spee and Wilson. The facial scan was used to define the interpupillary and midsagittal planes and to examine the tooth form and buccal corridor width with regard to the patient's smile line.

The facial scan information was made available to the laboratory technician to help with the design. Subsequently, the virtual setup was stored as a stereolithography (STL) file. A surface matching (registration) procedure was required to integrate the virtual arrangement with the patient's face. Pritimirror software was used to perform all matching procedures by selecting surface areas at anatomically corresponding locations in the scans. The facial scans were registered to each other by selecting the forehead area, which was reproduced consistently in the 3 scans (Fig. 4).[7]

Subsequently, the scanned prosthesis and occlusal records were matched to the facial scan with cheek retractors using the labial surfaces of the maxillary anterior teeth as a fixed reference. Identical landmarks on the labial surfaces were selected to orient the 3D images of the duplicate and occlusal records in the same coordinate system as the facial scan. Subsequently, the duplicate and occlusal records were matched to the scan

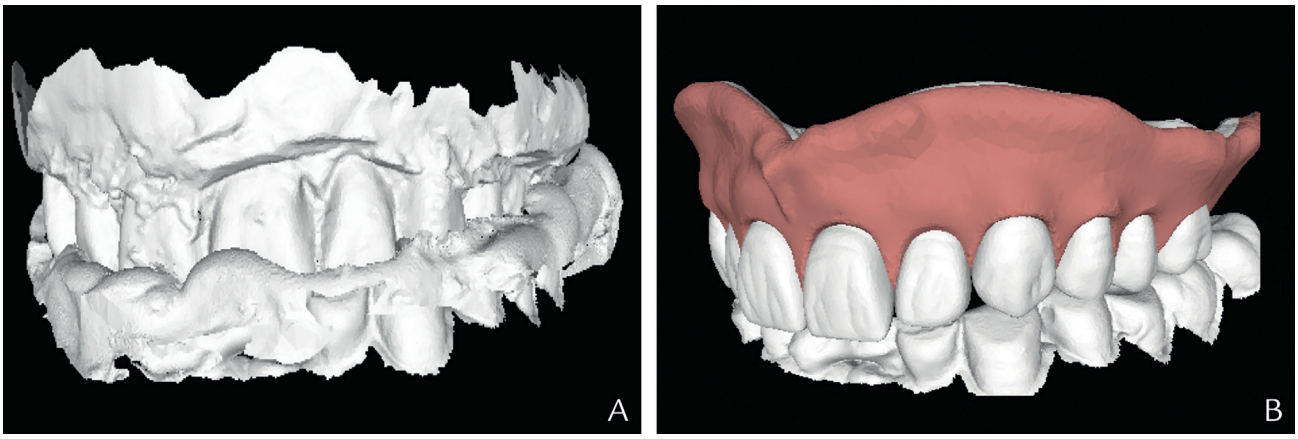

Figure 3. A, Three-dimensional model of denture duplicate and occlusal registration material. B, Virtual tooth arrangement in correct occlusal relationship.

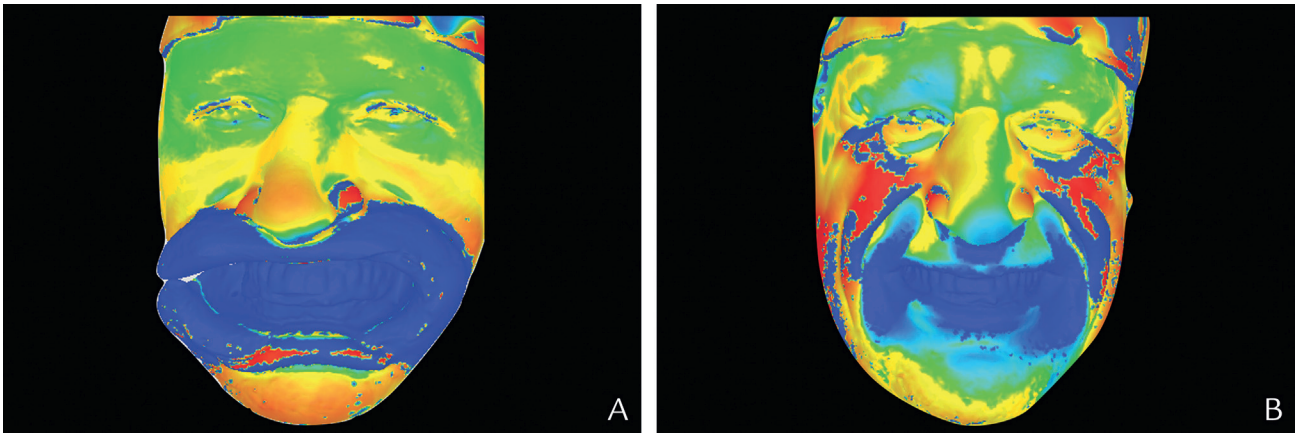

Figure 4. Registration (matching) using forehead as fixed reference (green area). A, Check retractor scan. B, Smiling scan.

