Tolerance Test of Five Different Types of Crowns on Single-Tooth Implants

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Purpose: The main purpose of the present experimental study was to compare five different types of crowns, cemented on implant abutments, regarding their capability to withstand loads.

Materials and Methods: Three types of all-ceramic crowns, a gold-foil-reinforced porcelain crown, and, as a control, a conventional metal ceramic crown were tested. Each crown was cemented onto an Astra Tech Single-Tooth Implant. The five types of crowns, three of each type, and the titanium implants were subjected to loading in Lloyd test equipment until part of them was damaged, at which point the compression value was recorded and the deflection and bending moment were calculated. Comparisons were made on the basis of these data.

Results: The results showed that the all-ceramic crowns fitted with a core should be able to withstand normally occurring biting forces without difficulty. The foil crown was also judged to be acceptable, while the bending moment of the cast all-ceramic crown without a core was considered unpredictable. The values for the metal ceramic design were as predicted, i.e., they were clearly the highest in the study; the superior strength of metal ceramics should still be taken into account when deciding between all-ceramic solutions and the conventional metal ceramic crown.

Conclusion: It was concluded that all-ceramic crowns are weaker than conventional metal ceramic crowns; however, based on estimated maximum clinical loading (370 N in the incisor and premolar regions), In-Ceram and AllCeram crowns seem to function satisfactorily on implants. Int J Prosthodont 1998;11:233-239.

In recent years implantology has often been considered as an alternative to conventional prosthetics. Replacing a single missing tooth, especially in the anterior region in a young person, has always been a challenge for the clinician. Increasing demands from patients have led to improvements in both the technical and esthetic aspects of implant dentistry. The use of implants for single-tooth replacement, e.g., after trauma, is increasing. Klineberg reported that the implant-supported single-tooth restoration was the most frequently used implant treatment in Australia and New Zealand in 1992. The main advantage of using an implant for single-tooth replacement is that the preparation of healthy adjacent teeth can be avoided. At the same time, the field of dental technology has evolved and the esthetic potential has increased. In the future all-ceramic designs may eventually replace conventional metal ceramic fixed prosthodontic structures entirely.

Astra Tech has developed a system for replacing individual teeth: the Astra Tech Single-Tooth Implant. Currently metal ceramic crowns are recommended for this system since little has been documented about the combination of implant and all-ceramic crown. Crowns constructed using all-ceramic techniques (e.g., AllCeram, Empress, In-Ceram, and AllCeram) have been found to function satisfactorily on implants.
Table 1 Mean Dimensions (mm) of the Crowns, Three of Each Material

<table>
<thead>
<tr>
<th></th>
<th>AllCeram</th>
<th>In-Ceram</th>
<th>Empress</th>
<th>Foil crown</th>
<th>Metal ceramic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>9.5</td>
<td>9.4</td>
<td>9.6</td>
<td>9.7</td>
<td>9.6</td>
</tr>
<tr>
<td>Width</td>
<td>8.4</td>
<td>8.4</td>
<td>8.4</td>
<td>8.5</td>
<td>8.8</td>
</tr>
<tr>
<td>Thickness</td>
<td>6.1</td>
<td>6.5</td>
<td>6.5</td>
<td>6.4</td>
<td>6.4</td>
</tr>
</tbody>
</table>

In-Ceram) are based on entirely different principles of strength, and should therefore be investigated in regard to loading before being routinely used with implants.

In a study by Andersson et al, it was shown that the all-ceramic crown AllCeram was highly resistant to fractures and had a high bending strength, making it comparable with that of metal ceramic restorations. The esthetic and financial advantages of integrating all-ceramic crowns and single-tooth implants have been emphasized, although these factors were not taken into account in the present study.

The prosthetic restoration and implant must be able to absorb various degrees of loading and conduct these to the surrounding tissue. According to Haraldson et al, masticatory forces in the incisive and premolar areas are between 103 and 368 N, and Schwickerath reported forces in the range of 150 to 235 N in these areas. Gender, age, and occlusion are factors that affect the biting force. An implant system may benefit from having a crown with a tendency to break at excessive loading. Accordingly, the ideal crown should be modified so that it breaks before the bone is damaged in the event of trauma, while at the same time is able to withstand the maximum forces in function.

