Brazilian Dental Journal (2015) 26(3): 277-283
http://dx.doi.org/10.1590/0103-6440201300145

ISSN 0103-6440

Passivity of Conventional and CAD/CAM Fabricated Implant Frameworks

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The objective of this research was to evaluate the passivity by measuring the passive fit and strain development of frameworks screwed on abutments, made by CAD/CAM technology, and to compare these parts with samples manufactured by conventional casting. Using CAD/CAM technology, four samples were made from zirconia (Zircad) and four samples were manufactured from cobalt-chrome (CoCrcad). The control groups were four specimens of cobalt-chrome, made by one-piece casting (CoCrci), with a total of 12 frameworks. To evaluate the passive fit, the vertical misfit at the abutment-framework interface was measured with scanning electron microscopy (250×) when only one screw was tightened. The mean strain in these frameworks was analyzed by photoelasticity test. A significant difference in the passive fit was observed between the control and sample groups. CoCrcad exhibited the best value of passive fit (48.76±13.45 µm) and CoCrci the worst (187.55±103.63 µm); Zircad presented an intermediate value (103.81±43.15 µm). When compared to the other groups, CoCrci showed the highest average stress around the implants (17.19±7.22 kPa). It was concluded that CAD/CAM-fabricated frameworks exhibited better passivity compared with conventionally fabricated frameworks. CAD/CAM-fabricated Co-Cr frameworks may exhibit better passive fit compared with CAD/CAM-fabricated zirconia frameworks. Even so, similar levels of stress were achieved for CAD/CAM-fabricated frameworks.

Key Words: dental implants, dental prosthesis, computer-aided design/computer-aided manufacturing.

Introduction

Implant treatment to promote osseointegration has advanced implant dentistry by improving oral rehabilitation. However, problems associated with implant treatment occur when the prosthesis does not fit well in the implants or abutments, leading to non-passivity and a marginal gap in the prosthesis, ultimately causing distortion, screw loosening, fracture and failure of the implant (1,2).

Passivity is achieved when there is simultaneous contact, with full engagement between the framework and the surfaces of the abutments or implants. Therefore, passivity is considered as paramount for avoiding buildup of stress at the bone/implant interface and to maintain osseointegration (3).

Insufficient passivity leads to a vertical gap that comprises the distance from the intermediate or prosthetic implant platform to a point in a marginal area of restoration, measured parallel to the long axis of the abutment or implant (4).

Prosthetic configurations lacking passivity are characterized by misalignment between the screw holes and the abutments, leading to a slight deformation of the screws. Prostheses in this situation are not fully seated on the prosthetic abutment. There is a mismatch at the interface between prosthesis and abutment, which reduces the rigidity of the connection between the framework, abutment, implant and bone. Such a condition favors the uneven concentration of loads on the components of this system (5).

According to Hebel and Gajjar (6), better marginal fit and passivity can be achieved by cementing the framework onto the abutments, because the cement can compensate for small misalignments and vertical gaps. Nonetheless, screwed prostheses continue to be widely used because of their many advantages, such as reversibility, easier maintenance and the possibility to re-enable regions with reduced interocclusal space (2).

The findings of Lee et al. (7) differ from those of Hebel and Gajjar (6). Lee et al. (7) analyzed the areas of strain around the implants for two types of framework - screwed framework, manufactured by CAD/CAM (computer-aided design/computer-aided manufacturing) versus cemented framework, made by casting - with and without finishing. Strain gauges were placed on the mesial and distal region of each implant. The measured values showed no statistical difference between groups.

CAD/CAM technology has been widely applied to design and manufacture implant framework. This technology is believed to yield better quality and fewer inaccuracies in the finished parts (8). Furthermore, CAD/CAM simplifies the process and reduces the time required for manufacture (9). Despite its advantages, however, few studies have evaluated how the framework manufactured by this process adapts to the abutments. In view of the increasing use of CAD/CAM technology in manufacturing prosthetic components for implant dentistry, it requires verification that this technique yields adequate passivity.

