Correlation Between Bone Density and Angular Deviation of Implants Placed Using CT-Generated Surgical Guides

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Background: The aim of this study was to evaluate the correlation between the density of bone where implants were placed and the angular deviations that occurred between the virtually planned and actually placed implants using 2 different stereolithographic surgical guides.

Methods: The study population consisted of 54 patients who received 216 implants. Computed tomography machine was used for preoperative evaluation of the jawbone for implant therapy as well as determination of the bone density values (Hounsfield units [HU]) of the implantation site. All implant sockets were prepared using 2 different types of stereolithographic surgical guide. Ninety-four implants were installed using the surgical guides (Stentcad Beyond, Ay-Design; Kos-gep, ODTU, Ankara, Turkey) in the mouth, whereas 122 implants were placed after the surgical guides (Stentcad Classic; Kos-gep, ODTU) were removed.

Results: The mean bone densities of maxilla and mandible were 561.36 (SD, 229.46) HU and 890.63 (SD, 361.85) HU, respectively. The mean angular deviations between planned and placed implants using Stentcad Classic and Stentcad Beyond surgical guides were 5.32 (SD, 1.96) degrees and 3.73 (SD, 1.14) degrees, respectively. Highly negative correlation was found between the bone density of the placed implant sites and angular deviations in the group in whom implants were installed with freehand.

Conclusions: The lower bone density values have resulted in the greater angular deviations in the group, in whom the implants were placed after the surgical guides were removed. This deviation might have been derived from the freehand placement of the implants and the poor quality of the bone.

Key Words: Implants, bone density, computerized tomography, surgical guide, Hounsfield unit

Dental implants have become a favorable option in the treatment of edentulous patient in the last decade. The successful outcome of implant osseointegration involves patient-originated and procedure-dependent variables. The quality of the bone and the type of surgical procedure are of primary factors for long-term survival of dental implants.1

Various classification methods were introduced for the evaluation of bone quality as the mechanical behavior of the bone is a crucial factor for osseointegration.2–4 Lekholm and Zarb5 classified bone density into 4 types based on the amount of cortical versus cancellous bone in a given area of the alveolar process observed on a panoramic radiograph. Subsequently, Misch,6 based on the tactile sense of the surgeon placing the implant, has characterized 4 bone density classes.

Bone quality and quantity are generally estimated from radiographs or during implant placement.5 In most studies, classification of bone type was based on the subjective evaluation of the clinician.7 Computed tomography (CT) is primarily used for objective preoperative assessment of the bone with quantitative data, evaluating the relative distribution of compact8 and cancellous9 bone. Bone density can be evaluated using Hounsfield units (HU), which are directly related to tissue attenuation coefficients.6 Recent studies have shown that the bone density value is an important parameter for a successful implant.10–12

Research in the field of oral implantology has led to refinements resulting in highly successful and predictable restorative options for partially as well as completely edentulous patients; however, improper implant placement can have a profound and often detrimental effect on the long-term predictability and success of the implant-supported prostheses.13,14 It has also been suggested in previous studies that implants be positioned parallel to the path of insertion of planned prosthesis and as perpendicular to the occlusal plane as possible to minimize the bending moments.15,16

Although the ideal placement of dental implants should be determined by prosthetic parameters, the exact positioning of the implant with respect to location and angulation is often difficult.17 Moreover, aesthetic and functional planning is complex and requires a professional experience to detect patient expectancies in relation to the alternatives for final results.18 Problems may arise especially in complete-arch patients with multiple fixtures and in partially edentulous patients in which alignment is difficult or in grafted jaws.19

To reduce alignment problems, numerous types of radiographic and surgical templates and techniques have been proposed. A few studies emphasized radiographic scanning and surgical templates.20,21 A number of articles introduced templates for the dual use of the first radiologic planning and then guidance for the surgical implant placement.18,22 In vitro,23,24 ex vivo,25,26 and clinical studies27–30 showed the efficiency of stereolithographic surgical guides used for...
transferring the ideal implant position from the computer planning to the surgical guide.

