Split-Mouth Comparison of Accuracy for Computer-Generated Versus Conventional Surgical Guides

Thesis

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By

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Abstract

Recent clinical studies have shown that implant placement is highly predictable with computer generated guides. However, reliability of these guides compared to conventional guides has not been tested clinically. This study aimed to compare the accuracy of reproducing planned implant positions between computer generated and conventional surgical guides using a split-mouth design.

A total of 9 patients received 2 implants each, in symmetrical locations. All implants were planned virtually using a software program and information from CT scans taken with scan appliances. Patients were randomly selected for CAD/CAM guided implant placement on their right or left side. Conventional guides were used on the contralateral side. Patients received post-operative CBCT scans. Planned and actual implant positions were compared using three dimensional analyses capable of measuring volume overlap as well as differences in angles, coronal and apical positions. Results were compared using a Mixed Model Repeated Measures ANOVA and were further analyzed using a Bartlett’s test for unequal variance (alpha = 0.05).

Implants placed with CAD/CAM and conventional surgical guides had volume overlaps between planned and actual positions of 69.7% ± 6.8% and 48 ± 16.2%, respectively.
This measurement was a statistically significant difference (p < 0.05). Coronal horizontal differences also showed significance (p < 0.05) with CAD/CAM measuring 0.55 mm ± 0.24 mm and conventionally guided implants 1.22 mm ± 0.62 mm. Apical horizontal distance significantly (p < 0.05) showed CAD/CAM to be more accurate than conventional guides (0.93 mm ± 0.62 mm and 2.03 mm ± 0.95 mm, respectively). Other measurements made did not show statistical significance.

Implants placed using CAD/CAM surgical guides provided more accuracy in a lateral direction than conventional guides. In addition, CAD/CAM guides were more consistent in their deviation from the planned placements than conventional guides. Further research, including a larger patient population and multiple consecutive implants, is needed.
Dedicated to my wife, Laura B. Farley and children, Magei H. Farley, Sam E. Farley, and Talulah T. Farley who inspire me daily to be a good husband, father, and doctor. You will never understand how much your love and support gives me the strength and motivation I need to achieve my goals and dreams in life. I love you all very much.
Acknowledgements

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Fields of Study

Major Field: Dentistry

Prosthodontics
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Chapter 1: Introduction

Success in implant dentistry can no longer be limited to osseointegration and maintenance of alveolar bone. Osseointegration has been shown predictable in the literature time and time again\(^1\)\(^{-4}\). Another criterion is implant placement that allows for fabrication of a crown or prosthesis with an esthetic appearance\(^5\). Proper placement is among the critical factors in implant dentistry\(^6\)\(^{-8}\).

The reason for malpositioned implants is multifactorial. It has been speculated that losing sight of the restorative plan while placing the implant is contributory. Edge published one of the first articles describing the use of a surgical guide to assist in implant placement in 1987\(^9\). This guide identified the mesiodistal and buccolingual location for the osteotomy only. It did not guide the surgeon for desired angulation of the implant or provide any intraoral visualization of the final restoration. Many practitioners have published techniques on how to make the process more predictable\(^10\)\(^{-15}\). In 1993, Lima Verde\(^8\) stated that errors in positioning as minimal as 2 mm or in angulation of merely 10 degrees can render an implant fixture unusable. The importance of implant position is appreciated by any experienced restorative dentist. The challenge has been transferring the restorative plan to the surgery. With Cone-
Beam Computed Tomography (CBCT) imaging, there has been a dramatic improvement in the communication between the prosthodontist and the surgeon\cite{16,17}.

CAD/CAM surgical guides are an emerging technology which have the potential to go a step further towards achieving ideal placement. This technology allows for the virtual placement of implants in the three dimensional CBCT image. This position is incorporated in the CAD/CAM guide to transfer this location intraorally\cite{18}. Using this technique, implant positions may be planned for optimum surgical and prosthetic results. This virtual plan, brought into the surgery via the CAD/CAM guide, has many potential advantages. Accuracy is the primary reason these guides were promoted. Additional benefits include: decreased surgical time, the capability to place the implants without reflecting a flap, and the ability to predict the need for grafting\cite{18-20}.

The advantages of accuracy are paramount. Virtual implant placement makes it possible to account for anatomic limitations and visualize available bone relative to the ideal position of the final restoration. In the CBCT imaging software (e.g. i-CAT, Imaging Sciences, Hatfield, PA) and third-party softwares that allow for virtual implant placement (e.g. Implant Master, iDent Imaging, Foster City, CA) the restoring dentist and surgeon can see the anatomic limitations for each patient. The position of critical anatomy (e.g. inferior alveolar nerve, floor of the sinus) can be identified, bone thickness can be measured, and space can be evaluated three dimensionally. When these limiting factors are accounted for in the virtual placement of the implants, the
implant can be moved around until the ideal position is reached within these physical restrictions. The implant can be placed away from the inferior alveolar nerve, out of the sinus, and within the bone. Surgical revelations delaying implant placement, such as unexpected bone concavities, may be minimized.

