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STRESS ANALYSIS COMPARING EFFECT OF TWO DIFFERENT CAD-CAM IMPLANT SUPERSTRUCTURE MATERIALS (IN-VITRO STUDY)

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STRESS ANALYSIS COMPARING EFFECT OF TWO DIFFERENT CAD-CAM IMPLANT SUPERSTRUCTURE MATERIALS (IN-VITRO STUDY)

Abstract

Purpose: This study was conducted to evaluate the micro-strain around dental implant using two different CAD/CAM crown fabricated materials through strain gauge analysis. Materials and Methods: Five dental implants were fixed in a 5 previously drilled solid rigid polyurethane test blocks in the edentulous area with neighboring abutments mesial and distal printed out using special 3D Dental printer, Cyanoacrylate adhesive was then used to fix the printed-out part on to the polyurethane test blocks, creating the bounded saddle replicas. Ten CAD/CAM screw retained crowns were fabricated; five Enamic crowns from vita enamic blocks, and five zirconia crowns from presintered katana zirconium blocks. Each crown was cemented to abutment and screwed over the implant fixture. Two strain gauges were installed on their corresponding prepared sites to measure the micro-strains in the medium surrounding the implant. For each tested implant, loads were applied by a universal testing machine, micro-strains were recorded with the strain gauges and stress distribution around the implant was statistically evaluated. Results: Micro-strain recording revealed a statistically significant difference in mean micro-strain recording applied in central fossa between Zirconia and Enamic, for both the buccal and lingual measurements, Enamic was significantly lower than Zirconia. Conclusion: The modulus of elasticity of restorative materials has a meaningful effect on forces applied to dental implant and transmitted to the supporting bone.

Keywords
Implant, Enamic, Zirconia, Strain Gauge, Modulus of elasticity
1. INTRODUCTION

Dental implant provides several advantages over other tooth replacement options. In addition to esthetic and function like a natural tooth, a dental implant replaces a single tooth without sacrificing the health of neighboring teeth in addition to preserving the alveolar ridge, and reduces bone resorption after extraction. The other common treatment for the loss of a single tooth, a tooth-supported fixed bridge, requires that adjacent teeth be ground down to support the cemented bridge (Esposito et al. 2013).

An important difference between natural teeth and dental implants is the fact that no movement in dental implant in response to applied loads. As lake of periodontal ligament in titanium implants, intensive loads are transmitted and distributed to the adjacent bone (Mericske-Stren et al. 1996). Load transfer from implants to surrounding bone depends on type of loading, bone implant interface, shape and characteristics of the implant surface which in turn may cause excessive high or low stresses that may contribute to pathologic bone resorption or bone atrophy (Geng et al. 2001).

Variations in internal state of stress in bone determine whether constructive or destructive remodeling will take place. As low stress levels around a dental implant system may result in disuse atrophy similar to the loss of alveolar crest after the removal of the natural tooth. On the other hand, abnormally high stress concentrations in the supporting tissues can lead to bone microfractures that heal with non-mineralized connective tissue or can result in pressure necrosis and subsequently in the failure of the implant (Kenney et al. 1998).

Advanced ceramic materials such as Zirconia have shown to be appropriate substitutes for dental clinical applications. Zirconia has been used as an aesthetic restorative material for permanent teeth due to its excellent properties which include a high flexural strength, superior fracture resistance and an ideal color stability (Datla et al. 2015).

New restorative materials have been developed aiming a more realistic mimicking of the natural dental materials. These materials include polymer-infiltrated-ceramics (PICs) with a dual network structure, and consist in porous ceramics infused with polymers. According to Min et al., PICs have mechanical properties that are superior to those of pure ceramic, enabling stability against mastication stresses (Ramos et al. 2016) (Min et al. 2016). PICs prevent the propagation of cracks, due to the interpenetration of polymer in the material. Despite having a better behavior in terms of wear effect in the antagonist tooth.

Strain gauges is one of several techniques have been employed to evaluate the biomechanical loads on implants (Da Silva et al 2002), the device used to measure strain on an object. The most common type of strain gauge consists of an insulating flexible backing which supports a metallic foil pattern. The gauge is attached to the object by a suitable adhesive. As the object is deformed, the foil is deformed, causing its electrical resistance to change, which usually measured using a wheatstone bridge, and related to the strain by the quantity known as the gauge factor (Assunção et al. 2009).

2. MATERIALS AND METHODS

Solid rigid polyurethane test blocks were used as an alternative test medium for human bone, as they possess biomechanical properties resembling that of human bone (Patel et al. 2008). Five uniform consistent properties of rigid polyurethane foam for comparative testing blocks were cut in 2 cm length 5 cm width and 4.5 cm height.

Diagnostic cast with missing lower first molar; and an intact inter-abutment distance of the edentulous space was scanned using 3Shape 3D scanner. The edentulous area with neighboring abutments mesial and distal was printed out using special 3D Dental printer (Form lab2) with (E-Denstone), Cyanoacrylate adhesive was then used to fix the printed-out part on to the polyurethane test blocks, creating the bounded saddle replicas.

