The rehabilitation of edentulous patients using osseointegrated dental implants is a well-established treatment option, but can be challenging and complicated to execute. Complete tooth extraction or loss is often followed by varying degrees of alveolar bone resorption, which may be exacerbated by the use of ill-fitting complete dentures. These complications introduce significant anatomical challenges, as the overall bone volume required for implant anchorage becomes limited. Several bone augmentation procedures and techniques have been described to regenerate deficient alveolar bones in order to place dental implants. Pneumatization of the maxillary sinuses—which further reduces the alveolar bone height—along with esthetic demands can make the restoration of the edentulous maxillary arch more demanding than the mandibular arch.

Advances in digital technologies led to the development of computer-assisted implant surgery (CAIS), which has been introduced as a method to increase the accuracy and predictability of implant placement. Surgical templates (STs) or guides are used to transfer the virtual implant planning to the patient’s mouth and can be classified according to the type of supporting tissues into bone-supported, tooth-supported, mucosa-supported, or specially supported with fixation pins, screws, or...
transitional implants (TIs).\textsuperscript{11,12,16} Both tooth- and mucosa-supported templates show higher implant placement accuracy when compared to bone-supported templates.\textsuperscript{12} However, the accuracy of mucosa-supported templates is affected by positioning and stability, which may result in inaccuracies.\textsuperscript{11,17} Furthermore, the use of mucosa-supported templates when bone augmentation is needed can be challenging.\textsuperscript{1} Various fixation methods have been described to increase the stability of STs, including the use of fixation pins, screws, or TIs to support the templates.\textsuperscript{1,11,17–19}

TIs are implants with smaller dimensions that are intended to be used for a specific period of time or to support an interim prosthesis.\textsuperscript{20} These implants have been used to support fixed and removable prostheses as interim or definitive treatments in partially and completely edentulous patients.\textsuperscript{21–24} Several immediate-loading protocols have also been described for these implants.\textsuperscript{5,22,23,25} Moreover, when bone augmentation procedures are required, the use of TIs to support an interim prosthesis can reduce the pressure applied to the augmented sites, leading to undisturbed healing.\textsuperscript{6,23,26} Once TIs have served their purpose, they can be manually removed.\textsuperscript{27}

TIs have been used to stabilize surgical templates in an effort to improve the accuracy of implant placement.\textsuperscript{28–30} Innovative approaches combining the use of TIs and CAIS have been described to overcome the limitations of mucosa-supported templates by providing reproducible support for the radiographic templates (RTs) and STs, in addition to providing a fixed screw-retained interim or definitive prosthesis.\textsuperscript{1,18,19} As digital technologies continue to develop, new workflows and protocols can be introduced, each trying to push the envelope of applications of this technology. Therefore, the aim of this report is to describe a new digital workflow for CAIS in edentulous patients with the aid of TIs to provide fixed support for the ST. This workflow can be particularly advantageous for patients requiring staged bone augmentation.

CASE DESCRIPTION

A 67-year-old female patient with an edentulous maxilla presented to the Harvard Dental Center (Fig 1). The patient had been wearing a maxillary removable complete denture for about 3 years, but was unhappy with the function and esthetics of the prosthesis and was seeking a fixed rehabilitation using dental implants. The patient had well-controlled type I diabetes mellitus, with no other contributory medical conditions.

After a thorough clinical evaluation of the patient, a conventional trial tooth setup was made at a newly established vertical dimension that met the patient’s esthetic expectations. The trial setup was made flangeless for better evaluation of lip support, smile line, and gingival display.\textsuperscript{2,3} The prosthesis-tissue junction was not visible, nor was there a need for prosthetic gingiva.\textsuperscript{2} The proposed plan included a metal-ceramic implant-supported fixed complete dental prosthesis (IFCDP) supported by six implants.

Radiographic Evaluation

Once the functional and esthetic parameters were approved, a dual scanning procedure was performed.\textsuperscript{8} A minimum of three self-adhesive radiopaque markers (CT-SPOT 120, Beekley Medical) were attached to the trial setup. A maxillary CBCT scan was exposed at 120 kV, 5 mA, and with a voxel size of 0.3 mm (i-CAT, Imaging Sciences International) while the patient was wearing the trial tooth setup. This was followed by a second CBCT scan of the trial setup alone using the same scanning parameters. The images from both CBCT scans were stored as Digital Imaging and Communication in Medicine (DICOM) files.