Other advantages of reported accuracy are appreciated during the restorative phase of treatment. By planning the implant placement virtually with the final restoration visible in the software, the screw access holes can be placed more predictably. Currently, restoring dentists often need to utilize custom and angled abutments to correct angulation on implants for non-ideal implant placement. If the implants were planned virtually with the bone and final restoration in mind, prosthetics could be kept simpler\(^7\,19\,21\).

Although the potential advantages of taking the virtual plan to the surgery may solve some complications in implant dentistry, CAD/CAM surgical guides are considerably more expensive than the conventional guides. Utilizing these technologies may translate to increased patient fees.

These additional fees can include: the CBCT scan, the scanning appliance, implant planning software, updates to the software, the surgical kit, single use drills, and the guide itself. All of these costs vary in price and may decrease in price as competition has
entered the market. However, it remains a fact that there is a considerable investment for dentists and patients using this technology.

In an effort to evaluate the cost to benefit ratio, several studies have measured the accuracy of CAD/CAM guides. Di Giacomo\(^{(22)}\) studied 21 implants placed in 4 patients using CAD/CAM surgical guides. He reported differences in angulation between the virtually placed implant and the actual implant of $7.25^\circ \pm 2.67^\circ$. The differences found at the coronal portion of the implants was measured to be $1.45 \pm 1.42$ mm, while at the apex it was $2.99 \pm 1.77$ mm. Ersoy\(^{(23)}\) evaluated 94 implants placed using CAD/CAM guides in 21 patients. His results showed an angular difference of $4.9^\circ \pm 2.36^\circ$, a coronal difference of $1.22 \pm 0.85$ mm, and an apical difference of $1.51 \pm 1$ mm. Ozan\(^{(24)}\) compared the planned implant to the actual placement in 110 implants placed in 30 patients. He found an angular difference of $4.1^\circ \pm 2.3^\circ$, coronal differences of $1.11 \pm 0.7$ mm, and apical differences of $1.41 \pm 0.9$ mm. Valente\(^{(25)}\) evaluated 89 implants placed in 25 patients using CAD/CAM guides. He found angular deviations of $7.9^\circ$, coronal deviations of $1.4$ mm, apical deviations of $1.6$ mm, and also looked at the depth of the implants and found the deviation to be $1.1$ mm between planned and actual implants. Van Assche\(^{(26)}\) looked at 12 implants in 4 cadaver jaws. He found angular deviations of $2^\circ \pm 0.8^\circ$, coronal deviations of $1.1 \pm 0.7$ mm, and apical deviations of $2.0 \pm 0.7$ mm. In summary, these researchers found the angular deviations from the virtually placed implant to the actual implant are about $5^\circ$, the coronal about $1.26$ mm, and the apical
about 1.9 mm. Although these are crude averages of those found among the 5 studies, it may be concluded that the coronal placement of the implant may be predicted much better than the apical position and that the angles are not that far off. This guidance helps the restorative aspect more than the anatomic aspect. The coronal placement of the implant, along with the angle of the implant, determines the ease of restoring the implant. The apical location of the implant influences more the interferences with major anatomic limitations, such as the inferior alveolar nerve.

Currently, no clinical studies have compared CAD/CAM guides to conventional guides in the same patient population. Sarment made this comparison in vitro\(^{(27)}\). For this in vitro study, 5 different surgeons placed 10 implants in an epoxy mandible. Each surgeon placed 5 implants using a CAD/CAM guide and 5 implants using a conventional surgical guide. Using the conventional surgical guide, implants were found to have angular deviations from the planned placement of 8° ± 4.5°, coronal deviations of 1.5 ± 0.7 mm, and apical deviations of 2.1 ± 0.97 mm. When the CAD/CAM guide was used, the angular deviation was 4.5° ± 2°, coronal deviation was 0.9 ± 0.5 mm, and the apical deviation was 1.0 ± 0.6 mm. The results from Sarment’s study appear in Table 1.1. Angular deviations improved from 8° ± 4.5° to 4.5° ± 2°, coronal deviations from 1.5 ± 0.7 mm to 0.9 ± 0.5 mm, and apical deviations from 2.1 ± 0.97 mm to 1.0 ± 0.6 mm. Results of this study showed that these guides are more accurate than the conventional
method of implant placement; however, this in vitro study was limited in its ability to replicate clinical placement.

