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We live in a world where technology is evolving almost faster than we can keep up with it. We have digital radiographs, digital panoramic radiography, CBCT, CAD/CAM, intra-oral scanning, stereolithography and 3D printing, guided surgery with static and dynamic navigation, robotic navigation and surgery, and artificial intelligence making their mark within the dental arena. Computers are gaining speed and incredibly fast graphics processing power, yielding improved displays of dizzying resolution. We have 50+ MP cameras in our cell phones and Apple’s newest generation iPhone 11 even has three cameras! The Internet is everywhere with Wi-Fi access at faster and faster speeds to send our data around the globe in fractions of a second, allowing us to video-chat instantaneously via our smart watches, phones, tablets and computers.

Regardless of the technology, it will continue to evolve and become an integral part of society. In our niche of dentistry, we have every reason to embrace technological advances because these can enhance our approach to conventional treatment while helping to provide alternatives to treatment modalities that should impact our patient’s quality of life. However, there are problems with racing to keep up with the fast pace of change. How do we absorb all this incredible technology? How do we implement these changes in our daily practice? Are there enough educational opportunities available to teach proper use and appreciation of the newest and boldest technologies? Do we have enough time to spend on learning?

Clearly, the advent and incorporation of 3D imaging and interactive treatment planning software has provided clinicians with new tools for improved diagnostics because we can visualise and assess patient anatomy far better that we ever could with 2D imaging modalities. The incorporation of intra-oral scanning allows clinicians to digitise the oral environment and merge this with the DICOM data from a CBCT scan, a synergy that greatly enhances the diagnostic process. We can take this information and export the data into a CAD system to virtually assess occlusion and fabricate restorations or surgical guides via milling or 3D printing. Almost every day, another device is introduced to the marketplace. The real question is not how powerful the technology is, but who is going to teach us how to use it properly and whether we can spare enough valuable time to learn. We must remember that it is not the computers that make the decisions; it is a combination of clinical experience, imagination, and utilisation of technology that aids us all in making educated decisions for our patients.

The purpose of our CAD/CAM magazine is to provide a platform for dissemination of knowledge. We greatly appreciate all the authors who put pen to paper and document their work for inclusion in one of our issues, and of course all our readers who take the time to read and digest the wonderful work that is shared in each issue. Knowledge is one of the most important keys to success and we need to make the necessary time to keep up with progress.

Dr Scott D. Ganz
Editor-in-Chief
editorial
Do we have the time to learn?
Dr Scott D. Ganz

03

case report
A multidisciplinary digital approach to a complex case
Dr Antonio Lipari, Dr Mario Perotti, Marco Marzolla & Dr Valerio Bini

06
Full-arch implant surgical and restorative considerations
Drs Scott Ganz & Isaac Tawil

14
A fully digital workflow with 3D-printed provisional restorations
Drs Anthony Mak & Andrew Chio

20
Restoring a smile to proper form and function
Dr Ara Nazarian

26
trends & applications
A challenge in dental computerised photogrammetry
Dr Olivier Landwerlin, Prof. Michel Fages & Dr Gérard Subsol, France

30
feature
All smiles for AI:
How artificial intelligence can add value to orthodontic treatment
Simone Matt

42
cone beam supplement
Use of CBCT bone densitometry for pre-surgical decision-making regarding immediate implant loading
Dr Dr Angelo Trödhan

44
interview
Almost 70 per cent of my cases are performed with X-Guide
An interview with Dr Alessandro Pozzi

48
“Education remains a priority for the company”
An interview with Jo Massoels, Vice President of Global Marketing and Solutions at Dentsply Sirona Implants

50
meetings
The second MIS Makeathon: From start to start-up in 36 hours

52
International events

54
about the publisher
submission guidelines

56
international imprint

58
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A multidisciplinary digital approach to a complex case

Surgical, aesthetic and occlusal procedure planning for implant-supported full-arch prostheses

Dr Antonio Lipari, Dr Mario Perotti, Marco Marzolla & Dr Valerio Bini, Italy

Introduction

Thanks to digital technology, a growing number of edentulous or partially edentulous patients with residual malocclusion and dysfunction can now be offered a good-quality customised and aesthetically pleasing prosthesis as well as long-term restoration of occlusal function. The surgical planning and execution required to achieve correct occlusion can now be realised with the assistance of a variety of digital tools, with an accuracy that in the past would have required a great deal of time and resources to achieve. This article reports a digital approach that makes a complex workflow easier to manage and that has the advantage of wider access to high-quality customisation of surgical management and aesthetic and occlusal design.

Case presentation

The case concerns a 58-year-old male patient (Fig. 1) with no relevant medical history. There was clinical...
dence of tooth and bone loss as result of periodontitis and previous poor-quality dental treatment, the use of inappropriate removable dentures with compromised aesthetics, and crossbite malocclusion (Fig. 2) with dysfunctional symptoms. Edentulism and bone loss in the maxillary arch and the presence of three teeth and two implants with a poor periodontal prognosis were evident in the clinical examination and radiographic images (Fig. 3). The patient required fixed maxillary and mandibular implant-supported full-arch prostheses.

After removal of the residual teeth and implants, the patient was fitted with two removable dentures in the reference position, which improved jaw alignment, vertical dimension of occlusion, overbite, overjet, speech and aesthetics.

A cephalometric tracing on a lateral radiograph was done to obtain an initial aesthetic and functional evaluation of the case (Fig. 4), and this was followed by prosthetic and surgical (Fig. 5) planning.
The characteristics of the prostheses determined the surgical plan (SMOP, Swissmeda; Figs. 6a–c) and two surgical guides were subsequently laser-sintered (2INGiS), locating both implant positioning and, for the maxillary arch, the bilateral maxillary sinus lift sites. Implants were thus positioned as planned (Figs. 7 & 8), except for those in the posterior maxilla, where maxillary sinus lifts were bilaterally performed (Fig. 9).

After two months, an intra-oral scan (Fig. 10) was taken and the 3D-printed models subsequently obtained were stone-based and re-virtualised (Fig. 11) using a desktop scanner (inEos X5, Dentsply Sirona). Jaw alignment and implant positioning were also accurately recorded by duplicating the interim prostheses and intra-orally fixing the transfer positions on to the copies, whose fit and occlusion had to be
checked for complete accuracy. The jaw relation was used for mounting the casts, which were fixed on mounting blocks with a facebow in a fully adjustable arcon articulator (Reference SL, GAMMA). The central incisors and first molars were assembled bilaterally at an inclination of 12° to the occlusal plane (Fig. 12), which was previously defined using cephalometric tracing.

The teeth were then scanned with a desktop scanner, and using the positions of the central incisor and distal first molar cusps for reference, they were imported in the correct spatial positions into the CAD module (exocadDentalCAD Virtual Articulator, exocad; Fig. 13). Not having a virtual Reference SL articulator available in the CAD software, a virtual SAM system (SAM Präzisionstechnik) was used, because both the articulators have the same axio-orbital reference plane, and it is possible to superimpose the geometry of the SAM on to the Reference SL. Border movement condylography (CADIAX Compact, GAMMA; Figs. 14 & 15) was also produced for setting the virtual SAM as indicated by the software (CADIAX software, GAMMA), both for the setting of the condylar and incisal guides and for the adjustment of the sagittal condylar inclination and Bennett angles.

The aesthetic digital smile design and the CAD for the patient were therefore done starting with the vir-
tual models that defined the new occlusal plane. As the maxillary implants could not be immediately loaded, an aluminium try-in screw-retained mesostructure was CAM-milled for the lower jaw, together with a diagnostic wax-up made with singularly detachable wax teeth (Fig. 16).

The complete wax set-up was then transferred again to the Reference SL articulator. The condylographic output was used for a second programming. The wax set-up was further refined by the dental technician, who accurately shaped the functional surfaces according to the sequential functional occlusal design by Prof. R. Slavicek. Differently coloured waxes highlighted the centric ratios, the mediotrusive and protrusive tracking functions, and the retrusive protections (Fig. 17). All aspects of occlusion, the functional guides and uniform disclusions were checked (Figs. 18 & 19).
Copying back the wax-up by scanning to the CAD software (Fig. 20), the virtual prostheses were checked again regarding thickness, the surface and shape of the connections, and the adjustment of the offsets for the fit on the abutments. The file was then imported into the CAM machine (CAM 5-S1, VHF) in order to mill an interim complete denture for the maxillary arch and to mill a screw-retained full-arch prosthesis with a milled titanium mesostructure for the lower jaw (Fig. 21). Both were milled in PMMA with high-stability ceramic micro-fillers (breCAM.multiCOM, bredent).

After some months, another four implants were placed in the maxilla using the same laser-sintered surgical guide (Fig. 22), and after a further six months, the maxillary arch was ready for loading. All the mandibular procedures were repeated for the maxillary arch (Figs. 23 & 24), refining the aesthetic digital smile design and checking occlusal accuracy. Subsequently, we did another condylographic analysis of the CAD’s virtual articulator settings (Fig. 25), as after the many months that had passed, the oral function had changed, and a sequential waxing for the maxillary arch was also made (Fig. 26).

A full-arch screw-retained prosthesis with a titanium mesostructure (Figs. 27 & 28) was placed in the maxillary arch. During the follow-up period, the patient reported great satisfaction with both aesthetics (Fig. 29) and function (Figs. 30a–d).

**Discussion and conclusion**

The use of digital tools described in this article for surgical planning, aesthetic digital smile design and the planning of a canine-dominant occlusal sequential function proved to be convenient for the clinician and the patient, allowing a reduction in working time and a simplification of the procedures involved, as well as significantly facilitating greater customisation. The CAD prostheses can be milled in different materials, with high precision and repeatability in mock-ups and try-ins at lowered costs.

Furthermore, the opportunity to scan the casts, the wax-ups, the mock-ups and the interim prostheses allows for the acquisition of a large amount of valuable information regarding the patient’s anatomy, aesthetic considerations and tooth function data.

**Editorial note:** A list of references is available from the publisher.
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Full-arch implant surgical and restorative considerations

Utilising a full-template guidance technique

Drs Scott Ganz & Isaac Tawil, USA

Introduction

Full-arch dental implant reconstruction requires proper diagnosis and treatment planning to assess the existing patient anatomy, any pathologies, occlusion, soft-tissue volume, lip support, and aesthetics, and gain understanding of the desired outcome.¹ A decision tree can be established based upon sound prosthodontics and surgical protocols to maximise success when a full-arch implant-supported reconstruction is contemplated. Technological innovations can only enhance the diagnostic, treatment planning, communication, surgical and restorative aspects for each patient. Three-dimensional imaging modalities afforded by current CBCT provide the foundation for all that follows (Fig. 1).²,³

The native DICOM data, once imported into interactive treatment planning software (R2GATE, MegaGen), allows for careful inspection of the existing anatomical presentation to identify potential implant receptor sites that will aid in realistic implant placement simulations and avoid potential complications (Fig. 2).⁴ Regardless of the eventual surgical protocol, the authors believe that the diagnostic phase must be based on a complete and thorough review of the CBCT scan data.⁵

Fig. 1: Three-dimensional imaging modalities afforded by current CBCT are essential for proper diagnosis and treatment planning. Fig. 2: Interactive treatment planning software, such as R2GATE, helps clinicians identify potential implant receptor sites to aid in realistic implant placement simulations.