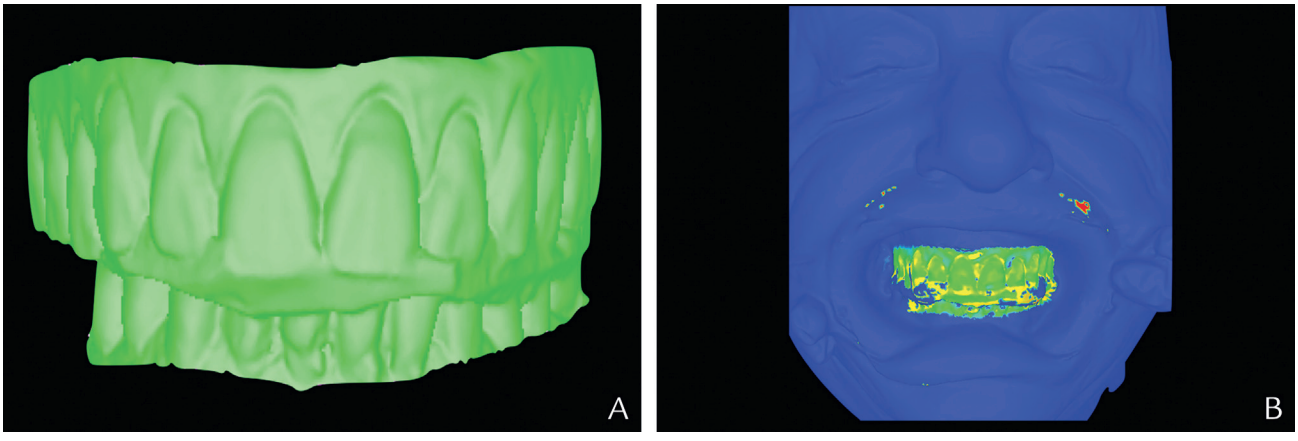

Figure 5. A, Three-dimensional model of scanned duplicate and occlusal record registered (matched) to cheek retractor facial scan. B, Labial surfaces of maxillary anterior teeth used as reference for matching with scanned duplicate.

with cheek retractors using the iterative closest point surface-matching algorithm (Fig. 5).[16] The virtual tooth arrangement was then placed in the same coordinate system as the facial scan in the exaggerated smile projection (Fig. 6). The virtual tooth arrangement was then used to evaluate tooth form and position, lip exposure, buccal corridor, and midsagittal and interpupillary lines with regard to facial esthetics.

Where required, adjustments were made to the virtual tooth arrangement and reinspected in the facial

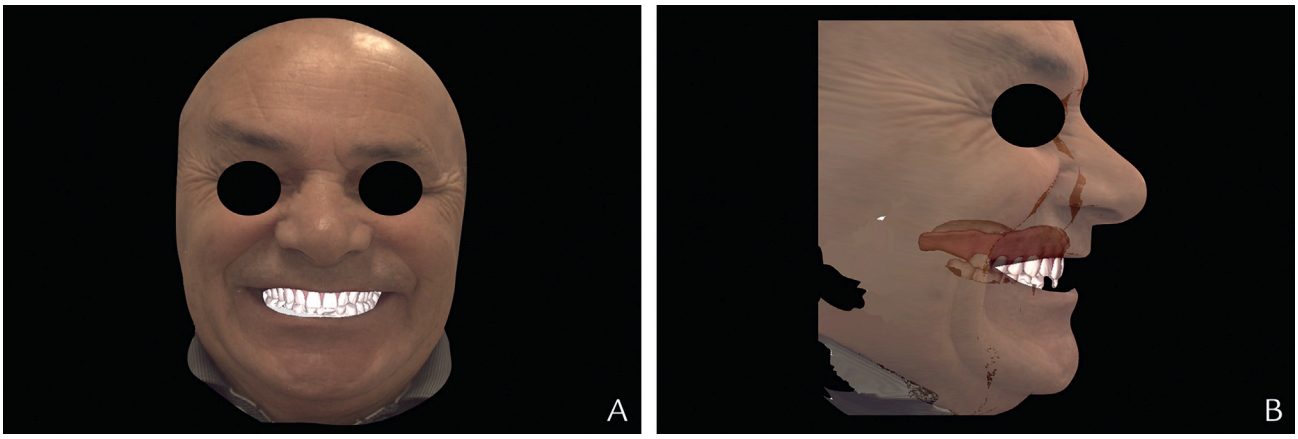

Figure 6. Virtual tooth arrangement integrated in facial scan. A, Anterior view. B, Lateral view.