Thus, this study aimed to evaluate the passivity by measuring the passive fit and strain development on framework fabricated using CAD/CAM technology and zirconia or cobalt-chrome alloy, fixed to abutments. These frameworks were compared with parts manufactured by casting using cobalt-chrome alloy.

The hypothesis was that the passive fit and strain development of fabricated fixed dental prostheses would not be influenced by manufacturing technique or material.

Material and Methods

A metal matrix of aluminum (19 mm high x 13 mm wide x 34 mm long) was used. Onto this matrix, three Brånemark dental implants were installed via external hexagonal connection. A 4.1 mm platform was also installed, with dimensions of 3.75×9 mm (Titamax Cortical Ti; Neodent, Curitiba, PR, Brazil). The implants simulated rehabilitation of the left 2nd premolar, 1st and 2nd molars and were assigned the letters A, B and C, respectively (Fig. 1).

Three abutments (Neodent), each with a 1-mm strap height, were installed on the implants with a 32 Ncm torque . A transfer impression of the position of the abutments served as the basis for a working model with type IV gypsum (Durone IV®; Dentsply, Petrópolis, RJ, Brazil).

CAD/CAM technology was used to fabricate the sample frameworks; four were fabricated in zirconia (Zircad frameworks) and four in cobalt chrome (CoCrcad). The control specimens (four CoCrci) were fabricated by conventional one-piece casting and using plastic cylinders with cobalt chromium (Neodent) brace, totaling 12 frameworks.

The sample size of 12 was chosen because the reproducibility of the CAD/CAM technology is expected to be high. This study was conducted *in vitro*, allowing for high precision analysis by eliminating many of the additional variables inherent in clinical studies dealing with real patients.

The scanning, digitizing and milling of parts were conducted in central production (Neoshape, Neodent), using blocks of yttrium-stabilized zirconia (95% ZrO_2, 5% Y_2O_3) pre-sintered (Neoshape; Neodent), for the Zircad samples and blocks of cobalt chrome (62% Co, 28% Cr, 9% W, 0.5% Si, 0.5% Mn - Neoshape, Neodent) for the CoCrcad samples. The cast samples were prepared from a cobalt-chromium alloy (Nobilium "PM"; Nobilium American Gold Inc., Albany, NY, USA; composition: 64% Co, 28.5 % Cr and 5.25% Mo).

The zircad and CoCrcad samples were prepared from a standard wax. The passivity of the standard wax samples was adjusted using the single screw test to check the nesting of the parts. Where a mismatch in the connection was identified, the piece was sectioned with a scalpel blade No.12, and melted wax was used to unite the region that was cut.

In addition, an index of the standard wax sample was fabricated from silicone (Silon 2APS; Dentsply), and this index was used to produce new wax templates for the CoCrci framework. The passivity of these new wax samples was also adjusted manually as needed.

Zircad, CoCrcad and CoCrci frameworks were then subjected to passive testing by a manual torque on the screw at part "A" and measuring the vertical gap at the framework/abutment interface in the mesial and distal regions of part "C". Subsequently, the screw was tightened in the terminal part "C" and the vertical gap was measured again with respect to "A" (non screwed part).

The vertical gaps were observed by scanning electron microscopy at 250× magnification. Thereafter, the images were printed and lines were traced onto them, parallel

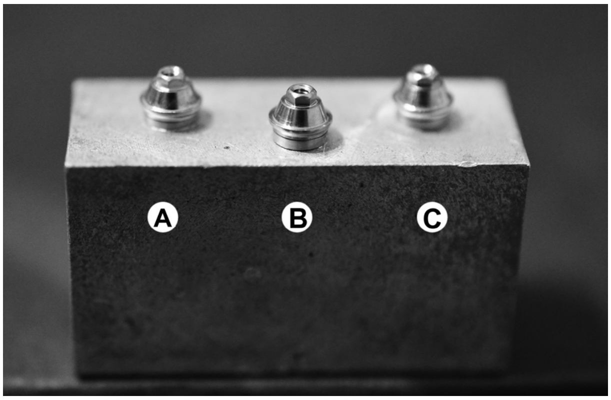

Figure 1. Metal matrix with abutments installed (417x276 mm).