Fig. 3: A failing maxillary and mandibular dentition exhibited mobile teeth, a poor occlusion, malaligned teeth and bone loss.
A failing maxillary and mandibular dentition exhibited mobile teeth, a poor occlusion, malaligned teeth and bone loss (Fig. 3). The CBCT data was analysed to determine the most appropriate treatment alternatives based upon bone quality, bone density and an appreciation of the patient’s desires. Utilising advanced software (Blue Sky Plan, Blue Sky Bio), the diagnostic information for implant planning can be fully appreciated in all of the necessary views, including cross-sectional, coronal, sagittal and axial, and in 3D reconstructed surface models. Implant receptor sites can be identified and virtual implants can be positioned with each of the previously mentioned views, as no single view can provide all of the necessary information to achieve success (Fig. 4a). Placing an implant into a cross-sectional slice is only the beginning of the process of helping to visualise the thickness and opacity of the buccal and palatal cortical plates and the quality of the intermedullary bone to determine whether an implant can be placed that has an appropriate length and diameter to fit the remaining alveolus, based upon the triangle of bone protocol (Figs. 4b & 4c). Additionally, virtual implant simulation plays a significant role in managing the desired restorative outcomes based upon tooth position and the choice of screw or cement retention. In the authors’
opinion, the most efficient manner of facilitating the process is to extend an abutment projection from the coronal aspect of the implant through the occlusal table, as visualised in yellow in Figures 4a and 4b. When a guided surgical approach is contemplated, the template can be designed to be tooth-borne, bone-borne or mucosal-borne. When appropriate, it is important that the drill guide be stabilised to prevent any movement during surgery. One aspect that is often under-estimated is the planning of fixation or anchor pins to help achieve the highest degree of surgical accuracy. Each potential anchor pin must be positioned to avoid adjacent vital structures and engage dense cortical bone, helping to gain bicortical stabilisation when possible. This will often penetrate both buccal and lingual plates and avoid close proximity to implant receptor sites (Figs. 5a & b).

The diagnostic phase is greatly enhanced when the existing intra-oral condition can be captured with either an analogue or a digital method. In a traditional analogue method, a physical impression records the teeth and soft tissue. A stone model can then be fabricated from the impression. To facilitate 3D planning, the stone cast can then be digitised using a desktop scanner. Alternatively, the impression itself can be scanned, resulting in an STL file that can be aligned to the opposing occlusion and then merged to the CBCT DICOM data set (Figs. 6a & b). The fully digital method utilises an intra-oral scanner to directly digitise the oral condition.  

An innovative approach to full-template guidance utilises the existing dentition to position a metal fixation base to which everything else will be related (CHROME GuidedSMILE, ROE Dental Laboratory). Positioning the fixation base over the teeth is accomplished with a pin guide that orients the base in the proper position. A full-thickness mucoperiosteal flap reflects the tissue sufficiently within the vestibule to allow for fixation of the anchor pins to the underlying bone (Fig. 9). Prior to seating over the teeth, the fixation base is securely attached to the pin guide with a series of Swiss locks and delivered over the teeth (Fig. 10a). This method allows for the metal frame to be correctly positioned. Proper fit of the pin guide over the teeth is essential and can be verified by visual inspection though the windows of the resin. In this case, four anchor pins were utilised to stabilise the metal guide (Fig. 10b). As previously stated, it should be noted that planning for the location of receptor sites for the anchor pins is as important as planning for the position of the implants—ensuring that they are all located in good-quality bone, often taking advantage of both buccal and lingual/palatal cortical plates.

**Figs. 8a–c:** To complete the planning process, the diagnostic wax-up or virtual tooth set-up of the desired prosthetic outcome was applied to the 3D surface DICOM data in seeking to achieve restoratively driven implant placement.

**Fig. 9:** A full-thickness mucoperiosteal flap reflects the tissue sufficiently within the vestibule to allow for fixation of the anchor pins to the underlying bone.
After the fixation base had been secured to the bone, the pin guide was removed, leaving the maxillary teeth available for extraction (Fig. 11a). The teeth were all carefully removed, leaving the remaining alveoli exposed (Fig. 11b). It should be noted that the metal guide for this case example was designed to sit floating away from the bone. Planning for a full-arch restoration may require bone reduction to provide the restorative space required, which can be accomplished with rotary instruments, piezo-ultrasonic surgery or a reciprocating saw (Fig. 12a). The amount of bone reduction needed was determined after a careful evaluation of potential implant sites in relation to the desired prosthetic outcome (Fig. 12b). The outer aspect of the metal fixation base was used as a bone reduction guide as first defined by Ganz.9

The carrier guide serves several purposes. The translucent resin plate is first utilised to check whether adequate bone reduction has been accomplished. The carrier guide will not fit passively into the Swiss locks if the bone has not been properly levelled. The compressed area of bone can often be visualised through the resin (Fig. 12c).

Full-template guidance allows for the precise drilling of the implant osteotomies with or without the use of sleeves embedded within the surgical template or separate key inserts that match the drill diameters of the guided surgical kit that must be utilised. Innovative designs have allowed for the elimination of these separate components, simplifying the drilling protocol. The R2GATE guided surgery kit consists of a series of sequential drills that match the diameter of either a resin surgical guide or a metal guide, as illustrated in this case example (Fig. 13). The wide drill core or barrel will engage the entire vertical height of the guide cylinder to ensure drilling accuracy and depth control. Starting with a short drill and gradually using longer drills within the initial osteotomy helps to maintain proper trajectory until final implant diameter and depth are achieved. The osteotomy drill guide was seated on

Figs. 10a & b: Prior to seating over the teeth, the fixation base was securely attached to the pin guide with a series of Swiss locks and delivered over the teeth (a). Proper fit of the pin guide was verified by inspection though the windows of the resin. In this case, four anchor pins were utilised to stabilise the metal guide (b). Figs. 11a & b: After the fixation base had been secured to the bone, the pin guide was removed, leaving the maxillary teeth available for extraction (a). The teeth were all carefully removed, leaving the remaining alveoli exposed (b).

Figs. 12a–c: Rotary instruments (round and serrated tapered burs, MEISINGER USA) was used to manage bone reduction and was required to provide (a) adequate restorative space as determined after careful evaluation of potential implant sites in relation to the desired prosthetic outcome (b). The carrier guide fitted passively into the Swiss locks to verify that the bone had been properly levelled (c). Fig. 13: The R2GATE guided surgery kit consists of a series of sequential drills to achieve full-template guidance in a keyless system.
to the fixation base and secured by the Swiss locks (Fig. 14a). Each osteotomy was carefully prepared with the R2GATE sequential surgical drills with the wide core or barrel that engaged the entire vertical height of the guide cylinder to ensure drilling accuracy and depth control (b). Each AnyRidge implant (integrated dental systems) was first attached to its matching implant carrier and then delivered to the site at the appropriate rotational speed and torque (c). Six AnyRidge implants were placed by first using the handpiece and then hand-torquing them until final depth was achieved (d).

Full-template guidance means the implant is delivered through the template after the osteotomies have been completed. In order to achieve full-template guidance, a manufacturer-specific implant carrier must be used to engage the inner walls of the template cylinders as specified by the planning software. Each implant was first attached to the implant carrier and delivered to the site at the appropriate rotational speed and torque (Fig. 14c). To maximise implant stability within the maxillary bone, it was important to use an appropriate implant design. Six AnyRidge implants (integrated dental systems) were placed, first using the handpiece and then hand-torqued until final depth was achieved (Fig. 14d). Each implant was tested for stability using resonance frequency analysis (Mega ISQ, integrated dental systems) and found to be sufficient to receive an immediate restoration.

Prior to inserting screw-receiving abutments, the carrier guide was once again seated on the fixation base. Depending upon the manufacturer, multi-unit abutments are generally available in various tissue cuff heights and angles that are established during the planning phase. The second purpose of the carrier guide is to help guide the placement of the multi-unit abutments through the predefined holes and on to each implant. The anterior implants received AnyRidge straight multi-unit abutments for the screw-retained prosthesis, and the posterior-most implants received 30° multi-unit abutments. The final purpose of the carrier guide is to orient the transitional prosthesis to the predetermined position of the implants by utilising the resin pillars (Fig. 15a). The right and left distal implants must be rotated so that the angled multi-unit abutments allow for the screw access hole to fit within the envelope of the prosthesis by utilising titanium sleeves and screws (Fig. 15b). The titanium sleeves will then be incorporated into the transitional prosthesis with a self-curing...
acrylic (Quick Up, VOCO). Prior to inserting the acrylic, a small, oval-shaped piece of rubber dam is placed over each titanium sleeve to protect the underlying surgical site. An alternative method allows for the prosthesis to attach directly to the fixation guide (Fig. 15c). Once the acrylic had reached a final set, the prosthesis was then removed and examined for any acrylic deficiencies or gaps. These gaps were all filled, and the prosthesis was polished. While the prosthesis was adjusted, any bony defects were filled with cortico-cancellous allograft (Maxxeus Dental, Community Tissue Services), and the area was covered with layers of platelet-rich fibrin and sutured around the multi-unit abutments. The transitional prosthesis was delivered to the patient with minimal occlusal adjustments (Fig. 16). The mandibular full-arch implant-supported reconstruction was completed during the same visit (ROE Dental Laboratory).

Closing comments

The ability to incorporate 3D imaging modalities, when combined with interactive treatment planning software, has greatly enhanced the clinician’s ability to diagnose and plan treatment for single and multiple implants. As technology has advanced, guided surgery protocols have improved, offering innovative alternatives for partially and fully edentulous patients. While CT-derived surgical templates have been available for almost two decades, the focus has been on the surgical aspect of implant placement. Interactive treatment planning software has provided clinicians with an appreciation of the bony anatomy to assess implant receptor sites and even more. The evolution of guided applications has included the development of the bone reduction guide, the sinus lift guide and the harvest guide for guided bone grafting procedures. Software, such as R2GATE and Blue Sky Plan, allows for the planning of implants in relation to the desired prosthetic outcomes. However, the missing link has been the accurate orientation of the prosthesis at the time of surgery. The merging of CAD/CAM design with 3D DICOM data enables restoratively driven implant planning at a very high level. Implants can be predictably placed with the prosthetic outcome in mind—critical for immediate loading of full-arch restorations.

The case example presented here illustrates the use of a stackable system that provides a fixation base anchored to the bone to which a drill guide can be mounted for accurate osteotomies and a carrier guide can be oriented to the transitional prosthesis. This greatly facilitates the processes of immediate placement and immediate restoration. Further research will be required to validate the methods and long-term outcomes of this full-template guidance solution for full-arch implant reconstruction.

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about

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The evolution of digital technologies in dentistry has paved the way for the development of simplified and predictable protocols in the field of restorative dentistry. Digital dental technologies have allowed the seamless delivery of complex treatments.