<table>
<thead>
<tr>
<th>Surgical guide (5 of each)</th>
<th>Angulation</th>
<th>Coronal</th>
<th>Apical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional guide</td>
<td>8° ± 4.5°</td>
<td>1.5 ± 0.7 mm</td>
<td>2.1 ± 0.9 mm</td>
</tr>
<tr>
<td>CT-guided guide</td>
<td>4.5° ± 2°</td>
<td>0.9 ± 0.5 mm</td>
<td>1.0 ± 0.6 mm</td>
</tr>
</tbody>
</table>

Table 1.1 - An in vitro comparison between CT-guided and conventional guides

In vitro research has shown that CAD/CAM guides are more accurate than conventional guides. There have been no in-vivo studies comparing the accuracy of CAD/CAM guides to conventional guides. This study aims to compare the accuracy of CT-guided CAD/CAM surgical guides against conventional guides in the same patient population.
Chapter 2: Materials and Methods

Patients selected for this study had symmetrical edentulous areas with similar bone heights so that the same number and length of implants were the same on both sides of the arch (Figure 2.1). The inclusion and exclusion criteria are summarized in Table 2.1.

<table>
<thead>
<tr>
<th>Inclusion</th>
<th>Exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone height after surgical reduction to gain adequate width will be at least 8 mm for both maxillary and mandibular arches. In addition patients will:</td>
<td>a. Untreated caries and/or periodontal disease of residual dentition</td>
</tr>
<tr>
<td>a. Be 18 years of age or older</td>
<td>b. History of edentulism in the area of implant placement of less than two months</td>
</tr>
<tr>
<td>b. Be willing to participate for the duration of the study including 5 year follow-up post restoration</td>
<td>c. Need for pre-surgical bone or soft tissue augmentation in the planned implant area.</td>
</tr>
<tr>
<td>c. Be willing to provide informed consent</td>
<td>d. History of pre-surgical bone or soft tissue augmentation, within 12 months, in the planned implant area.</td>
</tr>
<tr>
<td>d. Be in general good health</td>
<td>e. Any systemic or local disease or condition that would compromise post-operative healing and/or osseointegration</td>
</tr>
<tr>
<td>e. Have ample bone to fully accommodate the implants without impinging on vital structures</td>
<td>f. Need for systemic corticosteroids or any other medication that would compromise post-operative healing and/or osseointegration</td>
</tr>
<tr>
<td>f. Have had extractions done at least 3 months prior to implant placement</td>
<td>g. Present alcohol or drug abuse</td>
</tr>
<tr>
<td>g. Be restored following 2-3 months healing time for the mandibular arch and 4-5 months healing time for the maxillary arch.</td>
<td>h. Unable or unwilling to return for follow-up visits for a period of 5 years</td>
</tr>
<tr>
<td>h. Be restored opposing fixed or removable occlusion (same opposing two edentulous areas).</td>
<td>i. Current use of smoking tobacco</td>
</tr>
<tr>
<td></td>
<td>j. Current use of bisphosphonates</td>
</tr>
<tr>
<td></td>
<td>k. Pregnancy or lactation at the time of enrollment</td>
</tr>
</tbody>
</table>

Table 2.1 – Inclusion and exclusion criteria
Two pilot patients were included initially following the IRB approved protocol (Institutional Review Board, The Ohio State University, OSU Protocol Number 2009H0084, Columbus, OH). These pilot patients were treated to identify potential research problems. Through these initial patients, the protocol for this study was refined.

Patients who qualified using the inclusion and exclusion criteria had diagnostic impressions made with irreversible hydrocolloid (Kromopan 100, Lascod, Firenze, Italy). Casts were then poured in ISO Type 3 gypsum (Quickstone, Whip Mix, Louisville, KY). Teeth were diagnostically set in the edentulous spaces getting implants. Care was taken to make sure each tooth was the correct size for the final restoration, since a proper occlusal table was paramount in planning for ideal implant placement.

After the tooth was diagnostically set on the casts, Type II regular base plate wax (TruWax, Dentsply Trubyte, York, PA) was added to cover the patient’s teeth and create a lingual/palatal flange (Figure 2.2). The diagnostic teeth were not covered in wax,
preserving occlusal anatomy and free gingival margins. The cast and wax-up were then invested in a denture flask. The wax was subsequently boiled out and teeth were removed. The scan appliance was then processed using clear polymethylmethacrylate acrylic resin (Ortho-Jet, Lang Dental Manufacturing Company, Wheeling, IL). Upon retrieval from the flask, the scan appliance was removed from the diagnostic cast, trimmed and polished. A flange was maintained along the lingual of the appliance. Small 1 mm x 1 mm holes were ground into the lingual flange of the scan appliance (about 1 mm deep). These holes were then filled with gutta percha (Gutta Percha Points, DENTSPLY Maillefer, Tulsa, OK) and the same clear acrylic resin was used to seal the gutta percha into the prosthesis.

