A COMPARISON OF RESISTANCE TO FRACTURE AND DEFORMATION BETWEEN ONE AND TWO-PIECE SMALL DIAMETER DENTAL IMPLANTS

A Thesis

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By

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Graduate Program in Dentistry

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Abstract

Small diameter dental implants have been developed to overcome clinical settings of limited bone and dental spacing. These small diameter implants are available as a two-piece implant and prosthetic abutment or a one-piece implant. A concern with small diameter implants is an increased predisposition to implant and abutment fracture. The purpose of this research is to explore the strength characteristics of one and two-piece small diameter implants. 10 Astra Tech OsseoSpeed Ø3.0 x 13mm implants with Ø4.0 2mm TiDesign abutments (two-piece) where compared with 10 BioHorizons one-piece Ø3.0 x 15mm implants (one-piece). The implants were secured in a rigid clamp and subjected to static loading. The mean peak load was recorded for the specimens as well as load/displacement data. The mean peak load values for the one and two-piece implants were 414 N and 187 N respectively. The one-piece implants were significantly stronger than the two-piece implants. The practitioner should utilize careful patient selection when using two-piece small diameter implants.
Acknowledgments

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Minor Field:  Oral and Maxillofacial Surgery
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Chapter 1
Introduction

Bone quality, quantity and spacing between teeth often dictate whether a dental implant can be placed or if site preparation is required before placement. Techniques for bone grafting have been described with successful outcomes (1). However, reconstructive procedures add cost, time and morbidity to the treatment plan. Additionally, the edentulous space between natural teeth may impede placement of a normal size implant. To overcome these obstacles, small diameter (3-3.5mm diameter) dental implants have been developed and researched (2-6). A concern with small diameter implants is the potential for fixture fracture, both at the implant and abutment level (7). Graves, found that an implant five mm in diameter is three times stronger than a 3.75mm implant, and an implant 6mm in diameter is six times stronger than a 3.75mm implant (8). Small diameter implants are available as a traditional two-piece implant and prosthetic abutment and as a one-piece implant.

Both the one and two-piece implant system have advantages and disadvantages. Advocates of the one-piece system claim simplified prosthetic management, no “microgap” between the abutment and implant capable of harboring bacteria, no need for manipulation at the implant level, decreased surgical time and improved esthetics (9,10).
However, proponents of the two-piece system argue the one-piece system may to increased bone loss, difficulty controlling prosthetic angulations and implant level, and decreased success rates (11,12). Currently, there are more commercial options for one-piece small diameter implants than two-piece implants. This may be due to a concern that small diameter two-piece implants are more prone to fracture than one-piece implants (13). Recently, Astra Tech began marketing a 3.0mm diameter two-piece implant system. The literature is lacking in regards to strength comparisons of one and two-piece small diameter implants.

Fatigue testing is an accepted test design to evaluate strength characteristics of dental implants. However, static loading or load to failure can be used to generate useful information regarding the clinical performance of implants and is known as the implant’s ultimate tensile strength. The ultimate tensile strength and fatigue limit of titanium and titanium alloy implants are related. Cyclical loading of forces approximating 50% of the material’s ultimate tensile strength generally lead to catastrophic fracture after approximately $10^6$ to $10^7$ load cycles (14). The close relationship between fatigue and ultimate tensile strength has also been demonstrated in previous laboratory investigations. One study found that an implant exposed to less than 50% of the ultimate tensile strength could endure five million loading cycles. However, loads 50-60% of ultimate tensile strength resulted in significant failure before the end of the 5 million cycles (15). In other words, an implant subjected to less than 50% of its ultimate tensile strength would be
expected to endure 10-25 years of function (16,17). Using this knowledge we performed a static load test of one and two-piece small diameter implants. The aim of this study is to explore the resistance to failure of one and two-piece small diameter dental implants.
Chapter 2
Materials and Methods

Two commercially available implant designs were subjected to laboratory analysis. 10 Astra OsseoSpeed Ø3.0 x 13mm implants with Ø4.0 2mm TiDesign abutments (two-piece) where compared to 10 BioHorizons one-piece Ø3.0 x 15mm implants (one-piece), figures 1,2. The testing protocol was based on the ISO recommendations, ISO 14801 (18). Each sample was secured in a rigid clamping device 3.0mm apically from the normal bone level. The abutments of the two-piece implants were torqued according to manufacturer’s recommendations.

Figure 1. Astra Tech two-piece Implant
A custom implant holder was fabricated for this research project, figure 3. It was designed in compliance with the ISO recommendation for specimen holder. It is a vice-type holder fabricated from stainless steel. Two aluminum sleeves are placed around the implant and then secured in the vice. The clamp secures the implants 30° to the vertical axis.
Chromium cobalt crowns were fabricated that provided a loading surface equal height from the level of the rigid clamp; 17.5mm, Figure 4. The crown/implant assembly was angled 30° to the vertical.