The aim of the present study was to compare three different all-ceramic crowns and a ceramic crown with a base cap of 24-carat gold with regard to their ability to withstand loading stresses. A conventional metal ceramic crown was used as a control. This study also investigated the effect that loading had on implant components.

Materials and Methods

Fifteen samples (crowns of the maxillary right central incisor) were made, three of each type of material. The following materials were tested: AllCeram (Procera Nobel Biocare), In-Ceram (Vita Zahnfabrik), IPS Empress (Ivoclar), and a foil-reinforced porcelain crown, 24-carat gold with metal-bonded porcelain. As a control, a conventional metal ceramic crown of gold alloy with metal-bonded porcelain was used.

The crowns were made on plaster casts produced according to a standard silicon model. All crowns had similar dimensions (Table 1). The different crown types were fabricated in accordance with the manufacturers' directions. Each crown was cemented to an Abutment ST, which in turn was connected to a 13-mm Fixture ST (Astra Tech Implants, Dental System, Astra Tech). The crowns were cemented with zinc phosphate cement. After the cement had been set, the plaster casts, including the implant and cemented crown, were left in a hygroscopic tank for 48 hours (100% atmospheric humidity, 21°C).

AllCeram is a porcelain crown with a core. The aluminum oxide content of the core is 99.9%. An enlarged (20%) model of the preparation is coated with aluminum oxide, and undergoes dense sintering at high temperature (greater than 2,000°C). The fact that the model is enlarged compensates entirely for the shrinkage resulting from firing. Procera AllCeram porcelain is then applied to the aluminum oxide core. This technique is based on concepts presented earlier.

In-Ceram is a porcelain crown with a core. Seventy percent of the core consists of aluminum oxide infiltrated with glass powder. This increases the strength of the core, which is veneered with Vitadur Alpha porcelain (Vita Zahnfabrik).

IPS Empress is one of the leucite-reinforced porcelain crowns that uses microsized leucite crystals evenly distributed in the feldspar glass under controlled crystallization for reinforcement. This glass ceramic is ground and then pressed to form a seminished product. Following wax-up the crown is cast in this substance.
Fig 1 Loading of a crown. Definition of geometry. Courtesy of Dr Bernt Andersson. \( M = F \times L \) where \( L \) = the lever vertical to the force (mm), \( F \) = force, and \( M \) = bending moment (Ncm). \( P \) = bending moment between the fixture and the abutment along the center line; \( H \) = the distance between \( P \) and the incisal edge; \( W \) = the distance between the longitudinal axis and the loading point (mm); \( R \) = the hypotenuse in the resulting triangles (mm); \( a \) = the angle between the horizontal plane and the longitudinal axis (degrees); \( e \) = the angle between the direction of force and the longitudinal axis (degrees); and \( b \) and \( c \) = the angles in the resulting triangles (degrees).

The substructure of the gold foil crown is a thin (0.4-mm) gold coping that supports the overlying porcelain and enables it to better withstand the loading forces. There are different production versions of the coping; in the present study case a cast version of 24-carat gold (Sjödings) was chosen. It was gold plated (Heraeus Blendgold neu, Kultzer) and coated with porcelain (Shofu Vintage, Shofu).

A metal ceramic crown consists of a supporting metal substructure to which porcelain is bonded. The metal is generally a gold alloy, although other metals such as titanium or base metal alloys may be used. For this study, the gold alloy DL 76 (76% Au, ANA Ädelmetal) was selected. The porcelain (Klema Dentalprodukter) was then bonded to the metal.

In principle, the method of testing used was the same as that described by Andersson et al., who investigated how various crowns cemented onto implant abutments were affected by loading. Tests were also made of crowns cemented on abutments attached to implants; this method was used in the present study.

The sample (crown) was subjected to loading at an angle of 45 degrees to the direction of compression, i.e., the vertical, since this angle was assumed to produce the highest bending moment. The test equipment was set to apply a maximum load of 700 N. This value was chosen because it was expected that the metal ceramic crown could withstand loads of this magnitude. Loading occurred on the center of the lingual aspect of the incisal edge with the tip of a hard needle, 2 mm in diameter, at a rate of 0.5 mm per minute. The test equipment used, Lloyd LRX (Lloyd Instruments), was designed to exert a load on the system (i.e., crown and implant) until some part of it was permanently deformed or fractured. The temperature was 20°C for all the measurements. The sample consisted of different materials that were integrated; therefore, a measurement of the E-module was difficult to relate to a specific material, e.g., the ceramic crown or the implant. Small differences in the design of the crowns caused the angle to the vertical to vary slightly, although in no cases by more than 1 degree. The bending moment was the value used to indicate the strength of the crowns. A crack analysis was carried out after the tests using blue wavelength illumination, which made it possible to detect whether other cracks had occurred in the crowns in addition to those that were clearly visible. The principle is shown in Fig 1.