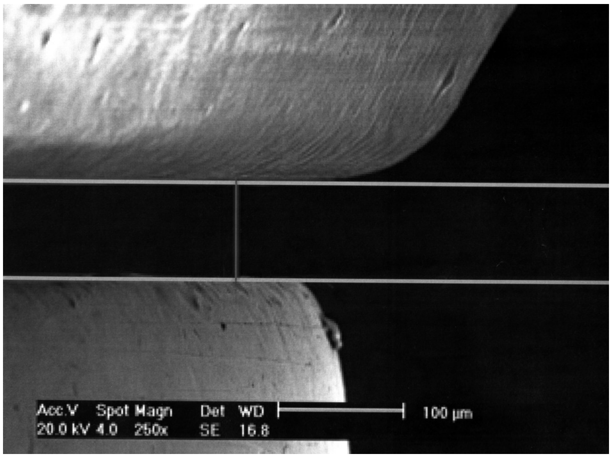

Figure 2. Measurement of vertical gap (184x137mm).

to the upper surfaces of the pillars and parallel to the lower surfaces of the framework. The distance between the two surfaces was measured in mm (Figure 2). These measurements in millimeters were converted into µm using a simple rule of three, based on the size of the existing ruler in the lower portion of the images, whose length in mm corresponded to an image size of 100 µm.

To assess the area of strain generated around the implants, a photoelastic model was built. On implants of the metal matrix, square transfer copings were installed and attached with metal rods fixed with cyanoacrylate-based adhesive (Super Bonder®; Loctite Co., São Paulo, SP, Brazil), and the bond was completed with red acrylic resin (GC Pattern Resin®; GC America Inc., Alsip, IL, USA). The matrix had its base fixed to the bottom of a plastic container, using the same cyanoacrylate-based adhesive. Pink wax plates were subsequently placed in the container, forming a barrier for delimitation of space to accommodate the molding material, and simulating a tray in that region.

Blue silicone rubber was prepared according to the manufacturer's specifications (ABS-10; Polipox Indústria e Comércio Ltda, Cesário Lange, SP, Brazil), using a 4% volume ratio of catalyst with respect to the base, and poured into the tray in such a manner as to keep exposed the ends of the transfer copings.

After 24 h of incubation to allow the rubber to polymerize, components of the screws were loosened and the silicone mold was separated from the tray and the plaster model. In the template, the implants were adapted in molding components. The flexible photoelastic resin (Polipox) was prepared according to the manufacturer's instructions and then incubated in a greenhouse at room temperature for 48 h to cure the resin.

With the photoelastic model ready, the abutments were installed on the implants with manual tightening, and the framework was then screwed on these components by initial manual tightening, followed by a torque of 10 Ncm applied by a manual torquimeter (Neodent), following the BAC sequence recommended by Watanabe et al. (10) and Torres et al. (11). The maximum shear strain was measured at four points tangential to the mesial and distal regions of each implant. Images containing the four points from each set were digitally recorded and processed using stress analysis software (Fringes; LPM, Uberlândia, MG, Brazil), developed in MATLAB environment (The MathWorks Inc., Natick, MA, USA). After measuring strain for a given area of framework, the screws were undone and an image of the photoelastic model was taken by polariscope to identify any residual stress fringes. If such fringes were present, the model was replaced; otherwise a new framework was assembled to perform another measurement. No new photoelastic model was fabricated.

