STRESS DISTRIBUTION AROUND DENTAL IMPLANTS: INFLUENCE OF DIAMETER AND NUMBER OF IMPLANTS

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Abstract

Three different implant configurations were analyzed (n = 3): five standard implants with diameters of 3.75 mm (C), three standard implants with diameters of 3.75 mm (3S), and three wide implants with diameters of 5.0 mm (3W). The samples were subjected to a vertical compressive load (1.33 kgf) applied at the end of the distal cantilever of the framework. The shear stresses were calculated around the implants and the data were analyzed using one-way ANOVA. Results: The implants nearest to the loading showed higher stress values regardless of the group. The C group showed lower shear stress when compared to the other groups (p=.001). No significant difference was observed between the 3W and 3S groups (p=.785). Conclusion: Decreasing the total number of implants resulted in higher stress concentrations around the implants.

Key Words*: dental implants; biomechanics; stress analysis; implant-supported prosthesis.*

1. INTRODUCTION

The Brånemark protocol calls for the use of five implants to support a total fixed denture in the mandible. Simplification of the Branemark protocol, particularly through a decrease in the total number of implants, could reduce the overall cost of the procedure (Mendonça et al 2009; Cooper 2009; Blomberg and Lindquist 1983; Sheiham et al 2001; Branemark et al 1999; Brink et al 2008; Engstand et al 2003; Van Steenberghe et al 2004; Sandowsly and Caputo 2004; Begg et al 2009; Fazi et al 2011; Hatano et al 2011). The Brånemark Novum concept was first developed in 1999 for the purpose of cost reduction. This concept involves the installation of only three implants in the mandibular interforaminal region, and provides a fixed denture using pre-fabricated components (Branemark et al 1999). Although the initial clinical results were promising, higher loading failures were observed when compared to the original Brånemark protocol (Branemark et al 1999; Hatano et al 2011). These loading failures can be attributed to the inclination of the implants during surgery that can inhibit the fit of the pre-fabricated metal framework (Hatano et al 2011). The use of customized or CAD-CAM designed frameworks could increase the success rate of fixed dentures supported by three implants.

Previous studies have suggested that implant diameter can have a greater impact on the distribution of stresses around implants than its length (Brink et al 2008; Mahon et al 2009; Himmlona et al 2004, Renouard and Nisand 2006). Studies have shown that increasing the implant diameter may compensate for reducing the total number of implants without increasing stress on the bone tissue that supports a fixed denture (Brink et al 2008; Mahon et al 2009; Himmlona et al 2004, Renouard and Nisand 2006).However there is no consensus on the literature (Begg et al 2009; Fazi et al 2011; Hatano et al 2011; Brink et al 2008; Mahon et al 2009; Himmlona et al 2004, Renouard and Nisand 2006; Rivaldo et a 2012; Duyck et al 2000; Silva-Neto et al 2014; Bevilacqua et al 2008; Kim et al 2011; Ogawa et al 2010, Olate et al 2010; Barikani et al 2014; Mijiritsky et al 2013). Therefore, the aim of this study was to investigate the influence of implant diameter and number on photoelastic stress patterns around implants supporting a fixed mandibular denture.

2. MATERIALS AND METHODS

The models were then used to simulate three possible configurations by varying the number of fixtures and the implant diameter. The following three configuration groups were compared: control (C) with five 3.75-mm diameter implants; three standard implant (3S) with three 3.75-mm diameter implants, and three wide implant (3W) with three 5.0-mm diameter implants.

2.1 Photoelastic models

Implants (13.0-mm long) were fixed to the frameworks by 20-Ncm torque screws with a manual torque meter (Conexão, Sao Paulo, SP, Brazil), and were immersed in photoelastic resin up to 12.0 mm of their length (Polipox, Sao Paulo, SP, Brazil) in an acrylic box. This acrylic box was partially adjustable and articulated, and was used to remove the photoelastic models in order to reduce residual stress and/or tears in the models after curing (Dally and Riley 1978, Bernardes et al 2009; Neves ets al 2013). After the resin polymerization was complete, each photoelastic model was fixed in a vertical circular polariscope (Mitutoyo, Tokyo, TYO, Japan) to check for the presence of border effects (Dally and Riley 1978, Bernardes et al 2009; Neves ets al 2013).