Using implant planning software (coDiagnostiX, Dental Wings), the DICOM files of the trial setup were aligned with the DICOM files of the maxillary arch using the radiopaque markers as reference. This allowed for the evaluation of the patient’s bone anatomy in relation to the proposed prosthetic plan (Fig 2a). Six standard-size implants (Bone Level Tapered, Institut Straumann) were planned. However, significant horizontal and vertical resorption was noted in the anterior region of the maxilla along with bilateral pneumatization of the maxillary sinuses, which preclude the prosthetically driven placement of implants without prior bone augmentation procedures. Alternative treatment options such as angled, narrow, or short implants were also not feasible without significant bone augmentation. Therefore, in accordance with the digital implant planning and the morphology of the bone defects, a decision was made to perform bilateral sinus floor elevation procedures to augment the posterior region and autogenous block grafts to augment the anterior region.\textsuperscript{5,10} The virtual planning for four TIs in sites away from future implant locations (ANEW, 

![Fig 1](Image)

Clinical appearance of maxillary arch upon initial presentation.
Dentatus) based on the proposed prosthetic plan was also carried out (Fig 2b).

**Bone Augmentation and TIs**

A lateral-window maxillary sinus floor elevation procedure was performed bilaterally under local anesthesia (Fig 3). After full-thickness flap elevation, a lateral window was created using piezosurgical tips. The sinus membrane was carefully elevated and a combination of deproteinized bovine bone mineral (DBBM; Bio-Oss, Geistlich Pharma) and freeze-dried bone allograft (FDBA; RegenerOss Allograft, Zimmer Biomet Dental) was packed into the sinus. The lateral window was covered with a resorbable collagen membrane, and the flap was reapproximated and sutured in place. The postoperative healing was uneventful.

After 6 weeks, TIs were placed under local anesthesia via a flapless approach. The TIs in both maxillary canine sites were 1.8 mm in diameter and 10 mm in length while the TIs in the second premolar sites were 2.2 mm in diameter and 10 mm in length. A mucosa-supported template and a custom guide sleeve were used to place the TIs in a guided approach, achieving primary stability (Fig 4a). Screw-retained titanium copings were attached to the TIs, which were then luted to a polymethyl methacrylate duplicate of the trial setup to provide the patient with a screw-retained interim prosthesis (Fig 4b). Due to the posterior position of the TIs and in order to avoid prosthetic complication, a bilateral balanced occlusion was established. Strict hygiene and soft food dietary instructions were given. The patient was asked to avoid anterior pressure on the interim prosthesis to limit the amount of force applied to the anterior cantilever. The following postoperative healing period was uneventful.

Four weeks later, the autogenous bone block grafting procedure was performed under local anesthesia. After preparation of the recipient bed by decortication, two bone blocks were harvested from the patient’s chin. Each block was fixed in the anterior maxilla in the maxillary central and lateral incisor sites using fixation screws (Figs 5a and 5b). Autogenous bone chips were packed in the gaps around the bone blocks, followed by a layer of DBBM. After that, a resorbable collagen membrane was placed over the bone block to allow for primary bone union. The postoperative healing period was uneventful.

Fig 2  (a) Sagittal view of maxillary CBCT with outline of soft tissue (pink) and trial setup (white) visible. (b) Virtual planning of 6 implants and 4 TIs.

Fig 3  Panoramic radiograph following bilateral maxillary sinus augmentation.

Fig 4  (a) TIs placed. (b) Screw-retained interim prosthesis.
Bio-Gide, Geistlich Pharma) was used to cover the entire graft. Periosteal releasing incisions were made to release the flap to ensure tension-free primary closure. The screw-retained interim prosthesis was then delivered after adequate relief of the intaglio surface to prevent undue pressure on the grafted sites. Uneventful healing followed.

**Radiographic Evaluation and Implant Planning Following Bone Augmentation**

During the healing phase, the tooth setup was refined to improve the esthetics based on the new postsurgical tissue anatomy. The modified setup was able to be screw-retained directly on the TIs. After 6 months of healing, a new maxillary complete-arch CBCT scan was exposed using the same scanning parameters as previously described, with the interim prosthesis attached to the TIs. Self-adhesive radiopaque markers were attached directly to the patient’s hard palate to serve as reference points. Two direct digital impressions using an intraoral scanner (TRIOS 3 Pod, 3Shape) were taken and stored in standard tessellation language (STL) format. The first scan, named STL 1, included the maxillary arch, interim prosthesis, and radiopaque markers. The interim prosthesis was then removed, and a digital impression of the edentulous ridge, TIs, and the markers was made and named STL 2.