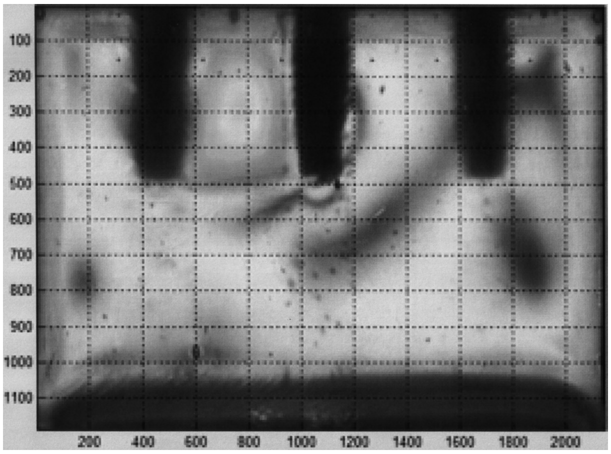

Figure 3. Definition of 4 points around each implant, determined from the numeric chart. Areas of strain can be seen after tightening of the screws (183x140 mm).

A numerical plot was generated in the software to define four points around the implant (Fig. 3). To measure the values of photoelastic fringes at each point, the isoclinic and isochromatic fringe patterns were determined using the method of Tardy compensation. Subsequently, to obtain the values of maximum shear stress in kPa, the optical law was applied using stress analysis software. This law is represented by the equation $\tau=(K\sigma N)/2h$

where τ is the shear stress, $K\sigma$ the photoelastic material constant (0.25 N/mm) as determined by a calibration test, N the value of the fringe and h the resin thickness (h=10 mm).

All statistical analyses were performed with SPSS for Windows (SPSS/PC for Windows Inc., Chicago, IL, USA) and p values of less than 0.05 were considered significant. The variables were passivity and the area of stress around the implants. The mean value, standard deviation, maximum, and minimum values for the variables were computed for each group, and the groups were compared. The Kolmogorov-Smirnov test was applied to verify the normality of the data. The mean values of passivity and strain area for each group were subjected to ANOVA for comparison. For the two-by-two comparison between groups, the t test was used to evaluate the passivity and Tukey's test to evaluate the strain.

Results

When evaluating the passive fit condition, the ANOVA statistical test showed differences between the means of the groups, with p=0.0000 (Table 1). This difference was statistically significant for all groups compared by the performed t test. CoCrcad exhibited the best passivity (48.76±13:45 µm), while CoCrci exhibited the worst (187.55±103.63 µm), Zircad presented an intermediate value (103.81±43.15 µm).

The ANOVA test also identified significant differences between the groups (p=0.020). However, when applying the Tukey test (Table 2), it was found that the difference was statistically significant only for CoCrci when compared to the other groups, with CoCrci presenting the highest average strain around the implants (17.19±7.22 kPa).

Discussion

The samples fabricated using CAD/CAM showed the best passivity, that is, the best passive fit and the lowest mean strain. The frameworks made by casting had the worst passive fit and higher variability of results. Therefore, this technique was less accurate.

The results are in agreement with those of Takahashi and Gunne (12), who had compared the vertical marginal fit of frameworks in 17 edentulous cases and 2 cases of partial losses, where 15 frameworks were made of titanium alloy using CAD/CAM (Procera System - Nobel Biocare, Göthenburg, Sweden) and five frameworks were made by casting a gold alloy. Takahashi and Gunne (12) obtained impressions of films, which represented the space between the framework and abutment. The film thickness, viewed in an optical microscope at 30x magnification, showed significantly better fit for the frameworks manufactured using CAD/CAM. However, the limitations of this previous research include the difference between the number of parts of groups, and absence of case standardization.