![Crown and Implant in rigid clamping device](image)

**Figure 4.** Crown and Implant in rigid clamping device

The loading of the implants was performed using an Instron universal testing machine. The implant designs were selected and loaded in random order. A small pre-load was applied prior to commencement of loading to ensure complete seating. Off-axis loading was performed with the vertical piston at a rate of 0.5mm/min. This was carried
out until the implant fractured or underwent obvious deformation after obtaining the peak load value.

Load and displacement values were recorded throughout the loading with Testworks (Software Research Inc, San Francisco, CA) computer software. The data were then analyzed using Microsoft Excel (Microsoft, Redmond, WA). The data was used to create load displacement curves, and analyze maximum load levels. A t-test statistical analysis of the mean peak load values was performed. An a priori analysis revealed that 10 implants of each type would be sufficient for statistical analysis to detect a mean difference of 60 N.
Chapter 3

Results

There was a significant difference in load resistance between the one and two-piece implants. The mean peak load values for the one and two-piece implants were 481 N and 187 N respectively (P <0.0001), Tables 1,2. Load-displacement curves were generated for the two implant systems, figures 5, 6.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Peak Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>191 N</td>
</tr>
<tr>
<td>2</td>
<td>176 N</td>
</tr>
<tr>
<td>3</td>
<td>189 N</td>
</tr>
<tr>
<td>4</td>
<td>174 N</td>
</tr>
<tr>
<td>5</td>
<td>198 N</td>
</tr>
<tr>
<td>6</td>
<td>200 N</td>
</tr>
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<td>7</td>
<td>175 N</td>
</tr>
<tr>
<td>8</td>
<td>182 N</td>
</tr>
<tr>
<td>9</td>
<td>185 N</td>
</tr>
<tr>
<td>10</td>
<td>200 N</td>
</tr>
<tr>
<td>Mean</td>
<td>187 N (SD 10.2)</td>
</tr>
</tbody>
</table>

Table 1  Two-piece peak load values

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Peak Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>350 N</td>
</tr>
<tr>
<td>2</td>
<td>398 N</td>
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<tr>
<td>3</td>
<td>482 N</td>
</tr>
<tr>
<td>4</td>
<td>424 N</td>
</tr>
<tr>
<td>5</td>
<td>385 N</td>
</tr>
<tr>
<td>6</td>
<td>384 N</td>
</tr>
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<td>7</td>
<td>421 N</td>
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<td>8</td>
<td>404 N</td>
</tr>
<tr>
<td>9</td>
<td>406 N</td>
</tr>
<tr>
<td>10</td>
<td>481 N</td>
</tr>
<tr>
<td>Mean</td>
<td>414 N (SD 41.5)</td>
</tr>
</tbody>
</table>

Table 2  One-piece peak load values
Figure 5. Two-piece load displacement graph
Figure 6. One-piece Load Displacement Graph
A few of the two-piece implants fractured at the abutment screw, figure 8. The remaining implants displayed deformation. The majority of the deformation occurred in the abutment, figure 9. However, there was also deformation of the coronal aspect of the implant body, figure 10. This resulted in distortion of coronal aspect of the implant.
Figure 8 Fractured two-piece implant, note the fractured abutment screw and deformed abutment

Figure 9 Deformed two-piece abutment

Figure 10 Deformed two-piece implant
None of the one-piece implants fractured, but did show signs of obvious deformation. The deformation was gradual starting at the rigid clamp extending in the coronal direction, figure 11.

Figure 11  Deformed one-piece implant
Chapter 4

Discussion

Implants are at risk of fracture usually occurring with intermediate to long-term loading. Rangert showed that 80% of long-term failures are related to implant body fracture (19). The risk of fracture is related to the implant design, and treatment plan. There are two key aspects of the implant design that affect fracture potential and are size, and biomaterial used.

An implant’s ability to resist deformation and fracture is closely related to the implant size. The fracture resistance is related to the implant’s radius to the fourth power. This is demonstrated by the following equations:

\[
\text{two-piece implant; } I (\text{moment of inertia})_{\text{hollow cylinder}} = \frac{1}{4} \pi \left( \text{radius}_{\text{outer diameter}}^4 - \text{radius}_{\text{inner diameter}}^4 \right)
\]

\[
\text{solid one-piece; } I (\text{moment of inertia})_{\text{solid cylinder}} = \frac{1}{4} \pi \text{ radius}^4.
\]

A small change in wall thickness results in a significant change in fracture resistance. These equations can be used to compare two-piece and one-piece implants. A solid 1.23mm diameter implant has the same resistance to fracture as a 3.75mm traditional two-piece design. Additionally, a solid 3mm diameter implant has a 340% increase in moment of inertia over a 3.75mm two-piece root form implant (20). In light of this engineering principle, it is impressive that the one-piece implants were only slightly more than twice as strong as the two-piece implants. The moment of inertia of an implant is only one factor influences how a cylinder will respond to stress.
Yield stress is a way to examine strength characteristics of various specimens and describes the point when the force results in loading beyond the specimen’s elastic limit. When in function, an implant acts as a cylindrical lever arm. How the implant responds to stress is affected by the magnitude of load, angle at which the load is applied, size of implant, and distance from the bone level to the applied force. These variables are represented in the following yield stress equation:

\[ \sigma = \frac{(M*c)}{I} \]

where \( \sigma \) is the stress, \( M \) is the bending moment, \( c \) is the outer radius of the cylinder and \( I \) is the moment of inertia.