To achieve more accurate implant placements, some clinical reports mentioned that installation of the implants in the jawbone should have been done with appropriate surgical guide,

but there are no published studies regarding the relationship between angular errors and bone density of the implantation site, which can be derived from the freehand installation of the implants. The purpose of this study was to compare the correlation between the angular deviation of the implants and the bone density of the implant sites in 2 different surgical guide systems.

MATERIALS AND METHODS

The Institutional Ethics Committee of Ankara University, Ankara, Turkey, approved the study protocol. Each patient signed an informed consent. The study population consisted of 49 patients who were referred for implant placement. Twenty-nine male and 25 female (54 patients) (mean age, 50 [SD, 12] years) were treated with 216 implants (Tapered SwissPlus; Zimmer Dental, Carlsbad, CA) in this study. The 7 steps below were followed for all the patients.

Step 1: The Initial Template for CT Scanning

The scanning template is the vital key to the system, because it allows the transfer of the predetermined prosthetic setup to the actual implant-planning phase. The scanning template is an exact replica of the desired prosthetic result. Each patient used these scanning templates during CT scanning that allowed both surgeon and prosthodontist to plan the case according to the desired prosthetic outcome. The treatment plan was thus driven by the prosthetic end result. In this study, the scanning template using acrylic resin (Temdent Classic; Weil-Dental GmbH, Rosbach, Germany) and barium sulfate as the radiopaque material (15% for main axis of each tooth determined by using drills, 10% for denture base and teeth) was duplicated from the patient’s existing dentures or previously fabricated diagnostic wax-ups.

Step 2: Primary CT Scanning

The preoperative CT scanning was performed using a 16-slice scanner at 120 kVP and 25 mA with a display matrix of 256 × 256 (Discovery 16 ST; General Electric, Milwaukee, WI). Axial, coronal, and sagittal planes were obtained with 1-mm slice thickness and 0.8/s table feed with bone algorithm. Cross-sectional images for implant placement evaluation were obtained by the same radiologist.

Because the quality of CT scan is crucial, the following points were strictly taken into account by the radiologist: (a) the close adaptation between the scanning template and the underlying soft tissue was confirmed; (b) the axial plane was adjusted parallel to the plane of occlusion, with the Gantry tilt at 0 degrees so as not to affect measurement accuracy; (c) the CT scan was taken without interarch contact, biting on a piece of wood, to avoid overlapping of the dental images of the opposite arch; and (d) the occlusal side of the arch was clearly visible. Moreover, all CT scans were obtained according to the strict, standardized scanning protocol used in our clinic. Patients were placed in a horizontal position and stabilized with custom-made headbands and chin support and monitored to ensure that they remained without movement during the scanning.

Step 3: Treatment Planning Using Three-Dimensional Computer Simulation

The obtained CT data for each patient were imported to a planning software (Stent Cad; Media Lab Software, La Spezia, Italy), allowing both surgeon and restorative dentist to simulate implant placement on the three-dimensional model. The 2 reformatted planes were initialized with the axis of each tooth determined using drilling and radiopaque material on CT scanning template at the beginning of the planning procedure. Taking into consideration the anatomic structures, the dental team interactively simulated the position of the implant on each plane. The other planes were instantaneously recalculated so that cross-sectional slices always passed through the implant. In cases with several implants, the surgeon worked on one implant and then proceeded to the next one, while the images of the previously planned implant remained on the axial slices. If necessary, their position was adjusted to achieve optimum result. The simulated implants can be bodily translated or tilted about their long axis. To improve the relative position of implants in relation to one another, the surgeon also used the three-dimensional view showing the shape of the jaw, the ideal prosthetic axis, and the implant. The position of the planned implant is visualized on 3 planes: the axial slice and 2 reformatted views.