To evaluate the effect of fabrication techniques on the vertical marginal gap before and after mechanical cycling of the prostheses, Zaghloul and Youniis (13) fabricated 10 sample units for each group, analyzing them in an optical microscope with 50x magnification. A large vertical marginal gap was observed in all groups, which were fabricated from Cerec3 (Sirona Dental System, Bensheim, Germany), Zircozahn (Zirconzahn Gais BZ, Italia) or a casting monoblock. The worst results were observed in the CAD/CAM group, while the samples fabricated via MAD/MAM (Designing Aid Manual/Manual Milling Aid) method showed the lowest mean vertical marginal gap. This research used a different CAD/CAM system from another study, the CEREC 3 (Sirona), which may have influenced the results. The procedure used to scan, transfer the implant positions and milling may influence the fit accuracy of CAD/CAM-fabricated prostheses. In this study, indirect scanning was performed because this method reportedly provides more precise data compared with the direct approach. Furthermore, the same machine with high-speed 5-axis simultaneous motion under controlled conditions of pressure and temperature was used to mill the blocks of zirconia and Co-Cr. For milling of each new block specific drills were used and after each block was milled, the machine was calibrated again. These steps are routinely performed according to the manufacturer's recommendations. However, when processes are not well-controlled differences in precision of achieved fit may occur. Since the same conditions were used for the different materials, these factors did not influence the outcome of the present study.

Studies on the adaptation of framework fabricated by CAD/CAM abutments are scarce; until now, the only literature examples have been the reports by Takahashi and Gunne (12) and Zaghloul and Youniis (13). The evaluation of this adaptation on the implants, although scarce is still more studied than the previous. It was expected that CAD/CAM technology allowed greater accuracy in fabrication, because it eliminates the manual steps of waxing, inclusion, casting and polishing that may introduce inaccuracies. Moreover, the use of specific software may promote greater environmental control processing to determine the required dimensions of the manufactured frameworks based on the physical and mechanical properties of the materials (9,14).

However, the literature is divided regarding the vertical fit of framework fabricated by CAD/CAM as compared with that of an framework fabricated by casting on implants. While Torsello et al. (15) found that CAD/CAM produces parts whose fit is less precise, Katsoulis et al. (16) and Sierraalta et al. (17) obtained better results using CAD/CAM. However, comparison between studies is limited because neither the CAD/CAM manufacturing framework, nor the evaluation methodology is standard among surveys.

Katsoulis et al. (16) tested the type of material in their research and compared titanium with zirconia. There was

Table 1. Mean values (µm), standard deviation, minimum and maximum relative passivity

Groups	Mean (SD)	Min-max (µm)	p value
Zircad[a]	103.81±43.15	55.56-211.11	0.000*
CoCrcad[b]	48.76±13.45	25-69.44	
CoCrci[c]	187.55±103.63	40.28-374.55	

SD: Standard deviation. * Statistically significant difference at p<0.05 (ANOVA and t-test).

Table 2. Mean values (kPa), standard deviation, minimum and maximum strain on the area around the implants

Groups	Mean (SD)	Min-max (µm)	p value
Zircad[a]	12.14±3.11	8.90-17.34	0.020*
CoCrcad[a]	11.83±3.04	9.47-17.27	
CoCrci[b]	17.19±7.22	8.68-27.65	

SD: Standard deviation. * Statistically significant difference at p<0.05. (ANOVA and Tukey's test).

no significant difference in the vertical gap. On the other hand, the material was influence in this study, as ZirCAD showed higher gap vertical than CoCrcad.

Sierraalta et al. (17) used a virtual coordinate measuring machine (CMM) to measure the vertical gap. However, according to Hjalmarsson et al. (18) this process may underestimate the size of the vertical gap, since the method involves virtually overlaying images to see the gap between their components. Theoretically, the determined position is the one that provides the best fit. According to Katsoulis et al. (16), the best way to measure the gap is directly from the images that can be obtained from optical microscopy, or as in the present study, from electron microscopy. Electron microscopy can achieve higher magnification than optical microscopy.

Another important factor that should be standardized in future studies is how to evaluate the gap: with all screws tight (final fit), or by tightening one extremity of the framework (passive fit). Katsoulis et al. (16) had applied the single screw test, while Torsello et al. (15) provided no such information. The present study opted for the single screw test because, according to Hjalmarsson et al. (18), increasing tightness of the screws reduces the existing vertical gap, while at the same time generating high levels of strain on the screws and on the region of peri-implant tissue. Thus, tightening of all screws could lead to a false conclusion of high passivity.