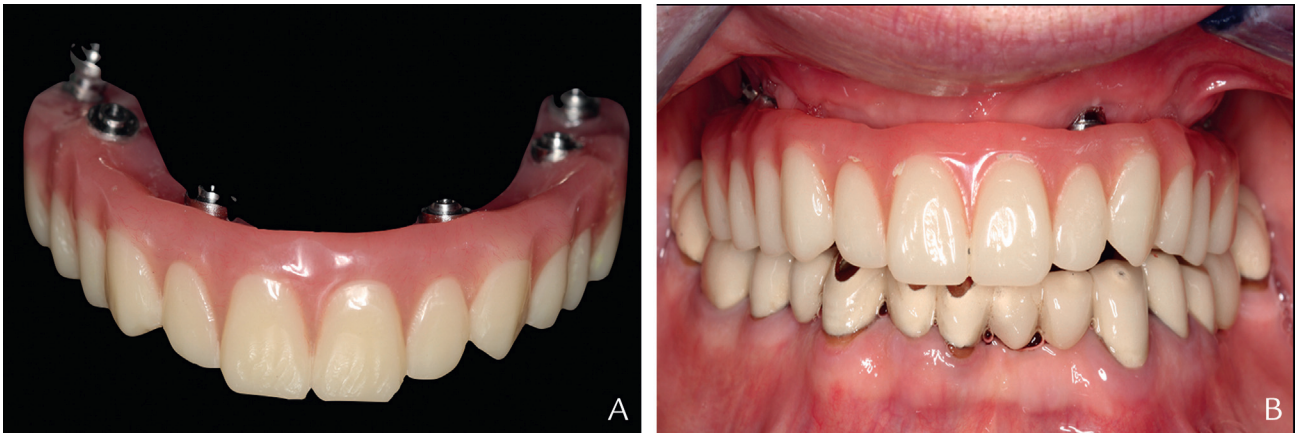

Figure 7. A, Milled interim prosthesis with implants cylinders. B, Intraoral view of interim prosthesis.

scan. The approved tooth arrangement was subsequently sent as an STL file to a milling machine using a 5-axis industrial milling unit (M7 CNC; Darton AG General). The interim prosthesis with teeth and gingiva were milled using an individually made puck (AvaDent Blank; Global Dental Sciences), and the prosthesis was polished and implant cylinders were fitted (Fig. 7).

RESULTS

Ten patients were treated with a complete rehabilitation using a novel digital approach incorporating facial scanning technology, virtual tooth arrangement, and CAD-CAM milling. The clinical fit and esthetics were acceptable, and all prostheses remained in function for at least 6 months with no notable biological or technical complications, except for 1 prosthesis that fractured. This may have been due to reduced vertical dimension of occlusion and reduced interocclusal clearance. The virtual tooth arrangement of these interim prostheses served as the basis for designing the definitive metal ceramic, implant-supported prostheses.

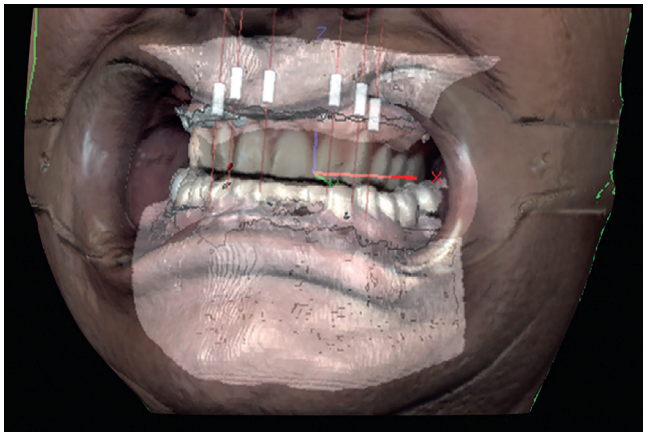

Figure 8. Virtual patient with compilation of facial scanning and intraoral and cone beam computed tomographic scans to plan implants position according to prosthetic demands.