Step 4: Stereolithographic Surgical Guides

A rapid prototyping machine using the principle of stereolithography was used to fabricate the stereolithographic models and guides (Ay-Design; Kos-gep, ODTU, Ankara, Turkey). Briefly, the SLA consists of a vat containing a liquid photopolymerized resin (Zenea Specialties; Blackley, Manchester, UK). A laser mounted on top of the vat moves in sequential cross-sectional increments of 1 mm, corresponding to the slice intervals specified during the CT formatting procedure. The laser polymerizes the surface layer of the resin on contact. Once the first slice is completed, a mechanical table immediately below the surface moves down 1 mm, carrying with it the previously polymerized resin layer of the model. Then, laser polymerizes the next layer above the previously polymerized layer. In this manner, a complete stereolithographic model of the patient’s jaw can be created. The surgical templates were fabricated in a similar manner, but there are a few differences in terms of parts and usage patterns:

The Stentcad Classic System (Ay-Design; Kos-gep, ODTU) consists of multiple stents according to the each drill diameter by stereolithography, and the positions of the drills are provided by the metal cylinder tubes that are attached in each surgical guide. This

FIGURE 1. Stentcad Classic is a multiple guide system without any depth control.
system does not have any depth control and any stabilization screws to hold the guide in place (Fig. 1).

The Stentcad Beyond System (Ay-Design; Kos-gep, ODTU) consists of 2 parts. First part is the handpiece guidance apparatus; the second part is the mucosa-supported surgical template, which is called “base part.” There is a triangular pin on the handpiece part, and it settles on the triangular tubes on the base part. Triangular tubes are designed according to the planned implant angulation on the software. Thus, the pin and the tube ensure the guidance of location and angulation of the handpiece, thereby implants. In this manner, the advantage of guidance of the handpiece can be achieved, and surgery can be performed with single surgical guide. The length of the tubes is adjusted according to the implant length. With the full placement of the pins into the tubes, depth control is provided. Also, stabilization of the guide can be achieved using osseosynthesis screws (Fig. 2).

Step 5: Surgery and Prosthesis

All surgeries were performed under either local anesthesia or intravenous sedation and local anesthesia. Only mucosa-supported SLA surgical guides were used during drilling procedure, and implants were placed using flapless surgical technique. The drilling procedures were performed using appropriate drills for each corresponding implant, and the implants were inserted without surgical guides according to the manufacturer’s guidelines of the surgical guidance system. Various types of interim restorations made in advance were relined using soft-reline materials and delivered after the occlusion was carefully checked and adjusted if necessary.

Step 6: Secondary CT Scanning and the Overlapping of the Preoperative and Postoperative Images After Implant Placement

After implant placement, new CT scans were taken using previous parameters that were mentioned in step 1. The locations and axes of planned and placed implants (Fig. 3) were compared using a software (Rhinoceros 4.0; McNeel Ins, Seattle, WA) that overlapped the presurgical and postsurgical CT images (Fig. 4). The presurgical and postsurgical CT scans were aligned observing the superposition of anatomic markers. For each planned and placed implants, 2 points were located (x, y, and z coordinates) on their long axes, and they were converted into cylinders (Fig. 5). The first point was the neck point (center of the most coronal portion of the implants) of the implant, whereas the second point was the apical point (center of the implant apex) of the implant. Both the distance between the centers of the simulated and placed implant and the angle occurred between the long axis of the simulated and placed implants were measured by means of the software by a single observer.

FIGURE 2. The Stentcad Beyond System consists of 2 parts. The first part is the mucosa-supported surgical template, which is called “base part”; the second part is handpiece guidance apparatus. There is a triangular pin on the handpiece part, and it settles on the triangular tubes on the base part.

FIGURE 3. Matching procedure between planned and placed implants. $\alpha$ = the angular deviation between planned and placed implant axes.

FIGURE 4. The overlapped image of the presurgical and postsurgical CT data.