Proper treatment planning protocols are the foundation of any fixed restoration in the arch involving dental implants. The data from the CBCT scan and intra-oral surface scans, combined with the use of CAD software, allows the simplification of workflows, including diagnostic facially driven mock-ups, restoration-driven implant treatment planning, and the design and fabrication of surgical guides. The design of the provisional and permanent prostheses and the design of the master die model can all be done on CAD software and then manufactured with either 3D printing or milling. The prosthetic design can be visualised, planned and even designed prior to the patient even attending for the surgical phase of treatment. An accurate and predictable outcome of the implant surgery as well as of the restorative rehabilitation is realised this way.

**Case report**

The following case study demonstrates a scenario in which a fully digital workflow was utilised with two provisionalisation phases to rehabilitate the full maxillary arch.

**Diagnostic record collation and treatment planning phase**

A 79-year-old patient presented with the chief complaints of mobile teeth and occasional discomfort from the areas around his existing maxillary fixed partial prosthesis. His medical history was unremarkable. The clinical and radiographic examinations indicated moderate to advanced bone loss affecting many of his maxillary and mandibular teeth and secondary decay on the abutments of his fixed prosthesis (Figs. 1a & b). Teeth #15, 16 and 28 had a poor prognosis and were planned for extraction. The goal of the treatment was to rehabilitate the maxillary arch with a combination of crowns and implant-retained restorations to provide the patient with a fixed solution.

In the initial treatment phase, teeth #16 and 28 were extracted and the remaining dentition was periodontally treated (Figs. 2a & b). After the initial clinical examination and treatment, further information was collated. This in-
cluded the use of 3D CBCT scanning for the pre-surgical planning and of intra-oral scanning. Digital impressions before and after removal of the original porcelain-fused-to-metal (PFM) fixed partial prosthesis were taken, as well as of the patient’s occlusion. Rough preparation of the abutment teeth was also completed prior to acquisition of the subsequent intra-oral scan.

The accuracy of image registration (superimposition of the intra-oral scan and CBCT scan data) can be enhanced by prior removal of the PFM fixed partial prosthesis to reduce radiographic scatter caused by the metallic components of the prosthesis and by the use of radiographic reference markers (Figs. 3a & b). A composite such as G-ænial Universal Injectable (GC), with a radiopacity of 250% aluminium, does not result in radiographic scattering during CBCT scans.

Treatment plan
After collation of the information, the initial treatment plan was formulated. It involved guided surgical placement of implants in sites #16, 14, 11, 21 and 25. A bone graft was also planned for site #11 owing to bony defects. A two-stage surgical protocol was chosen for proper integration of the implants in sites #11 and 21. Immediate provisionalisation was to be performed with a 3D-printed provisional fixed partial prosthesis (Temp PRINT, GC) extending from site #15 to site #24. The existing shape and contours of the current failing fixed partial prosthesis were copied from the preoperative intra-oral surface scan to create the provisional fixed partial prosthesis. After implant integration, a second phase of provisionalisation was foreseen with individual provisional restorations (Temp PRINT) on the implants and natural teeth. This would allow verification of aesthetics and occlusion, soft-tissue management and extraction of tooth #15. It was planned to use lithium disilicate and monolithic zirconia for the permanent restorations on both the natural teeth and implant abutments.

Digital implant planning and surgical guide fabrication
Digital data from the three scans—the CBCT scan and the intra-oral surface scans before and after fixed partial prosthesis removal—was accurately merged. This enabled
virtual planning of the number, position, angulation and access position of the implants following a restoratively driven protocol (Figs. 4a & b).

Based on the planned implant positioning (Fig. 5), a surgical guide was designed with the dedicated software. Master sleeves from the guided surgical system were placed and fixed to the printed guide/framework.

The design of the previous PFM fixed partial prosthesis was also copied and replicated in the digital planning of the provisional fixed partial prosthesis. It was then printed using the Asiga MAX UV printer and Temp PRINT (medium shade) set at 50 µm on the 3D printer.

Guided implant surgery and first provisionalisation phase
All five implants were placed following a fully guided surgical protocol with the surgical guide (Figs. 6a & b) and primary stability was confirmed. A flap was then raised at sites #11–21, and a bone graft with bovine cancellous particulate was placed and covered with a porcine collagen membrane. Cover screws were placed, and primary closure was established with PTFE sutures after a relieving incision was performed. At the other implant sites (#16, 14 and 25), healing abutments were placed (Figs. 7a–c). The 3D-printed provisional fixed partial prosthesis was then cemented with Fuji TEMP LT (GC) to the remaining natural teeth (Figs. 8a & b).

A healing period of 16 weeks allowed complete osseointegration of the implants. During this period, tooth #24 (maxillary left first premolar) developed signs and symptoms of pulp necrosis. Hence, it was endodontically treated (Fig. 9).

Second provisionalisation phase after implant integration
Once the 16-week healing phase was completed and the implants were integrated, the restorative phase could
be initiated. The patient confirmed that he was happy with the shape and occlusion of the initial provisional fixed partial prosthesis (Figs. 10a & b). The aesthetic and occlusal scheme could therefore be replicated in the second phase of provisionalisation.

A pre-preparation intra-oral surface scan was taken with the healing abutment and provisional fixed partial prosthesis in situ (Fig. 11). The provisional fixed partial prosthesis was then removed, and preparation of the abutment teeth finalised and remargined to the healed gingival tissue levels. The second stage of implant surgery at sites #11 and 21 was completed using a soft-tissue diode laser. The implants were exposed and the cover screws removed.

An emergence profile scan was taken immediately after the healing abutments were removed to record gingival contours around the implant before any collapse of the tissue. Next, the full maxillary arch was scanned with digital scan bodies in place to capture the implant position accurately (Figs. 12a–c). All other prosthodontic records, including the maxillomandibular relationship record and the opposing arch, were also captured with the intra-oral scanner before replacing the provisional fixed partial prosthesis.

All the intra-oral scans were taken following the Mak optimised scan strategy (MOSS), allowing accurate stitching of intra-oral scan images. In soft-tissue areas, the availability of landmarks is often limited; MOSS uses a specific

Figs. 13: Second set of provisional restorations. Fig. 14: Completed provisional crowns, implant-retained crowns and fixed partial prosthesis characterised with OPTIGLAZE color (Bradley Grobler, Oral Dynamics).

Figs. 15a & b: Completed provisional restorations fitted on to the printed models to allow the refinement of the contact points and occlusal contacts, palatal (a) and labial (b) views. Figs. 16a & b: After removal of the provisional fixed partial prosthesis from the first provisionalisation phase (a). Tooth #15 was extracted (b).
scan path with or without markers for enhanced scan accuracy and was especially designed for cases with few teeth to correlate to. All the digital data was then sent to the ceramist for the fabrication of the second set of provisional restorations.

The provisional restorations were printed with Temp PRINT and characterised with OPTIGLAZE color (GC). Provisional abutment cylinders were utilised for the implant-retained restorations. The contours of the provisional restorations retained on implants #11 and 21 as well as of the pontic on tooth #15 were designed and fabricated to shape the soft tissue for optimal support (Figs. 13–15b).

After removal of the provisional fixed partial prosthesis, all the abutments were cleaned and tooth #15 was extracted (Figs. 16a & b). The provisional implant restorations, fabricated with direct screw access, were torqued to the manufacturer’s recommendation. All the other provisional printed restorations were cemented with Fuji TEMP LT (Figs. 17a–19b). The soft tissue was prosthetically shaped and allowed to heal for a period of three months before finalisation of the rehabilitation with the definitive restorations.

Conclusion

The case presented illustrates how advances in digital technologies can provide clinicians with the tools for diagnosis, treatment planning, and the execution and provision of dental restorative procedures in a truly transformative way. Simplification of clinical protocols, increased accuracy over conventional analogue techniques, and improved patient comfort and outcomes are compelling reasons for the use of a fully digital workflow in the field of restorative and implant dentistry.

about

Dr Anthony Mak obtained his dental degree at the University of Sydney in Australia and then went on to complete his postgraduate diploma in oral implantology. He graduated with multiple awards and has worked with some of Sydney’s most renowned practitioners. His interests lie in dental technologies and advances in materials and techniques. He has a unique understanding of CAD/CAM dentistry and currently owns two practices in metropolitan Sydney focusing on comprehensive and implant dentistry. Dr Mak has a thorough understanding of direct versus indirect dental restorations and has lectured internationally on the topics of aesthetic and digital dentistry. He is a sought-after speaker and a key opinion leader for several global dental companies.

Dr Andrew Chio graduated as a dentist at the top of his year from the University of Melbourne in Australia in 1995. On graduation, he undertook his dental internship at the Bendigo Base Hospital before spending the next one and a half years working in a rural hospital in Nepal. He is the principle dentist of Arawatta Dental Centre in Carnegie in Australia and an active member of various dental associations. He is a lecturer and gives advanced hands-on training to dentists in specific areas of restorative dentistry.
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More and more patients in our practice are expressing a strong desire for a “Hollywood” smile. When delivering cosmetic smile enhancements, whether utilising minimal-preparation porcelain veneers or durable zirconia crowns, there are three basic principles to consider: aesthetics, symmetry and function. Cohesively, these principles ensure mindfulness pertaining to the size, shape, contour and positioning of teeth. Equally as important is gingival architecture; uniform, pink gingivae are signs of a healthy smile and are highly desirable.

The restorative team, when using these guiding ideologies for each smile makeover, can successfully restore a smile to its proper form, function and appearance. This article demonstrates the significance of utilising a prosthetically driven treatment plan when restoring missing teeth in the anterior maxilla with dental implants to achieve an aesthetic smile makeover.

Case report

A 36-year-old female patient presented to the practice expressing dissatisfaction with her smile (Fig. 1). This unhappiness was the result of a car accident seven years before, during which the patient lost her maxillary anterior teeth (teeth #13–11 and 21) and tooth #22 was fractured. Restorative dental work included endodontic treatment, followed by a core and crown restoration, as well as a removable partial denture in this area of the mouth.

Approximately two years prior to this initial consultation, another oral health professional had placed three dental implants in positions #13, 11 and 21 with the end goal of delivering a fixed partial denture. However, during this process, the dentist was unable to provide a satisfactory fixed provisional restoration, and this led the patient to our practice.

Initial diagnostic evaluation consisted of a series of digital images with study casts, a centric interocclusal record, and the necessary radiographs. The CS 8100 (Carestream Dental) was used to obtain CBCT images to properly evaluate the bone surrounding the previously placed dental implants. Clinical examination revealed well keratinised tissue and bone surrounding the dental implants. However, tooth #22 was somewhat flared facially, and recession had exposed the gingival margin of the crown restoration. Radiographically, there was a periapical lesion at the apical region of the tooth.

Considerations regarding the incorporation of tooth #22 were discussed with the patient. Respect was also given to its position within the arch, the existing crown resto-
ration and the failed endodontic treatment. Ultimately, it was recommended that the dental laboratory fabricate a diagnostic wax-up illustrating the result should tooth #22 be removed. This would allow for a five-unit fixed partial denture (FPD) extending from position #13 to position #22 with three abutments and two pontics. DenMat Lab was chosen specifically based on its expertise in anterior aesthetic combination cases.