2.2 Photoelastic analysis

The loading apparatus had one active point coupled to a load cell (Kratos Ind., Sao Paulo, Brazil) of 50 kgf with a resolution of 0.2 kgf. To simulate a chewing force on the working side, a load of 1.33 kgf was applied vertically at the distal extreme of one of the framework cantilevers (Fig. 1). The model was positioned on a moving plate fixed to the circular polariscope in order to connect the distal cantilever of the framework to the loading device (Fig. 1).

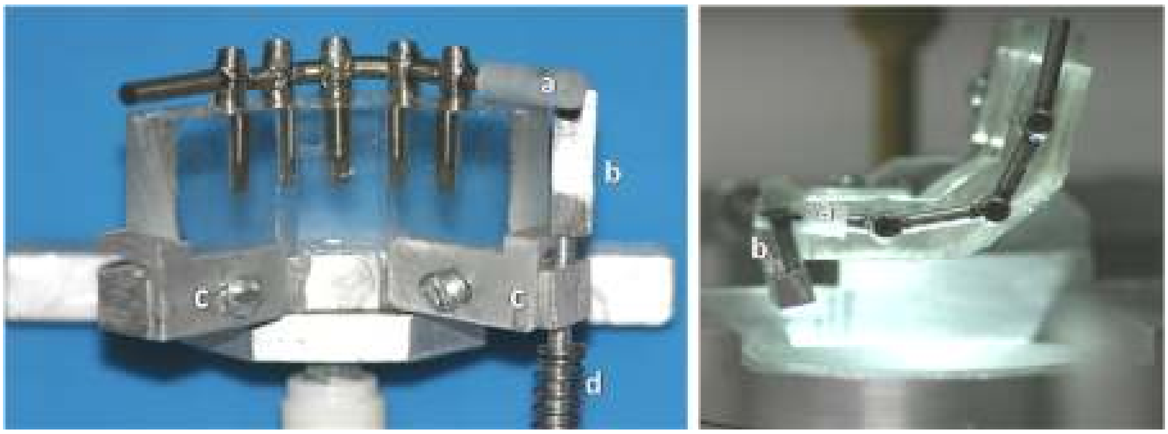

Figure 1 – mobile basis for specimen's installation:a) Vinyl backstop; b) "L" shape device; c) Model's positioning guides; d) Loading spring.

A numeric chart was printed on transparent film and used as a guide on the vertical polariscope screen for model placement during the analysis (Fig. 2). The implants nearest to the loading (a), center (b) and opposite to the loading side (c) were analyzed . Stress readings were taken at sixteen points around each implant (Fig. 2b) (Dally and Riley 1978, Neves ets al 2013). The isoclinal and isochromatic fringe values (N) of each point were determined by Tardy's compensation method (Dally and Riley 1978, Bernardes et al 2009; Neves ets al 2013). Maximum shear stress (τ) was then calculated by the stress optical law: $\tau=(K_\sigma N)/2h$ (KPa), where the optical material constant of the photoelastic material (K_σ) was predetermined in a calibration procedure to be 0.25 N/mm and the model thickness (h) was 9.5 mm (Dally and Riley 1978, Bernardes et al 2009; Neves ets al 2013).