![Figure 2.3 – Scan appliance with gutta percha](image1)
![Figure 2.4 – Scan appliance intraorally](image2)

Six gutta percha markers were placed in each appliance, equally divided between left and right sides (Figure 2.3). These markers were used in the software as reference points for a dual scan protocol\(^\text{[20]}\). The dual scan protocol required the patient to wear a scan appliance containing some type of marker during their CBCT scan (Figures 2.4 and 2.5). The scan appliance was then scanned alone by the CBCT scanner (Figure 2.6). The
scan of the patient wearing the scan appliance did not show the scan appliance in the CBCT image because of the patient’s dense anatomy obscures appliance details in the scan.

Once the scan appliance was fabricated, the scan guide was tried in the patient’s mouth and adjusted as necessary until a stable fit was achieved. This stability was needed to minimize error due to improper seating during the scan. Once the scan appliance was adjusted, a matrix was made using polysiloxane impression putty (Reprosil, Dentsply Caulk, Milford, DE). This matrix was made at an open interocclusal position to reduce scatter and interference from the opposing arch. This interocclusal matrix also allowed the patient to hold the scan appliance firmly in place during the scan to reduce movement and fully seat the guide. Reprosil was used because of it’s radiolucent appearance in a CBCT scan and it’s ease of achieving an open mouth record due to its heavy consistency.
Patients wore scan appliances and the interocclusal matrices during CBCT scans (Figure 2.5). CBCT scans (i-CAT, Imaging Sciences) were taken with settings recommended by iDent (iDent Imaging). This technique requires 0.4 voxels and recommended no more than a 6cm range\(^{(28)}\). Implant Master (iDent Imaging) software, was used to plan the implant placements (Figures 2.7 and 2.8).

After patients were scanned, scan appliances were also scanned using the same CBCT scan settings. Taking a scan of the scanning prosthesis alone allowed for a three dimensional image of the appliance in the same format as the patient’s scan (e.g. a DICOM image). Both scans were exported from iVision (Imaging Sciences) using iDent’s Legacy plug-in that optimizes the images for use in the Implant Master software.
Two scans for each patient were then imported into Implant Master, implant planning software by iDent. Once in the software, the gutta percha markers, visible in both scans due to its radiopacity, were identified and labeled 1-6 in the patient scan and then again in the scan appliance scan (Figure 2.9). Implant Master used algorithms inoverlaying those labeled markers from each scan. After initial meshing of data points, registration accuracy was viewed. This number revealed how closely the markers lined up between the two scans. The labels were finely adjusted to improve registration accuracy. For this study, an average of 0.09mm accuracy was achieved in the registration. For the end result, the scan appliance appeared in the patient’s scan. Therefore, the restorative plan was visible during the planning of the implant placement. It has been claimed that this dual scan protocol is more accurate than the method of using a radiopaque material (e.g. Barium Sulfate) in the patient’s scan appliance\textsuperscript{(29)}. 

To begin planning, the panoramic curve was labeled, inferior alveolar nerves were identified where applicable, and implants were placed in the sagittal view (Figure 2.9). The placement was then evaluated by the whole team of authors (N.F., N.C., E.M., K.K.)
in the sagittal plane, horizontal plane, and the three dimensional rendering (Figures 2.8). Adjustments were made as needed to place the implants in their most ideal location, satisfying both the surgeon’s desire for placement in bone and the prosthodontists’ desire for an ideal access for screw retained restorations.

![Figure 2.10 – Plan in three dimensional view](image1)

![Figure 2.11 – Conventional and CAD/CAM guides](image2)

After the plan was made and patient eligibility was confirmed, patients had surgical consults and decided whether they wanted IV sedation. After consults, the patients were informed whether they qualified for inclusion in the study. At that point, patients enrolled in the study by paying the determined fee. Once enrolled, patient surgical guides were ordered through iDent. Applying a split-mouth design, patients were randomly assigned to have the CT-guided CAD/CAM on one side and a conventional surgical guide on the other prior to ordering guides (Figure 2.11). Whichever side was assigned to be guided with the conventional guide had the opposite implant removed from the plan in Implant Master before CT-guided CAD/CAM guides were ordered.
Conventional guides were made using the same scan appliances that were used for initial scans. Scan appliances were placed on original diagnostic casts. Two of the prosthodontic authors (N.F., N.C.) collaborated on lining the patient’s cast with the scan appliance on a milling machine. Once angles were verified by both practitioners, holes were drilled through clear acrylic resin teeth on the conventional side. Conventional guides were then saved for the surgeries.