Planning

To develop a treatment plan, full-arch dental impressions (Silginat, Kettenbach) were taken and sent to the laboratory. Owing to the alveolar defect present in the ridge, it was suggested that the laboratory add pink wax in the gingival area, where it would be replaced with pink porcelain in the final restoration (via an FP-3). The FP-3 dental implant prosthesis, created by Dr Carl Misch, allows for the re-establishment of proper function, aesthetics, lip support and phonetics.1 This restoration assists clinicians in achieving their patients’ desired outcomes in the aesthetic zone.

The patient, upon seeing the diagnostic wax-up, was thrilled with the potential outcome of her case (Fig. 2). She immediately scheduled her appointment for the recommended treatment.

Starting with a 3.3 mm Narrow CrossFit implant (BLT, Straumann) level impression (Figs. 3 & 4), the technicians virtually extracted tooth #22, fabricated custom CAD/CAM abutments (implants #13, 11 and 21), and then fabricated a polymethylmethacrylate (PMMA) five-unit fixed provisional restoration. This restoration was designed as an FP-1 restoration to determine whether it would suffice in the aesthetic zone, as well as to try to further enhance the tissue contour.2

Preparation

The patient presented to the office once the abutments and provisional restoration had been received from the dental laboratory. Anaesthetic (1:10,000 Xylocaine) was administered and treatment initiated.

First, the healing caps were removed from the dental implants and replaced with gold anodised CAD/CAM custom abutments. The abutments were seated and torqued with a torque wrench at 25 Ncm, according to the manufacturer’s instructions (Fig. 5). Access openings were then sealed with PTFE tape. It is important to note that the dental laboratory designed the abutments so that the facial margins were 0.5 mm apical to the free gingival margin to avoid display of metal.

Next, tooth #22 was extracted using the Physics Forceps (GoldenDent; Fig. 6). The tooth was extracted with great care to avoid disruption of the surrounding tissue (Fig. 7). A curette (Hartzell, DenMat) was used to debride granulation tissue from the socket. An alloplastic material (OsteoGen, Impladent) was then inserted and packed into the socket (Fig. 8), ensuring it was in tight contact with the bony walls. The PMMA provisional restoration (Fig. 9) was then cemented with a temporary cement material (E.T.C. Easy Temporary Cement, Parkell) and the patient instructed on how to care for it during the three-month healing period (Fig. 10).

Upon satisfactory healing, the patient returned to the dental practice three months later for impressions to be taken for the definitive FPD. Using a polyvinylsiloxane material (Panasil, Kettenbach), a full-arch impression was taken of the maxillary arch using a traditional crown and bridge technique. This impression, along with occlusion registration records and the opposing model, was forwarded to the dental laboratory with instructions to fabricate the FPD with the LumiZir zirconia material (DenMat Lab).
owing to its aesthetics and strength. LumiZir full-contour crowns are fabricated from the strongest, most translucent zirconia on the market and offer a flexural strength of greater than 1,150 MPa. Thanks to these features, this restoration offers the benefits of unmatched strength and lifelike aesthetics.

Laboratory considerations

After reviewing the digital clinical images, diagnostic wax-up and patient’s feedback, it was determined that the definitive restoration would be much more aesthetic if it was designed similar to the wax-up as an FP-3 restoration. This would ensure that pink porcelain would be used to fill in the gingival embrasures, thereby contributing to a more natural appearance.

DenMat Lab is a specialised laboratory completely focused on anterior aesthetic cases. The laboratory is equipped with the latest CAD/CAM technology and employs a team of highly trained dental technicians, who consult with the dental professional at each phase of treatment. This leads to highly predictable and aesthetic outcomes, no matter how complex the case.

Cementation

Before try-in of the definitive restoration to verify fit, function and aesthetics, the provisional restoration was removed using a pneumatic crown and bridge remover (Dent Corp). Remaining cement was cleaned off the abutments (Fig. 11) and the FPD tried in for evaluation. The patient was first shown the retracted view, followed by a full-face view for acceptance of the definitive restoration.

With the patient’s approval, the cementation process was initiated. Implant cement (Infinity SE, DenMat) was used to cement the FPD (Fig. 12).

Conclusion

In cases such as this, it is important to look at the entire smile when restoring it to proper aesthetics, form and function. The process should begin with a diagnostic wax-up, which is an invaluable tool for planning and communicating with the patient about the proposed treatment plan. As dental providers, our goal should be to listen to our patients’ needs and guide them to the appropriate solution using our knowledge and experience.

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Editorial note: A list of references is available from the publisher.
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A challenge in dental computerised photogrammetry

Dr Olivier Lanzerlin, Prof. Michel Fages & Dr Gérard Subsol, France

Introduction

Developments in 3D digitisation processes in dentistry have been continually evolving over the past decade. Advancements have included tabletop scanners for dental plaster casts, intra-oral scanning1–4 for prosthetic purposes, and 3D face scanning for use in diagnostic instruments, namely for analysis of smile aesthetics.5–7

Notably, the number of dental surgeons who use intra-oral scanners in their practice is increasing. Many commercial models of intra-oral scanners are available, and according to manufacturer data, existing scanners can be characterised by the following features:

- The weight of cameras varies from 70 g to more than 600 g.8
- The scanning accuracy (under metrological conditions) varies from 5 µm to 30 µm.9,10
- The dimensions of the camera heads vary from 15 × 15 mm to 20 × 30 mm.
- Scanner costs vary from $12,000 to $50,000,11 amounts too high for many dental practices.

However, the costs of intra-oral scanners are expected to decrease owing to the growing number of scanners available on the market,2 including TRIOS 4 (3Shape), CEREC Primescan (Dentsply Sirona), iTero Element 2 (Align Technology), Emerald S (Planmeca), CS 3700 (Carestream Dental) and Medit i500 (MEDIT).

Technical principles for 3D measurement are based on various methods, such as confocal parallel microscopy, fringe projection with microphase shifting, and photogrammetry.12 In photogrammetry, a minimum of two small cameras are placed on the head of the device, and these acquire photographs of the tooth from two slightly shifted points of view. Based on the triangulation principle, it is possible to compute the distance to the tooth and then reconstruct a 3D model of its surface. The measurement can be performed with or without using structured-light projection, and this is referred to as “active” and “passive” photogrammetry, respectively.

Historically, photogrammetry was first developed to obtain 3D measurements of teeth.13 In initial experiments, contour maps of teeth from a study cast were generated using a custom-built camera with an accuracy of 0.025 mm. Quantitative 3D representations of the tooth surface could also be acquired using the contour maps. Several recent studies have shown that photogrammetry can also be used in implantology, thereby enabling a computerised analysis of implant positions14–18 in cosmetic and maxillofacial surgery19 or for digitisation of a plaster cast.20

Moreover, 3D surface reconstructions obtained by photogrammetric methods can be matched with the actual structures in the patient’s mouth or objects created by 3D modelling software.21 General computerised photogrammetric software is now available, giving anyone the ability to capture 3D representations of any object using multiple photographs taken from a single digital camera.

Photogrammetric reconstruction requires finding correspondences between the pixels of the different images. It is then possible to estimate both the displacement of the cameras and the depth of the object. Most algorithms that automatically compute correspondences are based on similarity or photo-consistency measures; in other words, they compare the pixel values between images. These measures can be defined in either the image space or object space.22

Fig. 1: 2D images captured with an HK790 USB 2D intra-oral camera.
Multi-image photogrammetric software may be a viable technique for dense 3D reconstruction. Moreover, the cost of such software is low, and some software packages can be leased. Furthermore, some software is even available for free.23

In this paper, we evaluate this technology for use in everyday dental practice. First, we describe a procedure for obtaining 3D reconstructions of teeth based on intra-oral photographs taken with a low-cost intra-oral camera and using commercial software on a standard computer. Then, we assess the results qualitatively and quantitatively with respect to a state-of-the-art intra-oral 3D scanner. We test several applications, and in particular, we show that the resulting reconstruction can be used under practical conditions to design and mill a dental crown. The key features of the method reported on in this article are its cost-effectiveness and ease of use.

**Materials and methods**

The equipment comprises 2D digital recording methods and various imaging accessories. The 2D images are processed by close-range photogrammetric software to reconstruct a 3D mesh file of the object. The mesh file can then be imported into 3D simulation software and used in various ways.

**Hardware**

**Computer**

We used a standard laptop computer (Intel Core i7, 8 GB memory with a 500 MB solid-state drive and a mid-range 3D graphics card, NVIDIA GeForce 820M) of a very affordable cost (less than $1,500).

**Camera**

We used a low-cost USB 2D intra-oral camera (HK790, EHang Beauty Equipment) to acquire intra-oral photographs. The camera was equipped with a pedal to capture the photographs and integrated software to record the data.

The camera has a working distance of 5–50 mm with a permanent autofocus, which is a favourable selection criterion. The speed at which a sharp image can be captured is directly related to the ability to easily and rapidly focus on the object. The position of the focus control on the camera, if any, also influences the ability to focus rapidly.

The camera has a 5 MP resolution (1,600 x 1,200 pixels), according to the manufacturer, and is comparable to the best USB cameras on the market. Note that resolution is not always an accurate indicator of the image quality of an intra-oral camera, as image quality also depends on many associated variables, such as overall design, lighting, lens quality and software.24

Optical quality allows distinguishing between a good intra-oral camera and suboptimal intra-oral camera. The best optical systems are created by placing the charge-coupled device (CCD) chip at the end of the wand next to the lens, but this is more expensive than placing the CCD chip in the middle of the wand. When the CCD chip is in the middle of the wand, an additional prism is used to direct the incoming image further down the wand to the CCD chip, and it degrades image quality.25 The HK790 camera we used is sold commercially for $200, which is very affordable for dental practices. However, this camera is not as accurate as the highest-quality intra-oral camera in terms of image quality and available features, such as depth of field and...
focusing options. A comparison of 14 intra-oral cameras was performed by an independent laboratory through a controlled test, in which cameras were rated for image quality (clarity, colour, sharpness, brightness and contrast). No camera under $900 was included in the evaluation. In fact, intra-oral cameras range widely in price, from $16 to more than $6,000. However, many dental practitioners have subjectively pointed out that inexpensive intra-oral cameras often appear to produce equivalent or even superior image quality to that of higher-end cameras, whereas higher-end cameras may cost two to three times more.25

**Reference 3D scanner**
To assess the results obtained by photogrammetry, we used a 3D intra-oral scanner, CEREC 3D Red Cam CEREC (Dentsply Sirona), with CEREC Version 3.85 software. This scanner (sold for approximately $50,000 in 2003 but no longer available) was designed specifically for a single visit for a one- to three-unit all-ceramic aesthetic dental restoration.26 The scanning accuracy of the scanner under metrological conditions is 25µm.27 All devices currently used in dentistry for intra-oral digitisation have a metrological resolution of below 20µm.28 Recently developed intra-oral scanners are smaller and faster, and they acquire an impression of the entire mouth.29 Nevertheless, in clinical situations, the precision of digital quadrant impression models for more recent intra-oral scanners remains between 41.1µm and 76.7µm.30

**Software**
For close-range photogrammetric software for reconstruction of the 3D mesh of the tooth from 2D images acquired from various angles into 3D, we selected Autodesk ReMake (Autodesk; educational licence) for the following reasons:
- A free educational version with an acquisition limit of 250 photographs is available.
- It includes an easy-to-use mesh editing tool that offers a fast and comprehensive toolset for fixing, optimising and exporting complex 3D scan data.
- It includes additional relevant tools and services, among them an upscaled web-based interface and cloud storage. The cloud storage provides the ability to use Autodesk’s photogrammetric engine online without utilising personal computer resources, which can then be allocated to the 3D reconstruction.
- The software is a more complete and stable version than similar software offered by the company, such as Memento and 123D Catch (discontinued).
- Moreover, Autodesk has a large user community, and the software is frequently updated.