DISCUSSION

This study was undertaken to evaluate the feasibility of incorporating 3D facial scanning information into a

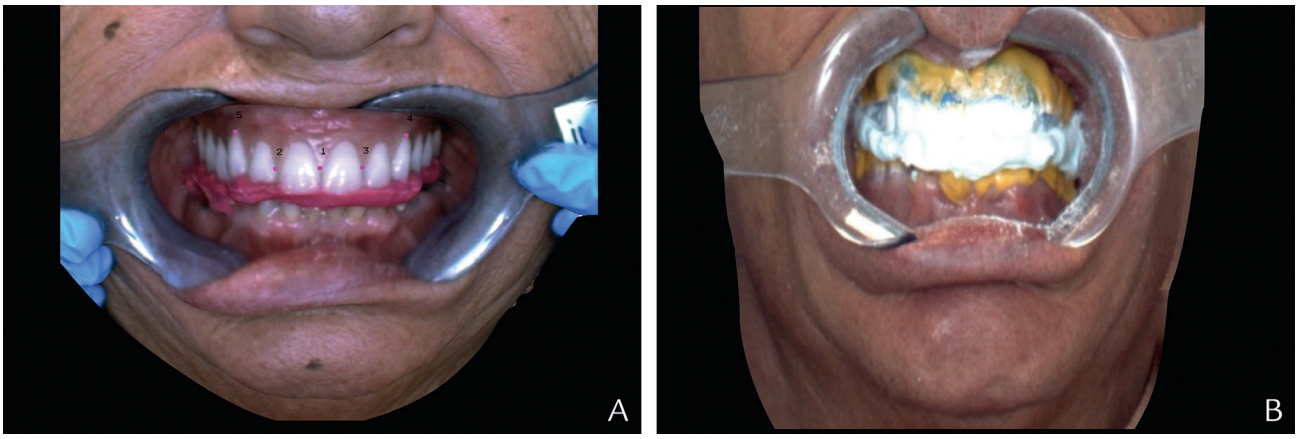

Figure 9. Visibility of intraoral record (labial surfaces of teeth) differs according to color of duplicate and occlusal registration material. A, Existing denture demonstrating good tooth visibility. B, Duplicate denture with opaque registration material with strong light reflection.

Figure 10. Problems with the registration procedure. A, Deep wrinkles on forehead. B, Facial hair.

complete digital workflow to rehabilitate patients with edentulism. In this case series, the feasibility of adopting such a digital approach was tested. Integrating a virtual clinical evaluation phase with facial scan permitted instant adjustments of tooth morphology and position with the immediate inspection of the impact on the patient's facial appearance. These procedures would require considerable manual labor, time, and cost in traditional waxing. Subjectively, using this digital approach also improved clinician and laboratory communication regarding prosthesis design. Indeed, a technician who usually only sees photographs of the patient immensely benefitted from the virtual clinical evaluation, which led to improved patient-dentist-laboratory communication. In 1 treatment, this digital approach also improved preoperative planning for a complete mouth rehabilitation with immediate implant loading (Fig. 8).[5]

However, this digital workflow has several drawbacks. The first is the issue of accuracy in integrating the different scanning data. Integrating the occlusal record into the facial scan depended on the visibility of the labial surfaces of the anterior maxillary teeth as a fixed reference in the 3D facial scanner.[2,7] White-colored duplicate dentures and occlusal registration material were poorly visualized compared with dark-colored occlusal records (Fig. 9). This is due to the lens reflection on the scanner, which reduces the visibility of the anterior teeth. Therefore, an acrylic resin material and occlusal registration material of darker color is recommended for the scanning procedure. Second, matching the 3 facial scans (neutral, exaggerated smile, and cheek retractor) to each other depended on the visibility of the forehead as a stable landmark. However, in elderly patients with deep facial wrinkles, this region deformed when the patient smiled, thereby hampering an accurate registration procedure.

Patient-related factors including movement during the scan, salivary flow, and facial hair might also influence the accuracy of the scanning and registration procedure (Fig. 10).

The authors found few published articles discussing the value of integrating facial scanning technology in clinical dentistry. Rangel et al[3] presented the concept of integrating digital dental casts with extraoral facial scans in

a healthy individual with an intact dentition and suggested that such an arrangement could be valuable for orthodontic applications. Rosati et al[17] assessed the validity of this approach on 11 patients and concluded that integrating virtual teeth and facial scans can be accurate and is technically feasible. Joda and Gallucci[18] presented a clinical report discussing the integration of cone-beam computed tomography, intraoral digital impression, and extraoral facial scan to rehabilitate a patient with 2 implants in the esthetic zone. To our knowledge, this is the first clinical study to apply the concept of virtual patient to rehabilitate patients with complete edentulism. Future research should concentrate on validating the accuracy of this approach and expanding its future applications.