FIGURE 5. Calculation procedure of the angular deviation (planned and placed implants) by converting them into cylinders.
Step 7: Evaluation of Bone Density Around Placed Implants

The postoperative CT images were transferred to another software (3D Doctor; Able Software Corp, Lexington, MA) to determine bone density in HU. Measurements were done using this software via drawing region of interest (ROI) in the axial images of the patients. The ROIs were placed as to be around 1-mm area surrounding the implant using all axial slices. The axial slices were used to obtain a three-dimensional cylindrical area (Fig. 6), and only 1 doctor measured the average bone density in this area by means of this software.

Statistical Methods

Statistical analyses were carried out using NCSS 2007 (Kaysville, UT) software program. Pearson $\chi^2$ test was used for the correlation among the groups (angulation deviations and bone density values [HU] of the implant sites), and Student’s $t$-test was used to detect the mean changes in the variables (angulation deviations of different surgical guide types, angulation deviation differences between different regions, bone density differences between different regions, bone density differences between males and females, and bone density differences between maxilla and mandible). A $P < 0.05$ is considered significant.

RESULTS

A total of 29 male patients with 112 implants and 25 female patients with 104 implants were uneventfully treated and analyzed. The findings are presented in Tables 1–4.

Of all 216 implants, 129 were inserted in the maxilla, whereas 87 were inserted in the mandible. The mean bone densities of maxilla and mandible were 561.36 (SD, 229.46) HU and 890.63 (SD, 361.85) HU, respectively, which is statistically significant ($P < 0.05$) (Tables 1, 2). The mean angular deviations recorded with Stentcad Classic and Stentcad Beyond Systems were 5.32 (SD, 1.96) degrees (Table 1) and 3.73 (SD, 1.14) degrees, respectively (Table 2). It was noticed that the angular deviations in the maxilla were significantly higher than the mandible in the Stentcad Classic System ($P = 0.0001$) (Table 1), whereas there were no statistical differences found in the Stentcad Beyond System (Table 2). It was observed that the lower the HU values of the bone, the more angular deviations occur in the Stentcad Classic System.

### TABLE 1. Mean Angular Deviations and HU Values of the Stentcad Classic Group (Free Hand Installed Implants)

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxilla</td>
<td>80</td>
<td>578.55</td>
<td>216.81</td>
<td>530.3</td>
<td>626.8</td>
</tr>
<tr>
<td>Mandible</td>
<td>44</td>
<td>909.66</td>
<td>320.49</td>
<td>812.22</td>
<td>1007.1</td>
</tr>
<tr>
<td>Maxilla</td>
<td>80</td>
<td>6.29</td>
<td>2.12</td>
<td>5.82</td>
<td>8.76</td>
</tr>
<tr>
<td>Mandible</td>
<td>44</td>
<td>4.35</td>
<td>1.8</td>
<td>3.8</td>
<td>6.89</td>
</tr>
</tbody>
</table>

$\triangle$ = statistical differences among the groups ($P = 0.0001$).

$\blacklozenge$ = negative correlation among the groups ($P = 0.0001$).
When 3 different regions (incisor, premolar, molar) were compared, no statistically significant differences were noted among these regions according to angular deviation and HU values for both of the surgical guidance systems ($P > 0.05$) (Table 3). The bone density (in HU) and angular deviations (in degrees) in males and females were 739.83 (SD, 248.87) and 4.38 (SD, 1.42) and 712.12 (SD, 342.44) and 4.67 (SD, 1.68), respectively, which showed no significant differences ($P > 0.05$) (Table 4).

**DISCUSSION**

Traditional radiographs (periapical and panoramic) with considerable shortcomings have been used by the clinicians to assess bone before implant placement. A panoramic image cannot provide clinicians with information about the width of alveolar bone or the inclination of the alveolar ridge. Angular measurements taken from panoramic radiographs tend to be accurate, but this is not true for linear measurements. Assessments of mesiodistal distance can be very imprecise because of inappropriate patient positioning and/or individual variations in jaw curvature.