Since 1 December 2017, the photogrammetric service of ReMake has been part of ReCap Pro under the name ReCap Photo and requires a subscription licence. ReCap Pro is available as a subscription for $40 per month or $300 per year in the US and €48.40 per month or €393.25 per year in Europe. An advantage is that Autodesk has increased the maximum number of photographs from 250 to 1,000.31

**Methods**
**Intra-oral photograph acquisition**
Digitisation consists of recording a shape from multiple angles for reproduction at full scale. OptraGate (Ivoclar Vivadent) is used to retract the soft tissue to acquire intra-oral photographs of a tooth that needs a crown. Despite the camera’s autofocus, which ensures optimal sharpness at different distances, it is advisable to capture photographs at a distance of approximately 1.5 cm for several reasons:
- A constant distance between the camera lens and the tooth is recommended by the supplier of the photogrammetric software.
- This constant distance is necessary to record characteristic details that will be visible on several views to ensure good correlation among the different photographs. In addition, if the camera is too close to the dental surface, the white LEDs of the camera
may blur some details that could be used in the photogrammetric correlation owing to overexposure and artifacts may be created owing to excessive reflection of light.

– Taking into account the limited space of the mouth opening, this distance makes it possible to observe the tooth to be registered and half of each tooth on either side of the tooth to be registered. Such a distance could be difficult to maintain without a good manual support point for stabilisation. The patient must keep his or her mouth open during the acquisition.

– Note that the photographs provide no metric information, and therefore, a complementary manual procedure is required to define the scale of the reconstructed surface.

Photogrammetry applied to intra-oral measurements

Photogrammetric systems used in dental research are of the close-range type, as the object–camera distance is less than 300 mm. The principle of reconstructing a 3D surface by photogrammetry is based on a method called bundle adjustment. This method involves simultaneously refining the 3D coordinates of surface points, the different positions of the camera and the camera’s optical characteristics.

More precisely, let us take a 3D point on the surface, which is captured in \( n \) photographs from different viewpoints by the same camera located at \( n \) different positions. Let us assume that we have a first estimation of the 3D coordinates of both the point and the \( n \) camera positions. For each viewpoint, we can construct the line of sight from the surface point to the optical centre of the camera. We can then intersect this line of sight with the optical plane of the camera and infer the 2D position of the projected point in the photograph.

If we can detect the actual observed 2D position of the point in the photograph by image processing techniques, we can compute an error between the projected and observed points. By minimising the sum of errors for the \( n \) photographs, we can find the actual positions of the camera and, by triangulation, the position of the surface point.

Practically, we position the intra-oral camera at angles \( \alpha_1, \alpha_2, \alpha_3 \ldots \alpha_{50} \) to take 50 photographs of the tooth from different points of view in a 15 mm radius hemisphere. An overlap of 60 per cent between the successive photographs is considered necessary to automatically find some correspondences between the points of a photograph and the subsequent photograph.

In the case of extreme angulation (\( \beta \)), photographs are difficult to obtain owing to the position of the teeth. The best results are obtained when we do not change the distance to the tooth between successive photographs. Each photograph is centred on the tooth, with approximately half of the adjacent tooth in the field of view.

All photographs are then sent to the Autodesk cloud via the Internet to be transformed into 3D models. Three uploads are performed separately for each image acquisition series (images of the tooth of interest and adjacent teeth, images of the opposing teeth, and images of the teeth in occlusion). Within 10 to 15 minutes, three
reconstruction files can be generated and visualised with ReMake software.

Calibrating the surface reconstruction
The intra-oral camera is not calibrated and thus does not produce photographs with metric information. Therefore, it is not possible to understand the scale of the reconstructed surface. The idea is then to plot two landmark points on the tooth and to measure their actual distances and the corresponding distances on the reconstructed surface.

Two points are marked with a pen on the prepared tooth, and on the opposing tooth during occlusion. These six reference points make it possible to report distance measurements in the software using a mini digital calliper. Distance measurements between each pair of points were taken in millimetres, with an accuracy of two decimals.

On the reconstructed 3D model surface in ReMake software, we click on the visible reference points to report the measured distances in millimetres to calibrate the reconstructed surface. Such a method has already been used by Knyaz and Gaboutchian for photogrammetric measurements on a plaster cast dental arch.34

Comparison of 3D meshes
We used the following procedure with CloudCompare software:
- rough alignment by manually pointing 6 corresponding points on the two 3D meshes;
- accurate automatic superimposition of the two 3D meshes (Fig. 13);
- computation of the distances between the 3D meshes.

Deviations between photogrammetric acquisition and the reference model are then calculated. Thus, we can investigate the difference between the whole surfaces. This difference is converted into a representative colour scale map (Fig. 14).

Dental CAD and CAM
The three parts of the photogrammetric models (prepared tooth, antagonist and occlusal) are imported as an STL file into exocad (exocad), which is a dental CAD software program. The shape of the crown is then digitally designed.

First, exocad helps identify the occlusion in a manner identical to the situation in the mouth. After drawing the finishing line on the model representing the gingival margin of the crown, the software is able to recreate, within a few minutes, the complete anatomy of the tooth by referring to both the morphology of the adjacent teeth and the opposing tooth and by using a library of teeth. The operation is finalised by minor editing of the design of the future tooth with a digital tool palette (adding or removing material and smoothing). Once the shape has been finalised, the file is saved and exported in STL format via a cloud server to a milling dental centre for CAM processing. The CAD crown is then milled in a hybrid resin–ceramic block (VITA ENAMIC, VITA Zahnfabrik).

Assessment of the results
We used two different methods to measure the precision of the reconstructed mesh. First, we quantitively and three-dimensionally compared the mesh obtained from photogrammetric computation with the mesh obtained with the intra-oral scanner. Second, we performed empirical control of the adaptation in the mouth of the crown milled from the photogrammetric mesh. More precisely, we clinically verify the adaptation of the crown to the core and to the adjacent and opposing teeth.

We should note the larger density of points on the photogrammetric 3D reconstruction (20,374 vertices) with respect to the mesh acquired by the CEREC scanner (only 13,636), even though recent intra-oral scanners may yield a much higher mesh density.

When we compare the 3D meshes, the pre-alignment of both models is a manual procedure that can take
several minutes. The difficulty with this procedure is that the models must be placed side by side and visualised in a similar way. Similar points on relatively flat and rounded surfaces with few characteristic angular areas must be identified in both models. For each comparison, adjusting the colour level to a definite scale is also time-consuming to obtain a representative and explicit map with a display range (distance map) of between –0.6 mm and 0.6 mm.

We calculated the distances between the two meshes. From CloudCompare software, we obtained a mean distance of –0.028857 and a standard deviation of 0.212223. The statistical distribution of the distances between the photogrammetric and the scanned meshes is represented in Figure 14. Most of the distance values in the histogram (from –0.1 mm to 0.1 mm) are below the threshold for clinical use, while the values above the threshold correspond to areas that are not directly related to future prosthetic restoration. The estimation of approximate distances between the two meshes shows that the results are within clinically acceptable limits. Recent research indicates that most CAD/CAM systems are capable of producing restorations with an acceptable marginal seal of less than 100 µm.35

Clinical assessment of the crown milled from the photogrammetric model
The clinically developed crown yielded entirely satisfactory results in terms of the following:
- internal adaptation to the core;
- external adaptation to the opposing tooth;
- marginal adaptation to the gingiva; and
- proximal adaptation to the adjacent tooth.

We reduced the occlusal thickness to adapt the surface of the crown to the surface of the antagonist in order to adapt the occlusion to the lateral movement of the mandible, and this is the same procedure employed for the manufacture of crowns by conventional methods (Figs. 15 & 16).

Discussion

The described photogrammetric method does not require any specific equipment or technical skills, and it is very easy to set up at low cost. We have shown that temporary or definitive crowns can be made using a CAD/CAM workflow within the limits of acceptable clinical precision. However, some difficulties persist, especially during the acquisition phase.

Technical difficulties
Limitation of intra-oral camera optics
In dentistry, high-quality intra-oral photography depends on a satisfactory depth of field focus and good illumination.36 Single-lens reflex (SLR) cameras with macro lenses are currently used in practice,37–39 but this was not possible in our experimentation. In fact, photographing all the surfaces of a tooth requires a mirror with SLR. This would create many practical problems for the image acquisition procedure, and it would be time-consuming owing to:
- positioning of the mirror with a constant angle in the mouth;
- moisture accumulation on the mirror; and
- post-processing of the image (symmetry of the photographs).

Nevertheless, SLR offers superior image quality, which makes analysis far easier using photogrammetric software. This advantage is mainly due to the increased degree of acutance, or sharpness of edges, in images obtained with SLR cameras.40

Like conventional cameras, intra-oral cameras allow the focal distance to be changed, for example, to capture a single tooth, a full arch or even the face of the patient. Therefore, there is no need to manually change the focus during the acquisition process. Intra-oral cameras have an automatic focal length, which is necessary because the depth of the field is quite variable when one approaches or moves away from the tooth (relative to the average distance). Fixed lenses have no focal change, which is good for the photogrammetric process. Autodesk engineers also recommend capturing photographs with a fixed lens. According to the ReMake user guide, a 50 mm lens is optimal for photogrammetric reconstruction. The small diameter and convex nature of the lenses, notably in close-up images, as well as the necessary approximation for the automatic variation in focal length, lead to geometrical distortion and blur at the periphery or within the photograph. However, the width of the lens seems to be sufficient if we take into
account the fact that deformations in images occur at the periphery, which is not the area of focus during the recording, because the camera is always centred on a particular tooth.

**Limitations due to image preprocessing**

Most economical digital cameras, such as the intra-oral USB camera, are not specifically designed for photogrammetry, and the implementation of automatic correction procedures of raw acquired images may introduce distortions and chromatic aberrations for our application. Good-quality intra-oral cameras maximise point matching, and a metric potential intra-oral camera with autofocus and an adaptive camera lighting system could increase the quality of the captured photographs (by decreasing artifacts and deformation due to light reflection on the surface).

We have observed that intra-oral USB cameras do not have as high an accuracy as SLR cameras do, but to our knowledge, SLR cameras cannot save photographs in raw format. This format may yield significant improvements in photogrammetric accuracy over results obtained with JPEG imagery. A standard JPEG image is a 24-bit image (256 tones per channel), which corresponds to 16.8 million colours, whereas a raw file contains 65,536 tones per channel, which corresponds to 281.4 trillion colours. A good colorimetry range improves the sharpness and clarity of the edges in an image, which is very important in photogrammetry. The best image quality is supplied by raw image data, but the amount of data increases drastically with reconstruction time and the size of the generated file. These factors would also increase the price of the camera.