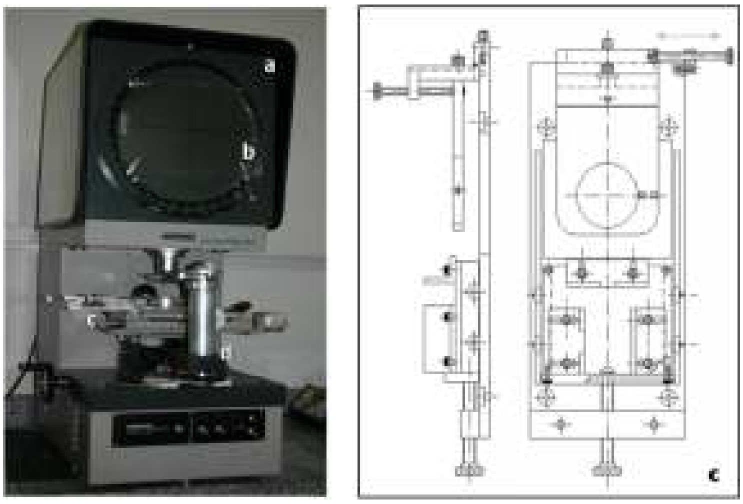

Figure 2 – Experimental apparatus: a) Profile projector; b) Numeric grid; c) Mobile support for specimens installation; d) Vertical circular polariscope.

All calculated shear stress values were plotted to determine the total stress around each implant for each group. The x-axis and the y-axis corresponded to the points and shear stress values, respectively. A program developed in a MATLAB environment (The MathWorks, Inc., Natick, MA, USA) was used to calculate the total area under the curve.

The shear stress values were analyzed using the statistical program SPSS 17.0 (SPSS Inc., Chicago, IL, USA). A one-way analysis of variance (ANOVA) was used to detect differences between the groups at a significance level of 5%.

3. RESULTS

Irrespective of the group, the stress values computed around the opposite-to-loading (c) and central (b) implants were lower than those observed around the loading side (a) implants (Figs. 4–6). Similar stress distributions were seen around (b) and (c) implants, whereas shear stress values for (a) implants varied along the implant length. Maximum values were observed at the apex region which comprises approximately two thirds of the total length.

The C group showed lower stresses than the 3W and 3S groups ($p < .001$), with stress values being similar between the latter two groups ($p = .785$). Comparing the means of the normalized areas at the loading side (a), it was determined that the 3W group had 8% and 20% lower stresses than C and 3S, respectively. However, the 3W and 3S groups had higher stress values than C at the other implant sites (b and c).

4. DISCUSSION

The proposal to reduce the number of implants was based on the estimated load distribution between them. The medial and distal implants receive the greatest load, irrespective of the number of implants between them or the total number of implants (Duyck et al 2000). Therefore it should not be necessary to use a large number of implants to support a prosthesis (Branemark et al 1999, Hatano et al 2011; Duyck et al 2000). An increase in diameter has been reported to be more effective for increasing the peri-implant bone surface than increasing the length of implants (Brink et al 2008; Mahon et al 2009;Himmlona et al 2004; Renouard and Nisand 2006; Mijiritsky et al 2013). In some cases, this diameter increase can compensate for reducing the number of implants (Mahon et al 2009; Himmlona et al 2004; Renouard and Nisand 2006; Rivaldo et al 2012). However, the present study found that increasing the implant diameter and decreasing the total number of implants simultaneously resulted in higher stress concentrations around the implants.

The use of three implants in mandibular implant-supported rehabilitations was first proposed by Brånemark et al. in response to reported failures in regular implants (Branemark et al 1999). Failures observed in the Novum system® have been attributed to inadequate positioning of the implants during surgical procedures, as well as difficulties with passive fit in pre-fabricated metallic frameworks (Hatano et al 2011). Recent studies have shown that, when compared to the five-implant configuration suggested in the Brånemark protocol, the use of three wide implants to support mandibular full arch rehabilitations may reduce the stress values around implants. Moreover, the medial and distal implants have been reported to exhibit a stress increase up to 30%, which could be compensated for by the greater resistance of this implant (Silva-Neto et al 2014). However, the present study showed that higher stress concentrations were observed in the 3W group than in C group ($p < .001$). This result indicates that increasing the implant diameter was not enough to compensate for the reduction in the total number of implants.