Therefore, the professions began to use CT scans to assess dental implant patients. Computed tomography scanning allows exact preoperative analysis of the available bone volume and helps to determine the appropriate position, angulation, number, and length of the planned implant. This modality also gives a high-density resolution, and the soft tissues can also be visualized to some degree. The reformatted CT images provide axial, panoramic, and cross-sectional images that are all cross-referenced to one another, allowing rapid correlation of the different views. In addition, the clinicians have also the possibility to assess the bone quality at the implant recipient sites by means of the relatively new software programs associated with the CT machines. It provides both precise three-dimensional anatomic localizations and direct measurements given in HU.

Recently developed three-dimensional implant planning softwares allow users to locate an implant recipient site and simulate the placement of the implant in various views reconstructed from the CT scan data. With the help of these softwares, implant planning can be achieved successfully; however, this time, the transfer of this planning to the clinic is required. Different methods have been proposed for the transfer of the planning on CT images or on a software planning program to the surgical field such as manually fabricated surgical guides and computer-controlled fabricated surgical guides. Computer-controlled fabricated surgical guides are generally produced by using rapid prototyping method. This technique introduced fast and highly accurate computer-aided manufacturing (CAM) method. Previous studies using this method concluded that computer-aided design (CAD) and CAM software may improve the association between dental implant planning and insertion.

In vitro and clinical studies showed the efficiency of stereolithographic surgical guides in transferring the ideal implant position from the computer planning to the surgical guide. Sarment et al compared the accuracy of recently developed stereolithographic surgical guides with traditional surgical guides. For the study, they used epoxy resin edentulous mandibles and planned 5

### TABLE 2. Mean Angular Deviations and HU Values of Stentcad Beyond Group (Implants Installed With Surgical Guides)

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxilla Bone density, HU</td>
<td>49</td>
<td>544.17</td>
<td>242.11</td>
<td>511.73</td>
<td>743.63</td>
</tr>
<tr>
<td>Mandible</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maxilla Angulation deviation, degrees</td>
<td>43</td>
<td>3.91</td>
<td>1.21</td>
<td>1.22</td>
<td>4.74</td>
</tr>
<tr>
<td>Mandible</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>

* $= $ statistical differences between the groups ($P = 0.0001$).

### TABLE 3. Angular Deviation and HU Values of the Molar, Premolar, and Incisor Regions*

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone density (HU)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incisor region</td>
<td>101</td>
<td>685.08</td>
<td>244.63</td>
<td>0.906</td>
</tr>
<tr>
<td>Premolar region</td>
<td>68</td>
<td>712.67</td>
<td>353.07</td>
<td></td>
</tr>
<tr>
<td>Molar region</td>
<td>47</td>
<td>691.34</td>
<td>320.32</td>
<td></td>
</tr>
<tr>
<td>Angular deviation with Stentcad Classic System, degrees</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incisor region</td>
<td>50</td>
<td>5.33</td>
<td>1.75</td>
<td>0.196</td>
</tr>
<tr>
<td>Premolar region</td>
<td>40</td>
<td>5.22</td>
<td>1.92</td>
<td></td>
</tr>
<tr>
<td>Molar region</td>
<td>34</td>
<td>5.41</td>
<td>2.21</td>
<td></td>
</tr>
<tr>
<td>Angular deviation with Stentcad Beyond System, degrees</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incisor region</td>
<td>51</td>
<td>3.44</td>
<td>0.85</td>
<td>0.196</td>
</tr>
<tr>
<td>Premolar region</td>
<td>28</td>
<td>3.82</td>
<td>1.24</td>
<td></td>
</tr>
<tr>
<td>Molar region</td>
<td>13</td>
<td>3.93</td>
<td>1.33</td>
<td></td>
</tr>
</tbody>
</table>

*No statistical differences were found among the groups ($P > 0.05$).
implants on each side with the aid of CT-based planning software. On the right side, a conventional surgical guide was used, whereas on the left side, the stereolithographic one was used. They pointed out the successful implant placement by using surgical guides and concluded the need of the further studies to validate its clinical use, which was also described by Van de Velde et al.²⁴