**Practical difficulties**

We encountered the same problems using both the intra-oral USB camera and the 3D intra-oral scanner. The use of sheaths and gloves negatively influenced the ability to adequately and consistently control the camera and tune its image quality.

The camera chosen for our experiment is controlled by a pedal, which provides limited blurring due to movements. This feature is relevant because even pushing a small control button risks moving the camera and blurring the image.

For good 3D reconstruction, the photogrammetric software requires distinguishing between the background and the foreground and finding various features in the images. However, teeth are quite uniform objects with minimal photometrical and geometrical landmarks. For that reason, we propose using a small amount of powder to create a random-texture surface not only in the foreground but also in the background. All surfaces must be cleaned and dried prior to application. The spray must be carefully aimed to ensure that the area for the impression is properly coated. The spray nozzle should be held approximately 10 to 15 mm away from the object. The tongue or cheek and lips should not be in contact with powdered surfaces, to avoid changing the random pattern of powder created. It is important to note that all surfaces do not require coating, because the goal is to create a random pattern suitable for photogrammetric recording. Therefore, we press gently on the spray button to deliver a minimal amount of powder each time.

Interference created in the background of the photograph by the movement of soft tissue (tongue, cheeks,
During photography leads to some problems when using the photogrammetric software, as such features are not able to be correlated among the different photographs, and some parts are hidden. Correlation of the vestibular and lingual surfaces is difficult. Blind spots (parts of the scene that are visible from one angle but not visible from another angle) can create point matching problems. It then becomes impossible to correlate these parts of the image, preventing 3D reconstruction. Moreover, saliva can create specular reflections which appear as white areas.

As body temperature is 37°C, when the temperature of the intra-oral camera lens is lower than 37°C, the moisture in the breath of the patient condenses on the camera lens, which leads to fog on the lens. The intra-oral camera has no anti-fog mechanism. Some photographs must be retaken at the same angulation to account for this limitation. Visual assessment of the quality of each photograph after capture is important. Although ReMake has an automatic procedure for ignoring poor photographs (due to fog or blurring problems), if too many photographs are contaminated, the correlation images will not be properly generated.

Imaging the last posterior tooth is extremely difficult because mouth opening is limited. It is not possible to introduce the intra-oral camera close enough to the tooth with respect to the short focal distance. Under this condition, 3D reconstruction is not possible or the deformations will be such that the obtained model would be unusable. It would be interesting to investigate whether using another intra-oral camera with a shorter focal length (rather than automatic focus) could be used to solve this problem.

Changes in light can occur from one photograph to another. The intra-oral camera has a built-in LED illumination device. Excessive lighting when the camera is brought very close to the tooth and shadowing can disturb image correlation in the photogrammetry process, and reflected light is also a problem.

Influence of the metric calibration
CAD/CAM applications require the reproduction of physical dental arches to scale 3D models. The problem is that the estimation of metric information on the resulting photogrammetric model depends on the parameters of the camera, which are not known by the user, such as the exact focal length of the lens, the coordinates of the centre of projection of the image, and the radial lens distortion coefficients. These parameters can be retrieved via a camera calibration process. Precise calibration is then required to produce a model with metric information. A fast camera calibration procedure based on a printable plane pattern can compute the camera focal length, principal point, aspect ratio and lens distortion.

Some photogrammetric software (such as Agisoft Metashape, Agisoft; or PhotoModeler, PhotoModeler Technologies) directly use parameters such as sensor size or focal length, which are either included in the EXIF metadata of photograph files or provided in the manufacturer’s specifications. However, in our case, no such information was provided by the USB intra-oral dental camera or its manufacturer. Therefore, it was impossible to obtain the sensor size of the digital camera, although such estimation may lead to imprecise measurements. Nakano and Chikatsu proposed an EXIF-dependent camera calibration. By this method, the camera is able to integrate the EXIF data into each image, and the photogrammetric software is able to interpret this data, from which metric information can be extracted.

Some commercial photogrammetric packages use predefined printed patterns for the automated calibration phase. These methods automatically calculate focal length, lens distortion aspect ratio and principal point. We tested such a method using PhotoModeler, although

Fig. 11: 3D mesh obtained with 50 2D photographs acquired with an HK790 intra-oral camera and reconstructed by ReMake 3D photogrammetric software (13,636 triangles).

Fig. 12: 3D mesh acquired by the CEREC intra-oral scanner (20,374 triangles).
the software did not result in good calibration because the pattern was not adapted with respect to the very short acquisition distance of the USB intra-oral camera and the large deformation of its lens.

We also tested another calibration method based on 3DF Lapyx (3Dflow), a free camera calibration software program associated with the close-range photogrammetric software Zephyr (3Dflow). The measurement quality and the reproduction of details were not satisfactory because the measured parameters were not constant after different calibration sessions. The data to be reported did not correspond strictly to the type of data to be entered in the software, and the instructions for this procedure were very limited. We were unable to obtain a 3D metric model using this software. Moreover, the calibration software is no longer available on the manufacturer’s website. In addition, photogrammetric reconstruction tests using Zephyr showed a less dense point cloud and a large portion of incomplete or distorted areas on the final image compared with ReMake. Zephyr also has an EXIF-dependent automatic calibration procedure, but it is not useful for our experiment because the EXIF parameters of our camera are unknown.

The tcalcib application written in MATLAB language, which is freely available, could be an interesting tool for extracting all the camera parameters, including effective focal length, lens distortion parameters and CCD chip size. However, these parameters would then have to be included in the close-range photogrammetric software, and ReMake has no functionality to import these parameters. Some authors have also proposed targetless approaches based on self-calibrating bundle adjustment algorithms. According to Barazzetti et al., targetless calibration can provide camera parameter values with the same theoretical accuracy as the standard target-based procedure. Nevertheless, for photogrammetric projects that require high precision, we believe that the target-based camera calibration procedure currently remains the best solution.

Solving problems of digitising tooth surfaces in photogrammetry

The correlation of photographs is based on intensity differences, is very sensitive to illumination differences and is not reliable in poorly textured or homogeneous regions. Owing to the high reflectivity of the enamel of teeth, some photographs of the white tooth surface are unsuitable for the photogrammetric process. In addition, the inevitable coating of saliva induces some imaging difficulties.

An object with a rough surface may be required by some techniques to initialise the correlation of photographs, but the reconstruction must also be performed in regions with poor textures or illumination. To solve this problem for smooth tooth or gingival surfaces, Mitchell and Chadwick made the enamel surface opaque and textured by painting the tooth with a weak water colour solution. The purpose of spraying the surface is not to create a uniform pure specular reflection surface but rather for fringe pattern projection.

The optical conditioning of CEREC preparations using scan sprays has been reported. Some sprays have been specifically developed for intra-oral scanners:
- APOLLO DI SpeedSpray (Dentsply Sirona) contains grey particles and provides high contrast and resistance to saliva humidity, but it is not designed to completely cover the tooth.
- MyCrown HD spray (FONA Dental) produces a thin layer of black and white particles that can be traced and measured to produce a precise model while maintaining the colour of the restoration.

Further investigation of different parameters of light (colour and intensity of the LED) could be performed to determine which photograph can produce better 3D reconstruction results and may avoid the need to powder surfaces.

Alternatives to ReMake
As mentioned already, at the end of 2017, Autodesk ended development of ReMake software and launched similar software called ReCap Photo. Other concurrent software, 3D Zephyr (3Dflow), RealityCapture (Geovast 3D), Agisoft PhotoScan (Agisoft) and 3DF Zephyr (3Dflow), could be interesting alternatives, and further investigation is necessary to compare their use in intra-oral photogrammetry.

In some situations, the reconstruction process of ReMake is surprisingly effective at ignoring background differences (such as small movements of the tongue). However, if an error occurs or if the model is incorrect, only the ReMake log file can be referenced, which does not provide sufficient information for determining the source of the error. This disadvantage could be considered a detraction to non-expert users in everyday practice. Moreover, ReMake has no manual stitching correction functionalities, as in other photogrammetric software (Autodesk ReCap 360, Autodesk; PhotoModeler), that can assist the correlation algorithm by prompting the user to select equivalent landmarks in multiple photographs. In conclusion, ReMake is simple, time-saving and user-friendly, but it is not possible to manually correct errors in the software without repeating the entire analysis process.

3Dflow recently introduced a completely free version of Zephyr for Windows with a 50-photograph limit. The software directly competes with the free version of ReMake.

Other possibilities for using photogrammetry in dental offices
Close-range photogrammetry in dentistry not only can be used for intra-oral applications but may also be interesting for use in several extra-oral applications, such as:
- smile analysis;
- 3D visualisation or simulation of the situation before and after facial surgery; and
- scanning of dental plaster models to create, for example, custom dental trays or to evaluate the occlusion between two models.

In addition to these applications, 3D photogrammetric models could be used for diagnostic purposes, as the colour provides an added advantage in comparison with plaster models (visualisation of dental and gingival tissue in cosmetic periodontic surgery). These models could also be used for student training purposes to present 3D simulations, which can be visualised from different viewpoints for a better understanding of clinical situations.

Fig. 14: Computation of distances between the 3D meshes by CloudCompare software.
Conclusion

In this paper, we have demonstrated that photogrammetry can also be used for intra-oral applications. Given the ease-of-use and the low investment required in terms of equipment, we believe that this technology could be of interest to the dental community. In our experiment, we were able to not only reconstruct the 3D dental anatomy of a patient but also manufacture a dental prosthesis using the 3D model. The dental prosthesis was successfully tested in the patient’s mouth.

A quantitative evaluation of the 3D surface reconstruction revealed small statistical differences between the 3D model generated herein and the 3D model obtained with the conventional intra-oral 3D scanner. We have also provided some guiding principles for the optimal acquisition of usable photographs for photogrammetric software.

We propose the following future developments of this method:
- Additional experiments should be conducted on other teeth, which could be more difficult to photograph. Additional devices may be necessary to scan different types of teeth (posterior, anterior maxillary and mandibular).
- This method should be tested with other cameras or software. Various close-range photogrammetric software and different types of intra-oral cameras could be compared to enable the fastest, most accurate 3D reconstruction.
- A reliable technique should be developed for metric calibration of the 3D model if the photogrammetric software does not include this feature.
- Photogrammetric methods could also be tested using video images rather than photographs.

Future studies are necessary to analyse the accuracy of the measurements of these 3D models compared with measurements obtained from other intra-oral scanners.

In addition, further assessments are needed to determine whether these 3D models could be used in current dental practice for CAD/CAM of prostheses.

Editorial note: A list of references is available from the publisher.

Dr Olivier Landwerlin is a practitioner in Cannes, France. He graduated (DDS) from the Dental University of Nice and postgraduated in 3D printing. He teaches in the dental CAD/CAM postgraduate at the Dental University of Montpellier and founded in 2018 a startup company in dental virtual reality Tooty VR (www.tootyvr.com).

Prof. Dr Michel Fages began using CAD/CAM in 2005 and currently teaches it as a lecturer at the University of Montpellier’s Faculty of Dentistry in France. He is also a lecturer in the dental CAD/CAM postgraduate diploma at Toulouse and the postgraduate diploma in aesthetic dentistry at the Université Nice Sophia Antipolis in France.