Bending moment is the force applied multiplied by the moment arm. Moment arm is the length from the clamp to the loading surface multiplied by the sin of the angle of the off-axis loading. Moment arm increases with increased length of exposed implant (bone loss) or increased degree of off-axis loading (angled abutments). A larger moment arm means that less force is required to generate the same yield stress. As the moment of inertia increases more force is required to generate the same yield stress. As demonstrated above moment of inertia increases with larger diameter implants.

In addition to the implant size, the type of metal used to manufacture the implant must also be taken into consideration. The BioHorizons one-piece implant is manufactured with titanium alloy, Ti-6Al-4V. However, the Astra Tech two-piece
implant system is manufactured with grade 4 commercially pure titanium. Titanium alloy has better tensile strength than commercially pure titanium, nearly twice as much (20). The decreased strength of the two-piece implant could be related to the design, material or a combination of both. Given the small diameter of the two-piece implant a titanium alloy may reduce its fracture potential. Equally important to the implant size and design is the clinical setting in which the implant is used.

The one-piece and two-piece implants used in this study are suggested for use in the maxillary lateral and mandibular incisor position. Results of other studies report a mean loading force of approximately 150 – 206 N in the human incisal region (16,21). This range may exceed the mean peak load values of the two-piece implant. Though these studies show high biting forces in the incisal region, the implant crown should not be subjected to the same load as the natural dentition. Mutually protected occlusion will decrease the loads applied to anterior implants. When selecting two-piece, small diameter implants one must pay close attention to the final occlusal treatment plan. It makes sense that the implant should have light contact in centric occlusion and be equilibrated to avoid premature contact in eccentric movement. Patients with a history of parafunctional habits like bruxism may be better served with a one-piece implant in regards to resistance to fracture. Additionally, yearly evaluation with close attention to occlusion may help to detect early traumatic occlusion. Using small diameter implants
outside of the manufacture’s recommendations and/or with disregard to final occlusion, may put the implant at risk for fracture.

The peak load values of the one-piece BioHorizons implant obtained in this study were lower than a prior report done by Allum et al (22). This report found a mean peak load of 648 N for this implant. The higher value is most likely related to the smaller distance from the rigid clamp to the loading surface. The distance from rigid clamp to loading surface was 17.5mm in our study and 14mm in Allum’s. A smaller length results in a small moment arm and will require more force to induce deformation. A search of PubMed did not reveal any prior studies evaluating strength of the Astra Tech Ø3.0mm implant.

The ISO requirement for fatigue testing requires clamping of the implant 3mm below the normal bone level. In our project the top of the crown was 17.5mm above the rigid clamp. This length is longer than what is normally found in the clinical setting. This length was selected for ease of casting the crown and to accommodate the different collars of the two and one-piece implants. Clinically, the crown would be shorter and 3mm of bone loss is more than what is typically seen. Both of these changes would result in improved implant strength characteristics in the clinical setting.
This research only dealt with the one element of comparison between one and two-piece small diameter implants, resistance to failure. As mentioned earlier, bone loss, ease of placement and prosthetics, esthetics and overall success rates vary between one and two-piece implants. Resistance to fracture or deformation is only one parameter of success. Additionally, the way in which masticatory force is transferred to the bone between the one and two-piece implants may be different. This could a factor in bone loss over time. In other words, just because an implant does not break as soon in a laboratory test, does not necessarily mean that it will be a “better” implant in clinical practice. Operator preference and experience should also be used when selecting a one or two-piece implant.

Given the findings of this research there is concern that long-term use of these two-piece implants may be at a risk of fracture or deformation. Careful patient selection and attention to the occlusal scheme should be used when placing Astra Tech 3.0mm diameter two-piece implants. However, if used in the correct setting both the one and two-piece small diameter implants would be expected to withstand normal function. The selection process should be based more on practitioner’s preference of using a one or two-piece implant than the implant’s strength characteristics. Additional clinical research is needed to evaluate the strength characteristics of one and two-piece small diameter implants.
1. There was a significant difference in resistance to maximum load between 3.0mm commercially pure grade 4 titanium two-piece implants and 3.0mm titanium alloy one-piece implants.

2. The peak load resistance values for the two-piece and one-piece implants were 187 N and 414 N respectively, ( p<0.0001)

3. Although, the difference was statistically significant, it was not as high as would be theoretically calculated.

4. The clinical significance of these laboratory results requires further evaluation.
References


