More dentists are placing implants as part of their practice and must plan implant placement to enhance restorative outcomes. Surgical guides aid in transferring the ideal implant position to the surgical field.

Two methods of developing surgical guides are available: conventionally or with computer-aided design/computer-aided manufacturing (CAD/CAM). Conventional surgical guides are fabricated directly on gypsum casts, and the location of vital structures is approximated. Enhanced imaging technologies, implant planning software, and CAD/CAM capabilities have increased the ability to plan and execute proper and safe implant placement.

With cone beam computed tomography (CBCT) or optical scanning (OS), casts can be digitized. Implant width, length, and position can be planned with specialized CAD software. The corresponding surgical guide can then be designed with a similar type of software. The digital replica of the surgical guide is evaluated by the surgical team and then printed by using CAM methods, such as stereolithography (SL) or 3-dimensional printing (3DP).

Three-dimensional CBCT imaging aids in diagnosis because of its accuracy in determining bone quality, bone volume, and anatomic restrictions, without the distortion and artifacts seen on 2-dimensional radiographs. Radiation doses are lower than those of...
The purpose of this investigation was to determine the internal fit of surgical guides on dentate and edentulous ridges by using implant surgical guides fabricated from conventional and CAD/CAM techniques. CAD was performed with scans from CBCT and OS, and CAM was completed with SL and 3DP.

**MATERIAL AND METHODS**

Two types of maxillary casts were selected: a Kennedy Class 2 (K2) cast with missing maxillary third molars, right molars, and premolars; and a Kennedy Class 3 cast (K3) with missing maxillary third molars and a right first molar, and a second premolar (Fig. 1). Both casts were duplicated (DoubleTake; Ivoclar Vivadent) 40 times with Type V dental stone for a total of 80 casts (DieKeen; Modern Materials). Eight casts were designated to the following groups: conventional (CON), optical scanning/3-dimensional printing (OS/3DP), optical scanning/sterelithography (OS/SL), cone beam computed tomography/3-dimensional printing (CBCT/3DP), and cone beam computed tomography/sterelithography (CBCT/SL) for each K2 and K3 classification. All surgical guides fabricated from CAD/CAM were labeled so that they were cemented to their respective scanned cast to minimize the dimensional variability of each cast. Casts scanned by CBCT were set to a voxel size of 0.160 mm and an 80×80 mm field of view. Images were viewed at 0.100 mm resolution (3D Accuitomo 80; Morita). Casts were scanned by the optical scanner (R-700TM Desktop Orthodontic Scanner; 3 Shape). The decimation setting was set to 40% (Fig. 2). All machines were turned on, calibrated according to the manufacturer’s instructions, and the settings verified.

CBCT images were converted from a DICOM to a .STL format with computer software (Mimics 12.1; Materialise Dental). CBCT and OS scans were then aligned to a single path of insertion with another software program (GeoMagic Studio 12; GeoMagic USA). Undercuts were eliminated by using a zero degree blockout (Fig 3). Undercut locations were uniform on all casts. A 2 mm thick surgical guide was designed and further refined with a software program (GeoMagic Studio 12; GeoMagic USA) (Fig. 4). The intaglio surface of the surgical guide was fitted to the cameo surface of the cast (Fig. 5). The surgical guide design was exported to the rapid prototyping printers.

Once the guides had been digitally designed, they were printed in 1 of 2 ways. The first method was with BuildStation 5.3 software and SL hardware (Viper si2 SLA system; 3D Systems). They were printed according to the manufacturer’s instructions. The guide material was made from a low-viscosity liquid photopolymer (Somos Watershed XC11122m; Somos Materials Group). The second method was with the Objet Studio software.
and 3DP hardware (Objet Eden260V 3D printer; Objet Ltd). They were printed according to the manufacturer’s instructions (Fig. 6). Resin (MED610; Objet Ltd) was used for this surgical guide. In order to standardize the path of insertion of the CAD/CAM surgical guide to the casts of the conventionally fabricated guides, an OS/3DP surgical guide was designed and printed with 3 chimneys. The internal fit of each chimney was the diameter of an analyzing rod (Ney Dental Intl). The surgical guide was placed on the cast and placed on a surveyor such that the analyzing rod could enter each chimney without tilting the occlusal plane (Ney Surveyor; Ney
Dental Intl). A carbon marker was used to mark the height of contour. Blockout modeling clay (Ticene; CMP Industries LLC) was added below the height of contour to give a zero degree blockout. The cast was duplicated 7 times with type 4 dental stone (Silky Rock; Whip Mix Corp).