Once the CAD/CAM guides were returned from iDent, they were adjusted intraorally to achieve the same stable fit achieved with the scan appliance. This fitting was done to improve the stability and insure the appliance fit well before the surgeries were scheduled. After confirming the fit of the CAD/CAM guides, patients were scheduled for surgery.

After sufficient anesthesia and/or sedation were achieved, the surgeon placed either two Biomet 3i Full Osseotite Certain or Certain Prevail implants (Biomet 3i, Palm Beach Gardens, FL) implants bilaterally. CT-guided implants were placed first using the
CAD/CAM surgical guide (Figure 2.12), using a flapless protocol\(^{(30,31)}\). Encode® healing abutments (Biomet 3i) were subsequently placed with no need for sutures. With Encode® healing abutments in place, conventional guides were adjusted to fit over the Encode® abutments. This required grinding a hole through the diagnostic tooth set in the scan appliance on the CAD/CAM side. On the conventional side, flaps were reflected and the implants were placed using the conventional guide (Figure 2.13). Standard healing abutments (Biomet 3i) were placed and tissues were sutured. Both sides utilized a one stage surgical protocol with a two stage implant.

After implants were placed, periapical radiographs were taken to confirm fully seated healing abutments. Adjustments were made as needed to reduce crestal bone if incomplete seating occurred. When necessary, a second periapical radiograph was taken to confirm the healing abutments were seated.

Once abutments were fully seated, the surgeon removed both healing abutments. Patients had post-op CBCT scans taken. During this post-op scan, patients wore the same scan appliance and interocclusal matrix worn for the initial scan (Figure 2.14). This was done so that the gutta percha markers used as the initial reference would be included in the scan of the patient once the implants are in place. This allowed actual implant placement to be compared against the virtual implant placement (Figure 2.15).
After the post-op scan was complete, patient’s healing abutments were returned and a periapical radiograph was taken to reconfirm full seating. At this time, interim prostheses were adjusted to fit over the healing abutments to prevent any pressure on the abutments.

The final step in this study was gathering the post-op measurements. The dual scan protocol provided gutta percha reference points to overlay the scan of just the guide. By simply having patients wear the same scan appliance after the surgery, the same common reference points were used to compare the planning against the actual implant placement.
Working with iDent, three dimensional coordinates of implants were extracted from iDent’s planning software. Coordinates were provided for long-axes of each implant for both the virtually planned positions and the actual implant positions. Since these coordinates were only provided for the virtual implants in the software, virtual implants had to be placed manually to overlay the image of the implant visible in the post-op scan (Figures 2.16 and 2.17). Overlaying was done twice for each patient, resulting in two data sets. Statistical analysis was done using an intraclass correlation test to verify the reliability of this protocol.

The implants were then recreated virtually in a third party software, RapidForm XOR/RESDESIGN (INU3 Technology, Inc., Seoul, South Korea), where measurements could be made to compare the position of the implants post insertion to how they were planned in the software (Figures 2.18 and 2.19). Various parameters were identified and measured. Just as other researchers have done, measurements were made of the difference in position of the coronal and apical parts of the implants and the difference in angle between the long axes of the planned and actual implants (Figure 2.20 a-c). A few other measurements were made, including the volumetric difference showing how much overlap in volume existed between the planned and
actual implants (Figure 2.20 d) and the horizontal and vertical portions of the coronal and apical distances mentioned previously (Figure 2.21).

These eight measurements were made for each implant two separate times. These two data sets were compared to measure the intra-class correlation of the post-op analysis. The results from the first set of measurements were then analyzed using a Mixed Model Repeated Measures ANOVA with a p-value set at 0.05. Factors considered were the length of the implants, the width of the implants, and the bone density (Hounsfield Units) around the planned implants. These analyses were done in SAS 9.2 (SAS, Inc., Cary, NC). Variability differences between the CAD/CAM and conventional guides were assessed using a Bartlett’s test for unequal variance. This analysis was done in JMP 9.0.0 (SAS, Inc.).
Chapter 3: Results