Di Giacomo et al.²⁷ emphasized the importance of in vivo studies, and therefore, they conducted a similar but in vivo study with the use of multiple stereolithographic surgical guides (similar to Stentcad Classic System in our study). The authors also compared the deviations with presurgery and postsurgery CT scans. They found mean angular deviation of 7.25 (SD, 2.67) degrees for planned and placed implants. In a retrospective study,⁻³ bone-, mucosa-, and toothborne surgical guides were used for implant socket preparation, but the implants were placed after these guides were removed from the mouth (similar to Stentcad Classic System in our study). They have found a mean angular deviation of 7.9 degrees. The authors stated that the deviation might have been caused by the installation of the implants by freehand. Also, they have emphasized that changing the guide after the use of each drill could result in deviation.

Different authors⁻²⁶,⁻³⁰ also pointed out the crucial importance of the insertion of the implants with surgical guides to prevent the additional angular deviations that can be mainly occurred in low-density alveolar bone. In our current study, it was statistically observed that the lower the HU values of the bone, the more angular deviations occur in the Stentcad Classic surgical guide surgery. However, no correlation was found between HU values of the bone and angular deviations of the implants that were placed with Stentcad Beyond System. Errors in the positions and the axes of the implants may occur in the freehand installation phase of the implants when alveolar bone density is low. Also, less angular deviation values observed in the high-density bone can be explained by the fact that the dense bone cannot affect the angular deviation, regardless of the implant placement method.

In the recently published clinical study, Arisan et al.³⁶ pointed out the superior clinical features of the flapless surgical guides. The authors compared the surgical and postoperative outcomes of a computer-aided implant surgery performed by bone- and mucosa-supported stereolithographic guides against the standard technique. They found lower duration for surgery (23.53 [SD, 5.48] minutes) and number of analgesics consumed (4 tablets) in the flapless group compared with those of standard technique (68.71 [SD, 11.4] minutes and 10 tablets) and bone-supported guide groups (60.94 [SD, 13.07] minutes and 11 tablets). The change in pain scores (visual analog scale) and the number of analgesics consumed in time were statistically significant (P < 0.01 and 0.05, respectively), and the flapless group reported a lower pain score than did the bone-supported guide groups (P < 0.01) and control groups (P < 0.001). They concluded that the use of mucosa-supported stereolithographic guides for flapless implant placement may help reduce the surgery duration, pain intensity, related analgesic consumption, and most other complications typical in the post-implant surgery period. In the current study, all of the surgical guides were mucosa supported, and the authors experienced the advantages of the flapless surgery. Although, the flapless surgery is advantageous for implant positioning, in a recently published review,⁻³⁵ it was concluded that, for cases with severe bone resorption, the guided surgery is helpful for virtual planning, but the flapped surgical technique was better recommended.

In the use of Stentcad Classic System with no retention screws for flapless surgery, some disadvantages such as the micromovement of the surgical guide may occur. For that reason, in our study, the mean difference between planned and placed implant positions in the Stentcad Beyond System was 3.73 degrees, whereas that in the Stentcad Classic System was 5.32 degrees. In our previous study,⁻³⁰ significant differences in angular deviations of the planned and placed implants were found among the surgical guides supported by mucosa, bone, or teeth.⁻³⁰ The tooth-supported guides showed significantly smaller deviations compared with mucosa- and bone-supported guides, which were not screwed to the jaw bone. This results can also be explained with better stability (provided from the existing teeth) of the tooth-supported surgical guide because no stabilization screws were used for fixation of the surgical guides, and all of the surgical guides hold in place by hand.

**CONCLUSIONS**

Under the guidelines of this study, the following conclusions can be drawn:

1. Computed tomography scanning is a useful tool not only in imaging the implant site but also for the assessment of bone density.
2. Guided implant surgery is still not completely accurate when using stereolithographic surgical guides.
3. SLA surgical guides should be designed and used for both drilling and implant placement, not only for the drilling phase, to achieve less angular deviations.
4. The lower bone density values may result in the greater angular deviations, which might have been caused by the freehand installation of the implants.

**ACKNOWLEDGMENT**

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**REFERENCES**