A printed CBCT/3DP surgical guide was sealed to a blocked-out cast with wax. The conventionally fabricated surgical guides were fabricated with autopolymerizing acrylic resin (Vitacrylic Resin; Fricke Dental International, Inc) in a silicone duplication material (Double Take; Ivoclar Vivadent AG) (Fig. 7). This protocol was repeated for the K3
casts. The intaglio surfaces of the surgical guides were examined for defects. A template was fabricated according to the manufacturer’s instructions and used to draw standardized lines in a mesiodistal direction (Triad Trutray; Dentsply Intl). Teeth selected for analysis on the K3 casts were the central incisors, canines, first premolars, and second molars. Teeth selected for analysis on the K2 casts were the central incisors, canines, left first premolar, left second molar, and the edentulous areas near the right first premolar and right second molar. The intaglio surface of each surgical guide was coated with zinc oxide eugenol cement (Tempbond Standard; Kerr Corp) mixed according
to the manufacturer’s instructions. The surgical guides were then placed on the cast without adjustment (Figs. 8, 9). Finger pressure was applied until the surgical guides were fully seated on the cast. A glass slab was placed on the occlusal surfaces of the surgical guide, and an 8.9 N load was applied on top of the glass slab for a minimum of 10 minutes to ensure consistent seating of the surgical guide to the cast.

Next, surgical guides were sectioned along standardized locations in a buccolingual direction to determine the internal fit of the surgical guide on the cast. Surgical guides were sectioned with a thin disk in a lathe. Three measurements were made on the canines and the central incisors on the incisal edge and the midpoint between the incisal edge of the inferior border of the guide (Fig. 10). Five measurements were made on each molar and premolar at the cusp tips, central groove, and midpoint between the cusp tip and inferior border of the surgical guides (Fig. 11). Five measurements were made on the edentulous areas at the buccolingual midpoints and at 2 points on both sides of the midline (Fig. 12).

After all areas to be measured were marked on the guides, they were examined with a stereomicroscope (AxioZoom.V16; Carl Zeiss Microscopy GmbH). Images of the guides were viewed under continuous exposure (Zen Pro 2011; Carl Zeiss Microscopy GmbH). Measurements were made with the guide in focus at ×16 magnification. Photographs of the sites measured were made with a color microscopy camera (AxioCam HRc; Carl Zeiss) and saved as JPEG files. Measurements of fit were averaged over surfaces for each tooth, then over all teeth in each cast to obtain an overall mean fit for each cast.

A sample size of 8 casts per group was required for a statistical significance of .05 and power of .80. This was based on the mean and standard deviation of 60 and 85.3 The mean for 1 cast is based on 8 teeth, which made the standard deviation for the cast average approximately 21.21 (60/√8) μm and 30.05 (85/√8) μm. To detect a similar difference for 206 μm and 243 μm with the casts, a similar standard deviation was assumed.

The least square means was used to measure each surgical guide averaged over 8 casts. The difference in fit of conventional and CAD/CAM surgical guides was analyzed with repeated measures with a 2-way ANOVA to compare CAD/CAM surgical guides with unequal variances for each of the 10 groups of 8 casts each. A post hoc Fisher LSD t test was also used to compare conventionally fabricated surgical guides with CAD/CAM surgical guides. The ANOVA is expected to be powerful because it pooled more group standard deviations and obtained a higher degree of freedom (α=.05).

RESULTS

In a 2-way ANOVA (factors of Kennedy class and guide), the difference between groups and Kennedy class were both statistically significant (P<.05). The interaction between groups and Kennedy class was statistically significant (P<.05). The least square means internal fit measurements and standard deviations for K2 and K3 casts are described in Table 1.