Implants installation:

A surgical guide, was utilized, and placed over the corresponding teeth in the printed model and through the titanium sleeve, a pilot spoon with a diameter of 2 mm was placed to match the diameter of the pilot drill and make a pilot hole into the block specimen using a digital torque wrench hand-piece, sequential drilling was done using specific spoons corresponding to the drills size to reach a diameter of
4.1 mm for implant installation, five dental implants of 4.1 mm diameter, 10mm length was fixed in the 5 previously drilled blocks.

Five Titanium straight abutments 4.1 mm of a diameter and 5 mm height with a metallic collar of 1.5 mm were screwed and tightened with 25 Ncm torque with the aid of a mechanical torque meter over the implants and scanning powder applied (Figure 1).

![Fig. 1: Abutment connected to implant and scanning powder applied.](image)

Construction of crowns:

Sirona in Lab CAD-CAM system was used for fabrication of ten crowns. With the aid of extra-oral scanner (InEos X5) and a milling unit (Sirona inLab).

With the aid of Sirona inLab SW CAD 15 software the abutments margins were traced and the insertion axis of the design was adjusted for the path of insertion. Spacing tolerance of 80 microns was obtained for the luting cement to facilitate passive fit of the crown over the abutment. Adding removing and correction options designed full contoured screw retained crowns of the mandibular first molar. Ten crowns were milled from the corresponding designs, five Enamic crowns from vita enamic blocks, and five zirconia crowns from presintered katana zirconium blocks.

Enamic crown were carefully finished and polished manually, were as zirconia crowns sintered in a special sintering furnace at 1500°C or 12 hours. Crowns were trial fitted to the implant abutments to ensure complete seating with proper contact, then all crowns were glazed in ceramic furnace.

Each crown was cemented to abutments using finger pressure to avoid the elastic rebound and dislodgment of the crown; excess cement was removed with an explorer, and screwed over the implant fixture.

Installation of strain gauges:

Two buccal and lingual channels with flat walls were prepared in the Polyurethane blocks at the crestal region and parallel to the long axis of the implant to receive the rectangular strain gauge rosettes, with an estimated depth to allow just 2mm thickness of Polyurethane between the strain gauge rosettes and the implant. Two strain gauges were installed on their corresponding prepared sites to measure the micro-strains in the medium surrounding the implant (Figure 2).
A thin film strain gauge cyanoacrylate adhesive was used to cement the strain gauges from their terminal end, parallel to the long axis of the implant.

A universal testing machine was used to apply static load through a special rod applicator with rounded end, which was attached to the upper head of the universal testing machine. Loads were applied from 0 to 100 N in vertical and oblique 45-degree direction with the loading tip of the device on the loading point at the central fossa of the crown. For each tested implant, loads were applied, micro-strains were recorded with the strain gauges and stress distribution around the implant was statistically evaluated.

3. RESULTS

Significant difference was found in mean micro-strain recording applied in vertical direction between Zirconia and Enamic. For both, buccal and lingual measurements, Enamic (103.3±80.0 buccal and 88.3±40.5 lingual) was significantly lower than Zirconia (630.8±359.4 buccal and 165±98.8 lingual).

In Enamic group where the buccal micro-strain mean value (103.3±80.0) was significantly higher than the lingual micro-strain mean value (88.3±40.5), as well in Zirconia group the buccal micro-strain mean value was significantly higher (630.8±359.4) than the lingual micro-strain mean value (165.0±98.8) (Table 1).

<table>
<thead>
<tr>
<th></th>
<th>Enamic</th>
<th>Zirconia</th>
<th>P1 value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUCCAL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>20.0-240.0</td>
<td>235.0-1255.0</td>
<td>0.001*</td>
</tr>
<tr>
<td>Mean±S.D.</td>
<td>103.3±80.0</td>
<td>630.8±359.4</td>
<td></td>
</tr>
<tr>
<td>LINGUAL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>45.0-155.0</td>
<td>60.0-325.0</td>
<td>0.0021*</td>
</tr>
<tr>
<td>Mean±S.D.</td>
<td>88.3±40.5</td>
<td>165.0±98.8</td>
<td></td>
</tr>
<tr>
<td>P2 value</td>
<td>0.036*</td>
<td>0.0001*</td>
<td></td>
</tr>
</tbody>
</table>

(*Significant at level 0.05)
In oblique load application, there was a significant difference in mean micro-strain recording for both Enamic and Zirconia as well, at buccal (123.3±80.0, 672.5±342.2) and the lingual surfaces (105.8±51, 204.2±108.5) respectively. No significant difference between the buccal and lingual surfaces of Enamic group (123.3±80.0, 105.8±51.8 respectively). While in Zirconia group, the buccal and lingual surfaces were significantly different (672.5±342.2, 204.2±108.5) respectively (Table 2).