Results

The maximum load, bending moment, and deflection are described for each crown in Table 2. The AllCeram crowns experienced a mean maximum load of 390 N, with a mean bending moment of 269 Ncm before failure. The titanium components were unaffected, and the mean deflection was 0.64 mm. The In-Ceram crowns showed a mean maximum value of 475 N, accompanied by a bending moment of 321 Ncm. The mean deflection for this type of crown was 0.98 mm, and no sign of deformation could be observed on the implant components.
Figs 2a and 2b  Fractures on the AllCeram crown. Cracks formed from the incisal edge to the cervical margin, causing the crowns to split and fall apart (arrows). The fixtures used in the test had machined surfaces. The Fixture ST available from the manufacturer has a defined surface texture, TiOblast.

Table 2  Maximum Force, Bending Moment, and Deflection Before Fracture

<table>
<thead>
<tr>
<th></th>
<th>AllCeram</th>
<th>In-Ceram</th>
<th>Empress</th>
<th>Foil crown</th>
<th>Metal ceramic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum force (N)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>498</td>
<td>506</td>
<td>277</td>
<td>334</td>
<td>700</td>
</tr>
<tr>
<td>2.</td>
<td>329</td>
<td>344</td>
<td>197</td>
<td>270</td>
<td>625</td>
</tr>
<tr>
<td>3.</td>
<td>342</td>
<td>576</td>
<td>190</td>
<td>413</td>
<td>702</td>
</tr>
<tr>
<td>Mean</td>
<td>390</td>
<td>475</td>
<td>221</td>
<td>339</td>
<td>676</td>
</tr>
<tr>
<td>Maximum bending moment (Ncm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>341</td>
<td>342</td>
<td>198</td>
<td>219</td>
<td>490</td>
</tr>
<tr>
<td>2.</td>
<td>234</td>
<td>230</td>
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<tr>
<td>3.</td>
<td>233</td>
<td>293</td>
<td>137</td>
<td>275</td>
<td>491</td>
</tr>
<tr>
<td>Mean</td>
<td>269</td>
<td>321</td>
<td>158</td>
<td>227</td>
<td>476</td>
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<td>Deflection (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1.</td>
<td>0.72</td>
<td>0.92</td>
<td>0.79</td>
<td>0.68</td>
<td>1.82</td>
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<tr>
<td>2.</td>
<td>0.60</td>
<td>0.72</td>
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<tr>
<td>3.</td>
<td>0.61</td>
<td>1.31</td>
<td>0.52</td>
<td>0.90</td>
<td>1.74</td>
</tr>
<tr>
<td>Mean</td>
<td>0.64</td>
<td>0.98</td>
<td>0.61</td>
<td>0.76</td>
<td>1.71</td>
</tr>
</tbody>
</table>

The Empress crowns had the lowest mean values. At the maximum load the crowns developed cracks on average at 221 N, with a bending moment of 158 Ncm. The deflection was 0.61 mm, slightly lower than that of the AllCeram.

The foil crowns with the 24-carat gold cap had means of 339 N and 227 Ncm, respectively, for maximum load and bending moment. A deflection of 0.76 mm was obtained.

The metal ceramic crowns, as predicted, withstood high loads. The mean values for maximum compression and bending moment were 676 N and 476 Ncm, respectively, while the deflection amounted to 1.71 mm.

None of the samples exhibited any defects in cementation, and the fluoroscopic examination using the blue part of the spectrum showed no other indications of the cement being cracked. The crack pattern for each crown type is shown in Figs 2 to 6.
Figs 3a and 3b Fractures on the In-Ceram crown. The damage varied. One crown cracked incisally and cervically, while the other two remained on the abutments. One crown had a crack that started in a porosity (arrow) on the proximal surface and extended toward the cervical margin, while the other had a loose chip on the labiocervical surface that extended incisally for half the length of the crown. The fixtures used in the test had machined surfaces. The Fixture ST available from the manufacturer has a defined surface texture, TiOblast.