Results from the first data set appear in Table 3.1 and those from the second are in Table 3.2. An analysis of variance was done to measure the intraclass correlation. This analysis was based on the same person performing the evaluations. This model is most frequently encountered in clinical research. An intraclass correlation of 0.9856 was calculated. In other words, there was an almost perfect agreement between the data sets. This fact eliminated the chance that results were incorrect due to human error in overlaying the virtual implant onto the three dimensional implant image in the post-op CBCT scan.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Conventional implant</th>
<th>Bone density (HU) (conventional)</th>
<th>CAD/CAM implant</th>
<th>Bone density (HU) (CAD/CAM)</th>
<th>Age</th>
<th>Sex</th>
<th>Implant size</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>18</td>
<td>276 ± 167</td>
<td>31</td>
<td>537 ± 54</td>
<td>68</td>
<td>F</td>
<td>5 x 10 mm</td>
</tr>
<tr>
<td>B</td>
<td>19</td>
<td>977 ± 97</td>
<td>30</td>
<td>667 ± 193</td>
<td>37</td>
<td>M</td>
<td>5 x 13 mm</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>239 ± 104</td>
<td>7</td>
<td>252 ± 168</td>
<td>18</td>
<td>F</td>
<td>3.4 x 11.5 mm</td>
</tr>
<tr>
<td>D</td>
<td>30</td>
<td>369 ± 90</td>
<td>19</td>
<td>320 ± 168</td>
<td>34</td>
<td>M</td>
<td>5 x 11.5 mm</td>
</tr>
<tr>
<td>E</td>
<td>30</td>
<td>458 ± 123</td>
<td>19</td>
<td>496 ± 164</td>
<td>64</td>
<td>F</td>
<td>4 x 10 mm</td>
</tr>
<tr>
<td>F</td>
<td>19</td>
<td>445 ± 206</td>
<td>30</td>
<td>437 ± 75</td>
<td>24</td>
<td>F</td>
<td>5 x 13 mm</td>
</tr>
<tr>
<td>H</td>
<td>7</td>
<td>839 ± 123</td>
<td>10</td>
<td>784 ± 86</td>
<td>66</td>
<td>F</td>
<td>3.4 x 13 mm</td>
</tr>
<tr>
<td>I</td>
<td>31</td>
<td>451 ± 278</td>
<td>18</td>
<td>380 ± 133</td>
<td>66</td>
<td>M</td>
<td>5 x 11.5 mm</td>
</tr>
</tbody>
</table>

Table 3.1 – Summary of patient demographics
### Table 3.2 – Measurements from the first data set comparing control (C) and CAD/CAM (T) results. Statistical analysis shows mean (m), standard deviation (sd), and p-value (p).

*Statistically significant.

<table>
<thead>
<tr>
<th>Volume Overlap</th>
<th>Angle (°)</th>
<th>Coronal Distances</th>
<th>Apical Distances</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total (mm)</td>
<td>Horizontal (mm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>A</td>
<td>73%</td>
<td>65%</td>
<td>6.52</td>
</tr>
<tr>
<td>B</td>
<td>26%</td>
<td>85%</td>
<td>1.05</td>
</tr>
<tr>
<td>C</td>
<td>46%</td>
<td>71%</td>
<td>0.51</td>
</tr>
<tr>
<td>D</td>
<td>45%</td>
<td>63%</td>
<td>7.84</td>
</tr>
<tr>
<td>E</td>
<td>46%</td>
<td>69%</td>
<td>5.94</td>
</tr>
<tr>
<td>F</td>
<td>57%</td>
<td>66%</td>
<td>7.76</td>
</tr>
<tr>
<td>G</td>
<td>62%</td>
<td>68%</td>
<td>3.73</td>
</tr>
<tr>
<td>H</td>
<td>28%</td>
<td>70%</td>
<td>15.83</td>
</tr>
<tr>
<td>m</td>
<td>48%</td>
<td>70%</td>
<td>6.73</td>
</tr>
<tr>
<td>sd</td>
<td>16%</td>
<td>6.8%</td>
<td>4.30</td>
</tr>
<tr>
<td>p</td>
<td>0.0099*</td>
<td>0.0956</td>
<td>0.1204</td>
</tr>
</tbody>
</table>

### Table 3.3 – Measurements from the second data set comparing control (C) and CAD/CAM (T) results

<table>
<thead>
<tr>
<th>Volume Overlap</th>
<th>Angle (°)</th>
<th>Coronal Distances</th>
<th>Apical Distances</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total (mm)</td>
<td>Horizontal (mm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>A</td>
<td>74%</td>
<td>66%</td>
<td>5.55</td>
</tr>
<tr>
<td>B</td>
<td>25%</td>
<td>84%</td>
<td>2.47</td>
</tr>
<tr>
<td>C</td>
<td>46%</td>
<td>66%</td>
<td>5.98</td>
</tr>
<tr>
<td>D</td>
<td>49%</td>
<td>63%</td>
<td>5.17</td>
</tr>
<tr>
<td>E</td>
<td>47%</td>
<td>68%</td>
<td>7.49</td>
</tr>
<tr>
<td>F</td>
<td>54%</td>
<td>64%</td>
<td>7.67</td>
</tr>
<tr>
<td>G</td>
<td>69%</td>
<td>64%</td>
<td>4.32</td>
</tr>
<tr>
<td>H</td>
<td>28%</td>
<td>73%</td>
<td>16.93</td>
</tr>
</tbody>
</table>

Patient G was not included in the statistical analysis because the surgical protocol was not followed; the implants used did not match the drilling protocol provided with the guide. This patient’s implant was not placed through the CAD/CAM surgical guide. A
Mixed Analysis Repeated Measures ANOVA was run for each parameter measured. This test was done to see if there were any significant differences in the accuracy of placement between CAD/CAM surgical guides and conventional guides.