Dr Gérard Subsol is a CNRS researcher within the ICAR team at the Montpellier Laboratory of Informatics, Robotics and Microelectronics (LIRMM) in France. His work on mesh modelling has a variety of applications in anatomy, CAD or environmental studies.
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One of the simplest definitions of artificial intelligence (AI) is “the ability of a computer program or of a machine to ‘think and learn’” and the term is often used to “describe machines or computers that mimic ‘cognitive’ functions that humans associate with the human mind, such as ‘learning’ and ‘problem solving’.”

Although the academic discipline of AI was founded in 1956, many people still feel that AI is a vision of a distant future. In reality, of course, the everyday lives of all of us are already strongly influenced by AI-driven processes—you only have to think of such simple examples as the algorithms of Google Search and social networks, not to mention digital assistants like Siri and Alexa.

Dental practices as a natural environment for AI

The health sector overall can be considered a natural field of application for AI. Among other reasons, this is due to the sheer volume of data and knowledge that may be relevant to a diagnosis or treatment decision, possibly overwhelming the practitioner. Intelligent and self-learning software can be used profitably here. In the physical execution of treatments, which is often characterised by extremely high demands on precision, hygiene and repeatability that are difficult for humans to satisfy, sensitive and intelligent machines can be a great help too.

Dentistry is not lagging behind other medical disciplines; on the contrary, the first attempts at working with AI already took place in the 1970s and 1980s, exclusively in the field of CAD/CAM procedures for restorative and prosthetic dentistry. These are still among the most developed and adopted dental applications of AI today. Owing to the increased use of intra-oral scanners and 3D radiographic devices, large amounts of data can be collected even for a single treatment situation, making such a diagnostic and possibly also decision aid no longer just a convenient option but almost a necessity.

All smiles for AI: How artificial intelligence can add value to orthodontic treatment

Simone Matt, Switzerland
The clinician may perhaps already be visually overwhelmed by the analysis and evaluation of all the data, but certainly will be in time. Of course, AI can offer this kind of help, and AI always remains subordinate to the clinician in the actual decision-making process and treatment planning.

Orthodontic clear aligners—a vanguard of AI applications

Despite the large amounts of data that can potentially be collected, missing, incomplete or inaccurate digital data sets in today’s average dental office are still one of the main obstacles to greater and faster penetration of practice processes using AI-controlled systems. Among the most common limitations are that the history of digital data does not go back long enough or has gaps and that the data records produced by different devices are incompatible with each other.

It makes it all the more interesting, in view of such obstacles, to see applications that already today provide dental services in a coherent way using AI that were previously not feasible. Orthodontic treatments, especially of mild to moderate malocclusion, are seen as some interesting developments at the moment. In recent years, clear aligners have experienced a strong upswing. On the one hand, this has been at the expense of classical correction methods, but on the other hand, such orthodontic treatments are perceived as less tedious by patients and are therefore increasingly in demand.

This trend could even intensify now, because the relative comfort of wearing such clear aligners will be complemented in the future by very user-friendly AI-controlled software, advancing the treatment experience for the patient. ClearCorrect, the Straumann Group’s aligner system, will be launched on the global market together with sophisticated software that can both process data input from the patient and the clinician and deliver output to the patient and the dentist.

Smart use of AI boosts patient acceptance of treatment

This app, called DenToGo, involves patients and healthcare providers equally in several stages. At the initial Vitals Check, a first assessment of the patient’s oral situation is made in the practice. All a dentist needs is the access to DenToGo VitalsCheck on a PC to read the report and a smart phone with the DTG VitalsCheck App for the scan. Vitals Check’s feedback is given in a patient-compatible language, and therefore the qualified clinician comes into play only for the discussion about treatment options, which is obviously the part with increased added value for the practice.

The next step of the DenToGo software is MySmile, which simulates the smile with the potential appliances for orthodontic correction—metal brackets, ceramic brackets, clear aligners. Further customer can see a simulation of his future smile—like before and after. This customised preview significantly increases the conversion rate from interested candidates to patients willing to pay for treatment—thanks to AI, of course.

During the treatment phase, DenToGo’s Monitoring function ensures close-meshed care and continuous exchange of information between the practice and the patient—most of the time without a traditional practice appointment. At agreed regular intervals, the patient takes photos of his or teeth with his or her smartphone using an app and a centring device, at home or even when travelling. This data can be processed by the DenToGo practice software, and the dentist can choose whether he or she wants the built-in AI to determine the progress of the treatment and to automatically send the patient the appropriate messages. Only if the dentist deems it necessary does he or she intervene in the communication or, if necessary, have the patient invited to a practice appointment.

Even after the actual treatment is finished, this extension of the clinician’s practice to the patient’s smartphone is retained. The DenToGo Smile Guard monitors the situation after treatment and helps to prevent relapses and to check sufficient oral hygiene—while keeping the number of necessary in-practice appointments relatively low.

Clinicians can focus on added-value activities

This example of an already running dental application of AI shows some remarkable potential for the clinicians who use it: the comparatively closely spaced follow-up intervals generated by DenToGo ensure patients feel well taken care of, promoting above-average customer loyalty. At the same time, the dentist can allocate chair time to activities with high added value, without compromising the quality of treatment. The patient benefits as least as much from this AI-driven approach to dental treatment: he or she sees his future smiling and different simulations of the clinician’s practice to the patient’s smartphone is retained. The DenToGo Smile Guard monitors the situation after treatment and helps to prevent relapses and to check sufficient oral hygiene—while keeping the number of necessary in-practice appointments relatively low.

There is even an instant chat function integrated into DenToGo that provides automated responses to frequent individual questions and, of course, recognition of more difficult questions. For digital natives, such a chat might well be much more than just an acceptable alternative to a call to the practice; it could even be their preferred channel of communication with a healthcare provider, at least for simple and everyday concerns.

Simone Matt,
Director of Solutions Management Orthodontics, Straumann
Introduction

A high prevalence of oral diseases, a growing geriatric population and rapidly increasing awareness of tooth replacement with dental implants force dentists, oral and maxillofacial surgeons to respond to such promises made by implant manufacturers as new teeth in one hour. While implant manufacturers seek to maximise their sales by such marketing strategies, it will always be the practitioner’s full responsibility to treat patients according to strictly evidence-based treatment protocols, especially when it comes to immediate functional loading of dental implants.

Esposito et al., Javed and Romanos, Walker et al. and Cannizzaro et al. proved in reviews, Cochrane studies and split-mouth randomised clinical trials that primary implant stability—represented by insertion torque values (ITVs)—shows a significant correlation between the biomechanical quality of bone and the risk of immediate and long-term implant failure when implants are loaded functionally at the time of insertion.\textsuperscript{1–4} Furthermore, experimental and clinical studies by Turkyilmaz et al., Pommer et al. and Wada et al. proved a significant correlation between primary implant stability measured by ITV and Cat-Scan based bone densitometry in native alveolar bone.\textsuperscript{5–7}

Since alveolar bone loss caused by natural atrophy or destructive iatrogenic procedures at the time of tooth extraction demands immediate (alveolar ridge preser-
vation) or later (guided bone regeneration) bone augmentation procedures, Di Lallo et al. and Troedhan et al., in randomised clinical studies, found a significant difference in primary implant stability between augmented alveolar bone and native alveolar bone.\cite{8,9}

Recently, a randomised clinical study was performed by Troedhan et al. to investigate whether a significant correlation between pre-surgical CBCT bone densitometry performed with X-Mind trium (ACTEON) and primary implant stability in augmented sinus sites could be proved.\cite{10}

**Study design**

A randomised clinical study was conducted on 128 patients. Of these patients, 101 with a sub-antral crest height of less than 4 mm underwent a unilateral or bilateral trans-crestal sinus lift using the hydrodynamic ultrasonic Piezotome-sinuslift (INTRALIFT, ACTEON) with four different and randomly allocated bone grafting materials (monophasic or biphasic mouldable and self-hardening biomaterial, and granular synthetic and xenogeneic bone substitute) in 114 INTRALIFT sites.
The trans-crestal Piezotome INTRALIFT procedure provides the least risk of membrane perforation and has proved to detach the periosteum of the sinus membrane cleanly from the bony base of the antrum, thus preventing a study bias already at the stage of the surgery. The clean detachment of the periosteum from the bone base does not interfere with regular bone regeneration in the sub-antral scaffold by dissection or laceration of the periosteal layer of the sinus membrane, which carries the pre-osteoblastic cell layer.10–15

Figure 1 shows a split-mouth case of a bilateral INTRALIFT procedure. After a small crestal booklet flap of approximately 7 × 7 mm was detached, the sinus floor was safely opened with ultrasonic Piezotome tips (Figs. 2 & 3). The sinus membrane was then detached by the hydrodynamic cavitation effect of the Piezotome TKW5 tip plugged into the approach canal (Figs. 4 & 5), the sub-antral scaffold was filled with 2 ml of randomly assigned biomaterial (Figs. 6 & 7) and the wound was sutured closed (Fig. 8).

After a mean healing period of 8.4 months, CBCT scans were performed with X-Mind trium, the digital set-up of the future bridge was constructed with the AIS 3D App software and the bone density was determined in the sinus lift site around the virtual implant (Fig. 9). A standardised implant (ø 4 mm, 12 mm) was then inserted in the position of the virtual implant and the ITV was measured intra-surgically (test groups; Fig. 10).
Twenty-seven patients with sufficient native sub-antral crestal bone (minimum crestal width: 6 mm; height: 12 mm) were screened with X-Mind trium for bone density around the virtual implant (Fig. 11). The standardised implant was inserted and the ITV recorded (control group). Figure 12 depicts the final result after implant insertion in the patient case shown in Figures 1–9.

**Study outcomes**

As can be seen in Figure 13, the mean CBCT bone density values in Hounsfield units (HUs) at the implant site differed significantly (p < 0.05) between all four test groups and the control group. The precise numerical HUs are converted by the AIS 3D App software to colour gradations for easier interpretation (Fig. 14). The brighter green the CBCT voxel matrix appears around the virtual implant, the higher the bone density. The virtual neutral threshold is 500 HU. In contrast, the more reddish the CBCT voxel matrix around the digital implant, the worse the biomechanical bone quality.

The corresponding ITVs of the inserted standardised implants measured at the location of the trans-crestal INTRALIFT approach (Fig. 2) differed significantly as well between all test groups and the control group. Figure 15 depicts the cumulative result of the correlation between HUs and ITVs for all test groups and the control group.

**Clinical implications**

As the presented study proved, contemporary CBCT technology adds another outstanding feature to the general CBCT-based digital workflow as the only tool with which to safely determine the grade of primary implant stability to be expected at each individual implant site already in the planning phase before the treatment or surgery is performed (Fig. 16). Using CBCT-based bone densitometry as an integrated diagnostic step in the digital workflow, the clinician for the first time can decide individually for each patient and each implant site whether implant insertion with immediate prosthetic loading might bear an unacceptable risk of early or delayed implant loss and therefore can inform the patient accordingly based on evidence.