Table 2: Comparison between Micro-strain recording (oblique load 45°) in the two groups at the two sides.

<table>
<thead>
<tr>
<th></th>
<th>ENAMIC</th>
<th>ZIRCONIA</th>
<th>P1 value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUCCAL</td>
<td>Range 40.0-260.0</td>
<td>285.0-1255.0</td>
<td>0.0013*</td>
</tr>
<tr>
<td></td>
<td>Mean±S.D. 123.3±80.0</td>
<td>672.5±342.2</td>
<td></td>
</tr>
<tr>
<td>LINGUAL</td>
<td>Range 45.0-175.0</td>
<td>90.0-375.0</td>
<td>0.0062*</td>
</tr>
<tr>
<td></td>
<td>Mean±S.D. 105.8±51.8</td>
<td>204.2±108.5</td>
<td></td>
</tr>
<tr>
<td>P2 value</td>
<td>0.107 N.S.</td>
<td>0.0002*</td>
<td></td>
</tr>
</tbody>
</table>

(*Significant at level 0.05)

4. DISCUSSION

One of the most important issues affecting the success of the dental implants is preserving the surrounding tissues around implant fixtures. There are many investigations made by researchers or manufacturing companies to ensure that the stresses occurring around the implant will be distributed to the surrounding bone in the most favorable manner. (Taylor et al. 2002).

In order to obtain reliable data in experiments assessing the forces that are applied on implants and transferred to the supporting bone, the use of strain gauges has been recommended. However, in vivo strain gauge studies cannot be easily conducted due to the difficulty in attaching the sensors to the oral cavity (Moretti et al. 2011).

The installation of strain gauges were done in prepared flat surfaces in the polyurethane blocks parallel to the long axis of the implant and perpendicular to the crest of the ridge buccally and lingually instead of placing it directly on the implant surface because it is preferred to bond the strain gauge on completely flat surface to minimize the possibility of obtaining incremental apparent strain that result from mounting the strain gauge on curved surface (EL-Gendy et al. 2007 and Akça et al. 2002).

CAD-CAM was used to ensure a perfectly designed and milled restorations of exact monolithic copied final crowns, producing by a perfectly contoured restoration, since gingival recession and inflammation is directly related to marginal adaptation, axial contour (Batson et al. 2014), in addition to all advantages of such technology including rapid production, improved wear properties, decreased laboratory fees and improved cross infection control (Freedman et al. 2007).

Loading was simulated through digital loading device occlusally by applying both vertical and oblique (inclined at 45) load of 100 N to the central fossa of the crown. The selection of the force amount and direction was utilized by several previous studies (Moraes et al. 2018), (Lin 2005).

Time frequency of the load was chosen based on the study by Po et al which indicates that each mastication cycle lasts approximately 0.5 seconds (2 Hz) (Po et al. 2011). Since occlusal forces are composed of vertical and horizontal (oblique) components, the masticatory loads are transmitted not only vertically but also laterally. These forces are transferred through the prosthesis into the fixture and, finally, into the bone (Weinberg et al. 1995 & Weinberg et al.1996), Which may lead to bone resorption around the implants (Guo et al. 2001).
Under vertical loading, in both groups, strains were found to be higher in the buccal aspect than the lingual aspect, these finding maybe owing to the fact that the anatomy of the crown was tapered buccally and so the forces falling per unit area are not well dissipated as they are lingually, may be due to high impact forces on functional buccal cusps.

On the other hand, under oblique loading, the higher microstrain values were recorded buccally. This is due to the crown’s orientation on the self-developed jig where the crown was tilted buccally. Therefore, higher forces were concentrated on the buccal cusp and higher readings were observed in the strain meter. Similar studies stated that oblique load is associated with higher stresses (Verri et al. 2014 & Siadat et al. 2015). It is important to emphasize that oblique load application has been related to more realistic occlusal loading (Pesqueira et al. 2014).

In the current study, the overall strains developed around the implants restored with hard material like Zirconia were higher than those developed around the implants restored with resilient material like Enamic, when vertical loads were applied and these differences in the strains were found to be statistically significant. Also, in case of oblique (45° inclination) load application, the strains were higher around implants restored with Zirconia crown than those developed around implants restored with Enamic and differences in the strains were statistically significant. These findings were in accordance with Tiossi et al. 2012, and Menini et al. 2013, who stated that polymer infiltrated ceramics as Enamic are more resilient materials than stiffer ceramics as Zirconia, which reduce stresses transmitted to the implant fixture and consequently to the surrounding bone.

5. CONCLUSION

Laboratory evaluation using Micro-strain recording revealed a statistically significant difference in mean micro-strain recording applied between Zirconia and Enamic crowns over implant. For both the buccal and lingual measurements, Enamic was significantly lower than Zirconia. The modulus of elasticity of restorative materials has a meaningful effect on forces applied to dental implant and transmitted to the supporting bone.

REFERENCES