For volume overlap (Figure 3.1), the implants placed with the CAD/CAM surgical guides on average overlapped the plan by 69.7% (with a standard deviation of 6.8%), whereas the implants using a conventional guide were just 48 ± 16.2%. These differences were statistically significant (p = 0.0099).

Angular differences (Figure 3.2) in implants with the CAD/CAM guides were 3.39° ± 2.35°, and those with a conventional guide were 6.73° ± 4.30°. Angular differences were less with CAD/CAM – however, a difference in angular differences was unable to be detected (p = 0.0956).
Coronal and apical differences were measured and analyzed for total distances and also for their horizontal and vertical components. Total coronal differences (Figure 3.3) in CAD/CAM guided implants were less (1.43 mm ± 0.67 mm) than those for implants placed with conventional guides (2.19 mm ± 1.02 mm). A difference in total coronal distances was unable to be detected (p = 0.1204). The coronal horizontal distance (Figure 3.5) in CAD/CAM guided implants was 0.55 mm ± 0.24 mm which is much less than that in conventionally guided implants (1.22 mm ± 0.62 mm). This difference showed statistical significance (p = 0.0252). Vertical differences (Figure 3.6) showed much less difference between CAD/CAM and conventionally guided implants with 1.24 mm ± 0.78 mm and 1.72 mm ± 1.00 mm, respectively. A difference in vertical coronal distances was unable to be detected (p = 0.3171).
Total apical distances (Figure 3.4) were 1.72 mm ± 0.61 mm for CAD/CAM guided implants and 2.81 mm ± 1.24 mm for conventionally guided implants. A difference in total apical distances was unable to be detected (p = 0.0620). Horizontal apical distances were 0.93 mm ± 0.62 mm for CAD/CAM guided implants, compared to 2.03 mm ± 0.95 mm for conventionally guided implants. This difference was significantly different (p = 0.0287). Vertical apical distances were 1.26 mm ± 0.75 mm for CAD/CAM guided implants and 1.81 mm ± 1.08 mm for conventionally guided implants. A difference in vertical apical distances was unable to be detected (0.2778).
The effects of implant length and width on the accuracy of placement were analyzed. A correlation for implant length or width was not detected. Likewise, a relationship between bone density and placement accuracy was unable to be detected. Using a Bartlett’s test for unequal variance, it was shown that the CAD/CAM guides had a significantly lower standard deviation (p = 0.0369). This analysis was done on the volume overlap measurements and is shown graphically in Figure 3.9. Figure 3.10 displays the patients’ results for volume overlap in chronological order.

Figure 3.9 – Volume overlap

Figure 3.10 – Volume overlap in chronological order surgeries happened. CAD/CAM in blue and Conventional in red.
Chapter 4: Discussion

Computer guided implants were generally placed closer to planned positions for this prospective clinical study. Results were statistically significant for volume overlap, coronal horizontal distance, and apical horizontal difference ($p = 0.0099$, $p = 0.0252$, and $p = 0.0287$, respectively). In addition, CAD/CAM guided implants showed more consistency in accuracy, whereas the conventional guides were more variable.

Results of this study were similar to previous studies measuring the accuracy of CAD/CAM surgical guides$^{(22-26)}$. A summary of these results appears in Table 4.1. Angular differences using the present CAD/CAM guides were close to angular differences reported by both Ersoy$^{(23)}$ and Ozan$^{(24)}$. Present coronal differences were comparable to Di Giacomo$^{(22)}$ and Valente$^{(25)}$. In regards to apical position, results were similar to those of Valente$^{(25)}$. In summary, the accuracy of the CAD/CAM guides used for the current study were well within the range of results reported by previous authors.
<table>
<thead>
<tr>
<th>Author</th>
<th>Angulation</th>
<th>Coronal</th>
<th>Apical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Di Giacomo</td>
<td>7.25 ± 2.67°</td>
<td>1.45 ± 1.42 mm</td>
<td>2.99 ± 1.77 mm</td>
</tr>
<tr>
<td>Ersoy</td>
<td>4.9 ± 2.36°</td>
<td>1.22 ± 0.85 mm</td>
<td>1.51 ± 1 mm</td>
</tr>
<tr>
<td>Ozan</td>
<td>4.1 ± 2.3°</td>
<td>1.11 ± 0.7 mm</td>
<td>1.41 ± 0.9 mm</td>
</tr>
<tr>
<td>Valente</td>
<td>7.9°</td>
<td>1.4 mm</td>
<td>1.6 mm</td>
</tr>
<tr>
<td>Van Assche</td>
<td>2 ± 0.8°</td>
<td>1.1 ± 0.7 mm</td>
<td>2.0 ± 0.7 mm</td>
</tr>
<tr>
<td><strong>Current study</strong></td>
<td><strong>3.39 ± 2.35°</strong></td>
<td><strong>1.43 ± 0.67 mm</strong></td>
<td><strong>1.72 ± 0.61 mm</strong></td>
</tr>
</tbody>
</table>