Additionally, the results of this study lead to another interesting conclusion: since different biomaterials lead to significantly different biomechanical bone qualities of regenerated bone with precisely correlated higher values in CBCT-based bone densitometry and ITVs, the scientific dispute of whether autologous, xenogeneic or synthetic bone grafts should be considered the gold standard needs to now take a different pathway. Native maxillary bone, especially, demonstrates a very weak biomechanical quality, which can obviously be substantially improved by biomaterials used for augmentation. Therefore, the clinician might be better advised to seek the highest possible biomechanical quality of regenerated bone in guided bone regeneration sites instead of seeking complete bone regeneration by only native bone (which—as has been histologically proved—is never the case even when using only autologous bone).

High-resolution CBCT devices such as X-Mind trium as used for this study seem to have become an indispensable, non-invasive and patient-friendly, tool not only for enhanced diagnosis, treatment planning and the digital workflow but also for clinical research to add new knowledge to evidence-based dentistry.

**Editorial note:** A list of references is available from the publisher.

**about**

**Dr Dr Angelo Trödhan** is a specialist in cranio- and maxillofacial surgery with a focus on traumatology, and reconstructive and cosmetic surgery of the face, and in dentistry. As a leading ultrasonic surgeon and scientist in ultrasonic surgery, dental implantology, bone augmentation and maxillofacial surgery, he is regularly invited to lecture at universities and congresses worldwide and to present at international workshops.
Almost 70 per cent of my cases are performed with X-Guide

An interview with Dr Alessandro Pozzi from Italy, who explains the advantages of dynamic navigated surgery with X-Guide and why he thinks it will be the new standard of practice for guided implant surgery.

By Nobel Biocare

An internationally acclaimed implant surgeon from Italy, Dr Alessandro Pozzi is one of the biggest advocates of dynamic navigated surgery, which he performs with the X-Guide system in his dental studio in Rome. In this interview, he talks about how the technology sparked his interest, how it can help to improve implant treatment outcomes and why he thinks it will be standard practice in the years to come.

Dr Pozzi, you have been placing implants for more than 20 years. What sparked your interest in dynamic navigated surgery with the X-Guide system?

I have been placing implants using surgical templates since I entered dentistry back in the 1990s and always thought it was the perfect way to perform guided surgery. Four years ago, I discovered the X-Nav system through Prof. Peter Moy from the University of California, Los Angeles. I was quite sceptical at first, but as a clinical researcher, I immediately tried to challenge the system and compared it with static guided surgery in order to find out about the advantages and limits of each approach.

Using a surgical template is a very static concept, which means that what we plan with the software cannot be changed or modified thereafter to fit in with the outcome of the surgery or the need to establish better primary stability for immediate function. With the implant planning and dynamically navigated surgery empowered by DTX Studio Implant, we now have a very flexible system at our disposal that allows us to adapt our treatment plan in real time and provide quick, safe and predictable treatment outcomes, even in challenging cases or emergencies.

What are the main advantages of dynamic guided surgery with X-Guide compared with static guided surgery?

The main advantage is having full control of the surgery. When placing an implant immediately in a fresh extraction socket, for example, it can be difficult to visualise the anatomy of the recipient site in the software or to be fully confident that the buccal plate has been maintained after the extraction. I cannot remember the number of times during the last 15 years that I was not perfectly sure about the level of the buccal plate because it was hidden by the metal artefacts of a porcelain-fused-to-metal crown or post or it had, indeed, been disrupted during the extraction.

With X-Guide you can deliver guided surgery with an open surgical field, since there is no template obstructing the view. We can see and immediately adapt to unexpected complications, for example when the alveolar wall or a knife-edge shaped edentulous bone crest drives the drill into the wrong position. With a template you can never visualise those events, as it would need to be removed to enable you to see. With the dynamic navigated concept, we can see what is happening in real time and can immediately adapt our plan to overcome complications.
What are the clinical indications for X-Guide?

There are still some clinical scenarios where the use of templates has advantages. However, with the continuous use of X-Guide, I have found more and more indications becoming possible to treat. Over the last three years, I have been treating single-tooth, partial, full-arch and terminal dentition cases with the navigation system. Performing the last with a template, in particular, can be tricky, as you need to keep the strategic teeth that can support the template and this sometimes is unrealistic and can affect the proper prosthetically driven implant positioning. With dynamic navigated surgery, you don’t need this: you can position the implants exactly where the ideal prosthetic outcome demands.

Looking back at your positive experience with the system so far, what role do you think dynamic navigated surgery will have in the future?

I have performed guided surgery for more than 15 years, but the dynamic navigation concept has completely changed how I approach my work. Almost 70 per cent of the cases in my practices are now performed with the help of the X-Guide system. I think that is amazing! My patients can be treated on the same day without the delay of surgical template production.

With this technology, we can really meet patient expectations in terms of reliability and effectiveness. I believe that, in a few years, we won’t be talking about freehand, static or dynamic guided surgery anymore because dynamically guided surgery will be standard practice. With surgical templates, we often had to make compromises in the past, but now the surgeon is in full control of his or her procedure. The good thing is that we are still following the proven concepts we learnt from Prof. Per-Ingvar Brånemark and other implant pioneers from the last 50–60 years.

X-Guide can be a system for everyone, beginners, as well as experienced clinicians, who wants to challenge themselves to take on more demanding cases with confidence.

What recommendations would you give anyone starting with the X-Guide system?

For beginners, it can be a good tool for helping them increase their confidence when they start their careers as surgeons. Especially for clinicians who do not have much surgical experience, X-Guide can be a way to improve the safety and predictability of their treatment. You have to remember, however, that it is not a shortcut, and you still need to be knowledgeable in the basics of implant surgery.

Using a template is fine, but it always detaches you somewhat from clinical reality. X-Guide is basically like a GPS, which matches the virtual patient with the real patient and looks over your shoulder in order to guide you through the procedure.

In the last couple of months, I have been training people from all over the world on treatment with X-Guide, and it is amazing to see how quickly they are able to overcome the learning curve and improve their clinical performance. In my experience, it usually takes them less than ten procedures to switch from performing simple cases on a model to a real patient.

Thank you very much for this interview.
At the recent European Association for Osseointegration (EAO) annual congress in Lisbon, Portugal, Dental Tribune International had the opportunity to speak with Jo Massoels, Vice President of Global Marketing and Solutions at Dentsply Sirona Implants, about some of the company’s recently launched products and its focus for the future.

Mr Massoels, the theme of this year’s EAO congress is “The bridge to the future”. How is Dentsply Sirona living up to this theme, both here and looking beyond Lisbon?

Well, here in Lisbon, we are mostly focused on our implant solutions, given that this is the main specialty of the EAO. How Dentsply Sirona lives up to this theme, both at this congress and in general, is through our scientific approach to research and development. This knowledge remains our foundation, but at the same time, our digital portfolio continues to expand, and so what Dentsply Sirona is doing is developing a bridge between this scientific knowledge and a digitally based future.

Of course, this is not to say that we are not focused on implantology as a path forward—here at EAO, we have been showcasing our new Astra Tech Implant System EV, for example. Implant dentistry, as a whole, is moving towards being able to provide patients with immediate loading, and this is definitely an area of focus for Dentsply Sirona. Another focus of ours is digital workflows—making sure that these workflows are open and customisable. And, of course, education remains a priority for the company, as it’s not always easy to optimise your clinical digital workflows without sufficient training.

Will there be specific training courses offered by Dentsply Sirona for the Astra Tech Implant System EV as it is rolled out across North America and Europe?

Yes, absolutely. That’s where Dentsply Sirona will really be able to leverage its dedication to training. We have built and are building many training facilities around the world to educate dental professionals in general, where they are able and will be able to engage in training sessions for the Astra Tech Implant System EV, Azento and other Dentsply Sirona solutions.

Dentsply Sirona took the opportunity at the 2019 International Dental Show to launch the Primescan intra-oral scanner, among other products. What has the feedback been to this point?

It’s been tremendously positive, to be honest. We knew it was a great product, but I did not expect it to be such a tremendous success—there are quite a few intra-oral scanners on the market already, but with the launch of Primescan, we enabled users to take a digital impression easily and with great accuracy at an outstanding speed. That’s also the feedback that we’ve received from clinicians—that the speed and accuracy are extremely useful, particularly for something like implant dentistry where you want to be able to capture the implant position with precision.

Can Primescan be connected to, and used in conjunction with, other software?
Primescan has a seamless connection with the rest of the CEREC system, which is ideal when a clinician wants to work chairside. The big difference, however, is that we’ve really opened up the connectivity of Primescan so that it can be used not only chairside but also when you’re working with a dental lab or other partners. I think it’s safe to say that our customers have expressed their appreciation of this feature.

To return to the Astra Tech Implant System EV: are there any specific areas of implant dentistry that Dentsply Sirona aims to address with this upgrade? Definitely. The main trend that this implant is designed to address is immediate restorative temporisation. In general, there is a growing demand for immediate temporisation, and it’s something that many clinicians want to be able to offer their patients. However, a crucial factor for clinicians is achieving primary stability in the implant—this is a requirement for successful immediate temporisation.

As patients are requesting faster dental care, there are a growing number of clinicians conducting immediate temporisation. This is what the Astra Tech Implant System EV seeks to address, with its deeper apical threads designed to allow for ideal primary stability. What we’ve done is improve an already very versatile implant system, allowing it to be used for an even greater set of indications, without compromising the guiding principles of the Astra Tech Implant System EV, and providing outstanding marginal bone maintenance. I am confident that this will be appreciated by our customers. They’ll be able to treat more cases than ever before using the same implant system with the same drilling protocol.

We’ve built on what we already have—not just the products but also the science that serves as our foundation.

Thank you very much for this interview.
At the beginning of September, 60 experts in different domains and from various countries gathered at MIS Implants Technologies’ headquarters to discuss how innovations in dental implantology can influence the work of dental practitioners and the quality of life of their patients and to come up with such innovations to specific problems.

For the intensive two-day programme, the participants were divided into eight teams, among them dental specialists, students, engineers and designers. First, they listened to presentations by MIS experts and opinion leaders on problems in dental treatment, and then worked on developing their own ideas in teams to come up with a solution to one of the problems presented.

On the final day of the MIS Makeathon, the teams presented to the panel of judges and the rest of the audience the issue they had chosen to address and their plan for solving it. They explained the issue and how it effects both dentists and patients, revealed their proposed solution and demonstrated the feasibility of producing the product they had come up with.

The panel of judges—Shlomi Magal (General Manager of MIS), Prof. Nitzan Bichacho, Prof. Lior Shapira, Yossi Shnit, Dr Tali Chackartchi, Doron Peretz and Dr Alon Schifter—awarded prizes to four teams. The third prize went to two groups, who both tackled the need for better drill wear recognition. The second-place winners, came up with an innovative alternative to existing types of prosthetic restoration. The first prize was given to the team who presented a plan for addressing the issue of drill use tracking and wear recognition.

The second Makeathon was an inspiring experience for the participants and organisers alike, and the organisers are planning to continue this idea in the future. Dror Sarig, Vice President of Research and Development at MIS, believes in the importance of this event: “In a place where ideas grow, the future is built,” he said.
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