Further, decreasing the total number of implants while maintaining implant diameter was also found to be ineffective. Higher stress concentrations were observed around the implants of group 3S than around those from group C ($p < .001$). This result is consistent with a previous study that used finite element analysis to predict a 16% increase in stress values when the number of implants was reduced from five to three (Fazi et al 2011). Furthermore, in an *in vivo* study, Duyck et al (2000) found that rehabilitation with a five-implant configuration produced significantly lower stress than those with three- or four-implant configurations.

No significant differences were observed in stress concentrations around implants between the 3W with 3S groups. These results are not consistent with the previously discussed finite element analysis study, in which lower stress levels were observed around implants in configurations with reduced implant diameters. 18 In our study, the implant nearest the loading point (a) exhibited higher stress values than implants (b) and (c). However, lower stress values were observed on implant (a) in the 3W group than in groups C (-8%) and 3S (-20%). This group difference was not observed for the other implant locations (b and c), which were more sensitive to a reduction of the total number of implants. Moreover, the increase in stress for the groups with fewer implants can be attributed to there being a smaller number of fixations to dissipate the loading force. This result indicates that even indirectly loaded implants can be overloaded to the point of failure.

Plain transmission photoelasticity can be used to analyze stress distributions around implants. Several studies have used this technique to analyze experimental stresses (Begg et al 2009; Renouard and Nisand 2006; Kim et al 2011; Dally and Riley 1978; Bernardes et al 2009). Unlike other studies in which only qualitative analyses were performed, the method used in the present study enabled stress values to be quantified at predetermined points (Begg eta al 2009; Kim et al 2011). However, photoelastic resin does not simulate the characteristics of cortical and cancellous bone being a limitation (Dally and Riley 1978; Bernardes et al 2009; Neves et al 2013). The long-term presence of stress can cause bone loss in the peri-implant cervical area, and/or prosthetic fatigue, increasing the rates of screw loosening and even fracture of the abutment or retention screws (Duyck et al 2000; Dhima et al 2013; Heydecke et al 2012; Priest and Wilson 2014; Purcell et al 2008; Dhima et al 2014). Further, the use of wide implants in the anterior region of the mandible can be considered a limitation on the prescription of this technique due to the reduced bone quantity. However, the present study analyzed only the stress distribution around the implant. Thus, additional studies that examine dynamic loading should be considered to evaluate how such dynamic conditions influence prosthetic components over time, and to determine whether a smaller number of implants could affect the predictability of prosthetic rehabilitations. Clinical studies will be necessary to corroborate such findings.

5. REFERENCES

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7 .RESUMO

Três configurações diferentes de implantes foram analisados (n = 3): cinco implantes convencionais com diâmetros de 3,75 milímetros (C), três implantes convencionais com diâmetros de 3,75 milímetros (3S), e três implantes de largura, com diâmetros de 5,0 mm (3W). As amostras foram submetidas a uma carga de compressão vertical (1,33 kgf) aplicada na extremidade distal do braço de suporte da estrutura. As tensões de cisalhamento foram calculados em torno dos implantes e os dados foram analisados por meio de variância one-way. Resultados: Os implantes mais próximas à carga mostraram valores de tensão mais elevados independentemente do grupo. O grupo C apresentou menor tensão de cisalhamento, quando comparado aos outros grupos ($p = 0{,}001$). Não foi observada diferença significativa entre o 3W e 3S grupos ($p = 0{,}785$). Conclusão: A diminuição do número total de implantes resultou em concentrações de tensões mais elevadas em volta dos implantes.

8. RESPONSABILIDADE PELAS INFORMAÇÕES

O(s) autor(es) é (são) os únicos responsáveis pelas informações incluídas neste trabalho.