Table 4.1 Comparison of results with similar research on accuracy of CAD/CAM guides

These previous studies measured the accuracy of CAD/CAM guides, but they did not compare this accuracy to conventional guides. An in-vitro comparison of these guides types was done by Sarment. Findings for the present study were similar to this in-vitro study. Both studies showed that CAD/CAM more accurately reproduced planned implant positions.

The split-mouth design is the ideal way to compare a treatment against its control because bias and variability are minimized. The split-mouth design used for the current study provided a comparison of the two guide types within the same patients. Although previous clinical studies reported placement accuracy for CAD/CAM guides, they were unable to determine whether the placement was more accurate than conventional guides. This is an important comparison in determining whether the CAD/CAM guides are worth the increased investment.

Current comparisons for the two guide types included horizontal and vertical directional displacements in addition to total distance from planned implant positions (Figures 4.1
and 4.2). This information is critical in knowing if the risk is higher in a vertical or lateral direction. Translation in a lateral direction increases the risk of perforating the buccal or lingual plates, whereas a vertical displacement might cause impingment on the nerve or the sinus.

A total coronal difference of 1.43 mm ± 0.67 mm was measured for the present study. The large majority of this difference was in a vertical direction (1.24 mm ± 0.78 mm). A much smaller horizontal difference of 0.55 mm ± 0.24 mm was found. Interestingly, vertical displacement was consistent in the apical direction, meaning that the implants were always placed deeper than originally planned. The conventional guides had greater horizontal and vertical distances when measured coronally (1.22 mm ± 0.62 mm and 1.72 mm ± 1.00 mm, respectively). This measurement is almost twice the
horizontal difference coronally, when the conventional guide was compared to the CAD/CAM guide.

Apical distances revealed slightly different trends. The horizontal difference between CAD/CAM and conventional guides was 0.93 mm ± 0.62 mm and 2.03 mm ± 0.95 mm, respectively. The vertical error was 1.26 mm ± 0.75 mm for CAD/CAM guides and 1.81 mm ± 1.08 mm for conventional guides. Horizontal and vertical differences for CAD/CAM guides were similar apically. Conventional guides showed less vertical than horizontal displacement when measured apically.

Horizontal and vertical components provided some insight into virtual planning of implant placement. According to present results, the coronal position was more reliable than the apical position when using CAD/CAM surgical guides. This indicates a need for compensation in a lateral direction during planning at the apex of the implant. Depth of placement must be accounted for, almost equally, both coronally and apically.

Figure 4.3 – Guide not seating well
Figure 4.4 – Tube not fully seated
Limitations to this study include instances of CAD/CAM guides not seating well during the surgery (Figure 4.3, this example was from the pilot study), tubes loosening, and tubes not being placed properly in the surgical guides (Figure 4.4). Looseness of the drills within the keys and the keys within the drills were also observed. This is necessary to some extent to allow for the drills to move freely within the keys and the keys to be placed in and out of the tubes; however, it may decrease accuracy.

Within the limitations of this study, statistical significance was shown for volume overlap, coronal horizontal distance, and apical horizontal difference for single tooth implants. These measurements showed that the CAD/CAM guide was significantly more accurate than conventional guides. No difference was detected for the other measurements made. Implants placed with the CAD/CAM guides were more consistent in the level of accuracy compared to implants placed with the conventional guides. CAD/CAM guides may make more of a difference in regards to accuracy when multiple consecutive implants are placed. Further research, including a larger patient population and number of implants per patient, is recommended.
Chapter 5: Conclusions

Within the limitations of this prospective clinical study, the following conclusions were made.

1. Single implants placed with CAD/CAM surgical guides were generally closer to planned positions than those placed with conventional guides.

2. Differences between the accuracy of these guide types were statistically significant for volume overlap as well as coronal and vertical horizontal distances ($p = 0.0099$, $p = 0.0252$, and $p = 0.0287$, respectively).

3. Differences in angles of placement as well as coronal and apical total and vertical placements were unable to be detected.
References