On the implant planning software, the maxillary bone, radiopaque markers, and TIs were identified and isolated using the segmentation tool. Both STL files were registered on the CBCT scan using the markers as common references. As the necessary information regarding the bone anatomy, soft tissues, and prosthetic plan became available, the previous planning of six standard size implants (Bone Level Tapered, Institut Straumann) was finalized based on the new prosthetic design (Figs 6a and 6b). After completion of the virtual planning, an ST was designed based on STL 2 to sit directly on the TIs without any mucosal or bone support (Fig 7). The template was 3D printed using a desktop 3D printer (Form 2, Formlabs) and the screw-retained copings were retrofitted on the template.

**Implant Placement Surgery**

A full-thickness mucoperiosteal flap was raised under local anesthesia. The fixation screws used to stabilize the autogenous bone blocks were located and removed. The ST was screwed directly onto the TIs without any bone or soft tissue contact. All osteotomy preparations and implant placements were performed using the ST
according to the guided surgery protocol, achieving primary stability. The two most anterior implants were both 3.3 mm in diameter and 10 mm in length, while all posterior implants were 4.1 mm in diameter and 10 mm in length. A particulate bone graft consisting of autogenous bone and DBBM was performed for contour augmentation in the anterior region of the maxilla, which was then covered with a resorbable collagen membrane. After flap release and reapproximation, tension-free primary closure was achieved. The screw-retained interim prosthesis was screwed back in place after confirming adequate tissue clearance (Figs 8a to 8c). After 2 months of uneventful healing, a second-stage surgery was performed under local anesthesia to expose the implants. The definitive metal-ceramic IFCDP was fabricated based on the planned prosthetodontic design and was delivered shortly after (Fig 8d).

Accuracy Analysis
After the implants were exposed, scan bodies (CARES Mono Scanbody, Institut Straumann) were screwed onto each implant and a digital impression was made. The new digital impression was uploaded to the implant planning software and superimposed onto the virtual plan. Using the treatment evaluation tool in coDiagnostiX, the locations of the implants were identified and compared with the corresponding planned virtual implants. The average angular deviation was 2.9 degrees, while the average 3D deviations at the implant platform and apex were 0.79 mm and 1.05 mm, respectively. Table 1 describes the deviation values for each implant.

DISCUSSION

The Glossary of Oral and Maxillofacial Implants defines TIs as implants manufactured from the same biocompatible materials as standard implants, but made to smaller dimensional specifications to be used for a specific period of time or to support an interim prosthesis.20 Mini-implants are defined as those fabricated from the same biocompatible materials as standard implants with smaller dimensions and can be made as one piece for support and/or retention of an interim or definitive prosthesis.20 With no diameter threshold for either category, the terminology can be somewhat confusing.9 According to several studies, TIs have a diameter between 1.8 and 2.4 mm with several different macrodesigns and surfaces.23,26,27 This overlaps with the definition of mini-implants, which commonly includes implants with a diameter between 1.8 and 2.9 mm.9 This can explain why both terms have been used interchangeably.

TIs have commonly been used to support interim prostheses during the different healing phases of implant therapy.21–23 They have also been used to support definitive prostheses such as overdentures and single crowns, with 1-year survival rates up to 94.7%.4,7,9,24 The use of TIs to support surgical templates has been described since the early 2000s.28–30 It is necessary to precisely identify the future locations of the implants prior to TI placement in order to adequately avoid these locations, as implant placement between the TIs can be challenging.28 The use of STs during placement of the TIs has been emphasized.28 Likewise, the placement of two TIs in the posterior mandible to stabilize STs while avoiding the placement of TIs in close proximity to the standard-sized implants has also been described.29,30

More recent methods combining the use of TIs and CAIS have been described where the TIs were placed prior to CBCT scanning, which provided reproducible reference points and allowed for the fabrication of RTs attached directly to the TIs.1,18 Consequently, the RT itself can be converted to an ST, or an individual ST can be fabricated to sit directly on the TIs.1,18 Despite the reported predictability and success with these methods, the inability to visualize both the TIs and the implants simultaneously, and prior to the placement of either, could be a potential source of complications.1,18,19 Furthermore, these methods used conventional impressions and stone casts, which may add a potential source of error.1,18

Unlike the other methods, CAIS was used with both standard implants and TIs in the present workflow. The virtual planning of both sets of implants was carried out simultaneously, permitting proper implant alignment and distribution. Although bone augmentation was required prior to placement of the implants, the desired location for said implants was already predetermined in the virtual planning. Not only did this step ensure that the TIs avoided the selected sites, but the amount of bone augmentation required was able to be more accurately assessed. A mucosa-supported ST with custom guide sleeves was designed in order to perform guided osteotomy preparations for the TIs.