CONCLUSIONS

This pilot clinical study documented the completely digital workflow used to rehabilitate edentulous patients with implant-supported interim prostheses.

REFERENCES

1. Goodacre CJ, Garbacea A, Naylor WP, Daher T, Marchack CB, Lowry J. CAD-CAM fabricated complete dentures: concepts and clinical methods of obtaining required morphological data. J Prosthet Dent 2012;107:34-46.
2. Jivraj S, Chee W, Corrado P. Treatment planning of the edentulous maxilla. Br Dent J 2006;201:261-9.
3. Rangel FA, Maal TJ, Bergé SJ, van Vlijmen OJ, Plooij JM, Schutyser F, et al. Integration of digital dental casts in 3-dimensional facial photographs. Am J Orthod Dentofacial Orthop 2008;134:820-6.
4. Piermatti J. Using CAD-CAM technology for the full-mouth, fixed, retrievable implant restoration: a clinical report. J Oral Implantol 2007;33:23-7.
5. Kapos T, Ashy LM, Gallucci GO, Weber HP, Wismeijer D. Computer-aided design and computer-assisted manufacturing in prosthetic implant dentistry. Int J Oral Maxillofac Implants 2009;24:110-7.
6. Fuster-Torres MA, Albalat-Estela S, Alcañiz-Raya M, Peñarrocha-Diago M. CAD-CAM dental systems in implant dentistry: update. Med Oral Patol Oral Cir Bucal 2009;14:141-5.
7. Spyropoulous PE, Razzoog ME, Duff RE, Chronaios D, Saglik B, Tarrazzi DE. Maxillary implant-supported bar overdenture and mandibular implant-retained fixed denture using CAD-CAM technology and 3-D design software: a clinical report. J Prosthet Dent 2011;105:356-62.
8. Kleinman A, Avendano S, Leyva F. Esthetic treatment option for completely edentulous patients using CAD-CAM technology. Pract Proced Aesthet Dent 2008;20:185-91.
9. Pozzi A, Tallarico M, Mangani F, Barlattani A. Different implant impression techniques for edentulous patients treated with CAD/CAM complete-arch prostheses: a randomised controlled trial reporting data at 3 year post-loading. Eur J Oral Implantol 2013;6:325-40.
10. Baig MR, Rajan G, Rajan M. Edentulous arch treatment with a CAD-CAM screw-retained framework and cemented crowns: a clinical case report. J Oral Implantol 2009;35:295-9.
11. Da Silveira AC, Daw JL Jr, Kusnoto B, Evans C, Cohen M. Craniofacial applications of three-dimensional laser surface scanning. J Craniofac Surg 2003;14:449-56.
12. Mankovich NJ, Samson D, Pratt W, Lew D, Beumer J 3rd. Surgical planning using three-dimensional imaging and computer modeling. Otolaryngol Clin North Am 1994;27:875-9.
13. Hassan B, Gimenez Gonzalez B, Tahmaseb A, Jacobs R, Bornstein MM. Three-dimensional facial scanning technology: applications and future trends. Forum Implantol 2014;10. 78-6.
14. Lozada JL, Garbacea A, Goodacre CJ, Kattadiyil MT. Use of a digitally planned and fabricated mandibular complete denture for easy conversion to an immediately loaded provisional fixed complete denture. Part 1. Planning and surgical phase. Int J Prosthodont 2014;27:417-21.
15. Kau CH, Richmond S, Zhurov AI, Knox J, Chestnutt I, Hartles F, et al. Reliability of measuring facial morphology with a 3-dimensional laser scanning system. Am J Orthod Dentofacial Orthop 2005;128:424-30.
16. Besl PJ, McKay ND. A method for registration of 3D shapes. IEEE Trans Pattern Anal Mach Intell 1992;142:239-46.
17. Rosati R, De Menezes M, Rossetti A, Sforza C, Ferrario VF. Digital dental cast placement in 3-dimensional, full-face reconstruction: a technical evaluation. Am J Orthod Dentofacial Orthop 2010;138:84-8.
18. Joda T, Gallucci GO. The virtual patient in dental medicine. Clin Oral Implants Res 2015;26:725-6.

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