Of the K2 casts, the OS/3DP surgical guides had the average smallest measurements. The conventional
surgical guide measurements were statistically significant from CBCT/SL, CBCT/3DP, and OS/3DP surgical guides (P<.05). The average measurements of conventional surgical guide were closer to OS/SL (P>.05) than those of OS/3DP surgical guides (P<.05) (Fig. 13). Of the K3 casts, the conventional surgical guides had the average smallest measurements. The conventional surgical guides were statistically significant from CBCT/SL and CBCT/3DP, and from OS/SL surgical guides (P<.05). Conventional surgical guide measurements were closer to those of OS/3DP surgical guides (P>.05) (Fig. 14).

An additional analysis of K2 internal fit measurements was made where the posterior edentulous surfaces were compared with the posterior dentate surfaces. This resulted in a significantly better fit of the surgical guide on the dentition than the residual ridges (Table 2). A significant difference was noted in dentate and edentulous areas in CBCT scanned surgical guides (P<.05), a statistically significant differences in conventional and OS/3DP surgical guides (P<.05), and no difference in OS/SL surgical guides (P>.05). Overall, the OS surgical guides had the smallest least square means measurements, and CBCT surgical guides had the greatest least square means measurements.

**DISCUSSION**

According to this investigation, a difference in the accuracy of fit appeared to depend on the method of scanning for CAD.

The few published articles that investigated this topic compared only treatment-planned implants to placed implants.16,27,29-33 Sarment et al27 compared conventionally fabricated surgical guides to stereolithography surgical guides fabricated from a patient’s CBCT on epoxy resin mandibles. The conventionally fabricated surgical guides showed 1.5 mm mean difference at the entrance and 2.1 mm mean difference at the apex. This was reduced to 0.9 mm at the entrance and 1.0 mm at the apex when the stereolithographic guide was used. The authors concluded that 3-dimensional images used with CAD/CAM technologies produced a more accurate result. This investigation assumed that stereolithography surgical guides were fabricated with a better internal fit than the conventionally fabricated surgical guides.27

Nickenig et al26 compared implant placement with surgical guides made from virtual planning with CBCT data and placement without the use of a surgical guide. Twenty-three implants were placed in 10 patients. Implant placement was better with surgical guides fabricated from CBCT data compared to freehand implantation. The use of the surgical guides resulted in less variation between the planned and actual implant positions at the implant shoulder (0.9 ± 4.5 mm) and apex (0.6-0.9 ± 3.4 mm) than freehand implantation (2.4-3.5 ± 7.0 mm). The authors did not investigate whether the freehand method would have been more accurate if a CBCT image had been referenced for placement than a panoramic radiographic.26

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**Table 1. K2 and K3 values (µm)**

<table>
<thead>
<tr>
<th>Surgical Guide</th>
<th>OS/SL</th>
<th>CBCT/3DP</th>
<th>CBCT/SL</th>
<th>OS/3DP</th>
<th>CON</th>
</tr>
</thead>
<tbody>
<tr>
<td>K2</td>
<td>255.11±10.93</td>
<td>382.78±85.13</td>
<td>419.16±57.66</td>
<td>162.86±54.82</td>
<td>240.37±30.22</td>
</tr>
<tr>
<td>K3</td>
<td>207.30±11.94</td>
<td>267.04±22.74</td>
<td>324.19±36.75</td>
<td>155.69±19.67</td>
<td>152.36±17.10</td>
</tr>
</tbody>
</table>

Data presented as mean ±SD, unless stated otherwise.
K2, Kennedy Class 2; K3, Kennedy Class 3; OS, optical scan; SL, stereolithography; CBCT, cone beam computed tomography; 3DP, 3-dimensional digital printing; CON, conventional.
Most investigations were performed on tooth-supported surgical guides. Ozan et al.\(^29\) published an investigation comparing tooth-supported, bone-supported, and mucosa-supported surgical guides. This group used computed tomographic imaging to plan and place 110 implants with a SL surgical guide. They found deviations of 1.11 ± 0.7 mm at the implant platform and 1.41 ± 0.9 mm at the implant apex of planned and placed implants. One of the major findings of the investigation was improved implant placement with tooth-supported and bone-supported surgical guides. Deviations were credited to increased stability of the surgical guide on the teeth and bone, but investigation into potential distortion of the Surgical guide material was not presented.