The guided placement of TIs can potentially increase predictability and possibly reduce the need for intraoperative removal and repositioning, which may increase
The International Journal of Prosthodontics

the risk of TI fracture.25 CAIS may also increase drilling precision, making it easier to achieve primary stability, which is a requirement for immediate loading.25 Dörsam et al have demonstrated higher insertion torque when mini dental implants were inserted in dense cortical bone.25 Therefore, in this case, the TIs were placed in locations where more cortical bone was available. On the other hand, histologic studies have demonstrated that TIs do in fact osseointegrate.26 However, the degree of osseointegration varies, with greater integration observed in the mandible compared to the maxilla.27 Although TIs can function for up to 15 months in the maxillary arch and still be removed safely, care should be taken beyond the 10-month point as the risk of fracture increases.27

The presence of the TIs during CBCT scanning can produce scatter artifacts that lead to image distortion, which can complicate the fabrication of accurately seating surgical templates.16,18 The use of self-adhesive radiographic markers during both the CBCT scanning and digital impressions provided enough common reference points for the accurate registration of the STL files on the CBCT scan.13,16 As the STL file had clear and detailed representation of the intraoral position of the TIs, it was possible to design and fabricate an ST that screws directly onto the TIs. Furthermore, the accurate representation of the soft tissues on the STL file allowed for the design of an ST that is supported completely by the TIs with no tissue interference.

To reduce ST positioning errors in edentulous patients, fixation is always recommended. This is commonly achieved through the use of fixation screws and pins.1,11,14,17 Fixation screws may obscure visualization and prevent constant monitoring of the sites during preparation, and they may become loose.11,12 Also, micromovement may still be observed, resulting in deviations from the planning.1,14 A study looking into the

<table>
<thead>
<tr>
<th>Implant position (FDI)</th>
<th>Angular deviation (degrees)</th>
<th>Platform deviation (mm)</th>
<th>Apex deviation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3D</td>
<td>MD axis</td>
<td>BL axis</td>
</tr>
<tr>
<td>16</td>
<td>2.5</td>
<td>0.63</td>
<td>-0.56</td>
</tr>
<tr>
<td>14</td>
<td>2</td>
<td>0.77</td>
<td>-0.07</td>
</tr>
<tr>
<td>12</td>
<td>3</td>
<td>0.55</td>
<td>-0.02</td>
</tr>
<tr>
<td>22</td>
<td>2.6</td>
<td>0.83</td>
<td>0.00</td>
</tr>
<tr>
<td>24</td>
<td>2.3</td>
<td>1.22</td>
<td>0.04</td>
</tr>
<tr>
<td>26</td>
<td>5</td>
<td>0.74</td>
<td>-0.19</td>
</tr>
</tbody>
</table>

BL = buccolingual; MD = mesiodistal.

Fig 8 (a) Occlusal and (b) frontal views of implant placement. (c) Panoramic radiograph following implant placement. (d) Panoramic radiograph of definitive metal-ceramic IFCDP.
accuracy of mucosa-supported STs with fixation screws found the angular deviation to be 4.09 degrees, while the 3D deviation was 1.66 mm at the platform and 2.09 mm at the apex, all of which are greater than those reported in the present case. Due to the screw-retained design of the ST in the present case, the deviation values achieved are considerably improved and are comparable to those reported with tooth-supported STs, which tend to have the highest accuracy.

CONCLUSIONS

The described case demonstrates a novel approach for the use of TIs in conjunction with CAIS for the rehabilitation of an edentulous arch requiring bone augmentation. In this approach, the ST is made screw retained with no tissue contact, which provides adequate stability for STs and greater access during the procedure. A screw-retained fixed interim prosthesis can be delivered on TIs without applying pressure on the augmentation sites and without immediately loading the implants. Despite the high placement accuracy and promising results, further clinical research is still necessary to validate this approach.

ACKNOWLEDGMENTS

The authors report no conflicts of interest.

REFERENCES