Figs 4a and 4b Fractures on the Empress crown. The fractures were in the thinnest areas, i.e., the cervical portions (arrows). All of the crowns had a uniform crack region on the lingual surface, causing the material to separate from the implant, which was unaffected. The fixtures used in the test had machined surfaces. The Fixture ST available from the manufacturer has a defined surface texture, TiOblast.
Figs 5a and 5b  Fractures on the foil crown. There was a specific crack pattern that was shown only by this type of crown. Cracks first appeared in the cervical third of the lingual surface (arrows), without separation of the porcelain. A few minutes later cracks appeared facially and at the mesial and distal sides from the cervical margin to the middle of the crown (arrows). All the crowns showed the same pattern. The fixtures used in the test had machined surfaces. The Fixture ST available from the manufacturer has a defined surface texture, TiOblast.

Figs 6a and 6b  Fractures on the metal ceramic crown. Two of the samples experienced porcelain fractures on the cervical surface of the crowns (arrows), while the third crown was undamaged. There was no evidence of the implant components being damaged. The fixtures used in the test had machined surfaces. The Fixture ST available from the manufacturer has a defined surface texture, TiOblast.
Discussion

According to Schwickerath\(^\text{5}\) the strength of all-ceramic crowns is derived from their overall construction, and not solely their core material. The present study shows the same tendency for In-Ceram and AllCeram. In-Ceram, with its built-up supporting core, had a high capacity to withstand loading and showed a high degree of deflection. The different structure of the AllCeram core may partly explain why it had somewhat lower mean values. The core must be compatible with the enveloping porcelain and provide support to enable the porcelain to be applied in a uniformly thick layer. The importance of the core was confirmed by the Empress crown, which has no supporting part but fractured at its thinnest part early at a relatively low load. Timoshenko\(^\text{7}\) showed that porcelain reinforced with aluminum oxide is five times stronger than conventional porcelain, and that aluminum oxide alone is eight times stronger than conventional porcelain.

In the study by Andersson et al.,\(^\text{2}\) damage occurred around the abutment area, where sharp edges were assumed to cause stress concentrations. The load there affected the entire surface of the incisal edge. In the present study, the crowns were subjected to a load at one point incisally, leading to the formation of cracks that extended from the incisal edge of the crown to the abutment area, which is prone to stress, on the crowns fitted with a core. The point compression used in this study probably simulates more closely the loading forces that occur in function, since occlusion and articulation contacts are not assumed to occur over a large area of the dental crown. Andersson et al.\(^\text{2}\) obtained different results for AllCeram. In that study, the metal ceramic crown and the AllCeram crown showed similar test results. In fact, the AllCeram crown had an even higher bending moment than the metal ceramic crown. The maximum loading figures were generally lower than in the present study. One can only speculate on the reason for this. There are some factors that may be crucial: differences in the test equipment, load in areas of different sizes, and differences in how the crowns were made. The main reason for differences in the results may lie in the two different implant systems used and, as previously claimed by McGlumphy et al.,\(^\text{8}\) the different abutment screws. It has been suggested\(^\text{9}\) that a gold alloy abutment screw has an advantage over a titanium alloy abutment screw because the friction is lower. However, in the McGlumphy study\(^\text{8}\) it was reported that gold screws resist lower bending forces than titanium alloy abutment screws. Andersson et al.\(^\text{9}\) speculate that so many stresses are caused as a result of abutment deformation alone that they produce a fracture in the crown, and therefore that the loading per se is not the reason for damage to the crown. In the present study no deformations of the implant components could be seen. In a trauma situation it is desirable for either the crown components or the implant components to be the weakest link, rather than the biologic supporting tissue, ie, the bone. However, it cannot be inferred from this study that the Astra system is too strong.

Conclusions

Under the conditions of the present study, the following conclusions may be drawn:

1. All-ceramic crowns still have some drawbacks compared with the metal ceramic crown.
2. Greater toughness of the core materials and better adaptation to the enveloping porcelain are necessary if the all-ceramic crown and metal ceramic crown are to be of equal merit.
3. Based on an estimated maximum clinical loading of 368 N, all-ceramic crowns such as In-Ceram and AllCeram should function satisfactorily with the Astra Tech Implant Dental System.

References