The dental technique with a protocol most similar to this investigation was performed by Van Der Zel.\(^16\) CBCT images of both the maxilla and mandible were correlated with an optical scan of a corresponding gypsum cast. The scans were used to make SL surgical guides. The author claimed that this surgical guide was more stable when placed on the original casts than on the surgical guide that was fabricated with a CBCT scan of the cast; an investigation was not performed to support this claim and was based on subjective observations.

When interpreting the results of this investigation, 2 factors should be considered. The first is that this was an in vitro study performed under ideal conditions. Two casts were duplicated multiple times, and it was not known whether the surgical guides fabricated fit intra-orally. If an in vivo study had been performed, subsequent procedures could have produced less accurate data. The patient’s teeth may have moved or an inaccurate impression may have been made, resulting in surgical guides that do not fit accurately. Also, the K2 measurements may differ if the surgical guides come in contact with mucosal tissue: the surgical guides may flex and the mucosal tissue may be displaced, resulting in inaccurate seating of the surgical guide. The surgical guides for the K3 casts were all measured on teeth, which corresponds to hard tissue intra-orally. After imaging the patient, if a change in the position of the implant is noted based on the position of the bone, the change should be corrected on the surgical guide before surgery.

Additionally decreasing the field of view for the CBCT scan may have increased the internal fit of the surgical guides. An 80×80 mm field of view was selected to exaggerate the effects of the surgical guide fabrication, but a 60×60 mm field could have been used for the fabrication of a surgical guide. No previous investigation has tested implant placement or the accuracy of internal fit based on differing CBCT fields of view.

Overall, conventionally fabricated surgical guides displayed the most accurate internal fit on K3 casts. OS/3DP casts were more accurate, but not statistically significantly so, than conventionally fabricated surgical guides on K2 casts. From the results of previous investigations regarding implant placement, placing implants with conventionally fabricated surgical guides may result in less accurate placement than when using CAD/CAM surgical guides.\(^27\) The error of conventional surgical guide fabrication may be due to the approximation of the location of vital structures, especially if 2-dimensional radiographs are used as references.

Optically scanning casts for surgical guide fabrication appears to result in greater accuracy of fit than those scanned from CBCT. The differences of internal fit relative to printing method, SL or 3DP, do not appear to significantly affect statistical results. Although optically scanning the cast of a patient appears to be the most beneficial, if the patient has many metallic restorations, the CBCT scan of the patient may have too many streaks to correlate it with the optical scan. The use of a conventionally fabricated surgical guide generated on a stone cast would be the recommended treatment in this situation. Further investigation of this topic is warranted to include implant placement and should include tooth-supported, bone-supported, and mucosa-supported surgical guides.

The differences of internal fit between dentate and edentulous areas may be due to the differences in material properties of the surgical guides. If shrinkage of the material were to occur, it would be most noticeable and exaggerated over a flat surface compared with a convoluted surface. Clinically, the poor internal fit of the CBCT/SL surgical guides may not be desirable for bone-supported or long-span mucosa-supported clinical situations. An optical scan may be ideal because of the lack of metallic restorations in partially edentulous patients.

**CONCLUSIONS**

The following conclusions can be drawn from the results of this in vitro study:

1. Surgical guides fabricated from conventional and CAD/CAM techniques varied in accuracy of fit.
2. Conventionally fabricated surgical guides demonstrated the most accurate internal fit to the K3 casts, but the inability to correlate it directly with a CBCT image makes it more difficult to ideally place implants.

3. Conventionally fabricated surgical guides appeared more accurate on tooth surfaces than on residual ridges because OS/3DP surgical guides were more accurate for K2 casts.

4. Surgical guides printed from 3DP were more accurate than those printed with SL. This has a greater significance on surgical guide internal fit than those scanned from CBCT and optical scanners.

5. Optical scanners were more accurate than CBCT scans. The accuracy of optical scanners was more discernable on residual ridges than on tooth surfaces.

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Corresponding author:
Dr. Ilser Turkyilmaz
The University of Texas Health Science Center
7703 Floyd Curl Dr, MSC 7914
San Antonio, TX 78229-3900
Email: ilserturkyilmaz@yahoo.com