According to Millington and Leung (19), the concentration of strain is influenced by the marginal gap between the framework and abutment or between framework and implants. They were able to verify this influence in framework castings screwed on abutments with vertical marginal induced gaps by shims at the abutment/framework interface, using of the photoelastic test to measure areas of strain. Millington and Leung thus concluded that there is a direct relationship between the magnitude of the strain and the size of the gap.

After measurement, the stresses developed in the photoelastic model were significantly lower with the CAD/CAM-fabricated frameworks than with the conventionally fabricated framework. These results were probably related to the accuracy and reproducibility of the CAD/CAM procedure, considering that it is faster and may avoid the errors that occur during investment, wax removal, casting, finishing and polishing. A previous study found that the manufacturing technique is also a variable that influences the presence of a microgap, probably because of the different surface roughness produced by each manufacturing method. The authors observed that milled surfaces have a better fit and a larger number of contacts with the implant mating surface than cast surfaces, which allows a better closure of the microgap between implant components (20). The defects resulting from the casting procedure may explain the worst stress level in the photoelastic model presented for CoCrci group. This tension was evaluated by the photoelastic test, which delivers both quantitative and qualitative analysis (21). Similar results were observed by Karl and Holst (22), studying the strain generated around two implants with strain gauges placed on the mesial and distal region of the implants, They found that the framework made by CAD/CAM and screwed onto the implants, showed higher passivity than those bolted on the abutments and manufactured by casting.

By means of an extensometer, Lee et al. (7) also evaluated areas of tension around the implants in two bolted frameworks that were manufactured by CAD/CAM technology. They compared these with other cemented parts made by casting, with an axial load applied on all samples, and found no statistical difference between sample groups. Because the cement can offset small vertical misalignments and gaps (7), in contrast to screwed prostheses, it was possible to infer that the CAD/CAM technology is capable of producing framework with better fit. The comparison between this study and Karl and Holst (22) and Lee et al. (7) was limited, because Karl and Holst (22) and Lee et al. (7) used different methods to measure tension.

In the present study, the ZirCAD and CoCrcad groups showed no statistical difference in strain, although there is higher vertical gap for ZirCAD than CoCrcad. The presintered, yttrium-stabilized, tetragonal, zirconia polycrystal (Y-TZP) blocks were milled with minimal pressure and heat production, reducing potential chipping on the margins during milling and transformation for monolithic phase during milling due to heat generation. The frameworks milled 20%-25% larger were sintered to obtain the final framework. During the sintering process, zirconia shrinks to result in the final framework design with the appropriate resistance and physical properties. However, micrometric dimensional alterations may occur in different directions because shrinkage due to sintering is uncontrollable. The extent of the shrinkage exerts an extra challenge to the software that has to accurately mill an enlarged framework that will shrink precisely to the required dimension after sintering. In addition, the success of this numerical compensation fundamentally depends on the composition and homogeneity of the presintered zirconia blanks. This sintering process may explain the difference of the passive fit values for the CAD/CAM-fabricated zirconia frameworks than for the CAD/CAM-fabricated Co-Cr frameworks. Therefore, shrinkage due to the sintering process should be better controlled. Clinically, micrometric differences observed in this study did not represent a problem for the use of zirconia from the point of view of induced strains. The proven biocompatibility, decreased bacterial adhesion, favorable chemical properties, high flexural strength, and better esthetics compared with Co-Cr alloy makes it an alternative material for three-unit, implant-supported frameworks.

Regarding the clinical significance of the present findings, it is very difficult to judge whether the chosen parameters are clinically relevant, reflecting important information for predicting clinical problems, it should be the goal of each clinician to strive for maximum passivity of fit. Small differences in micra and stress level observed in this study must be judged with caution and it has probably more theoretical than clinical elevance. But the choice of techniques that provide micrometer precision and less variability should be mandatory. In this perspective the CAD/CAM systems should be the first choice for manufacturing framework.

With the evolution of implant dentistry, the search for highly esthetic or low cost solutions in situations of partial edentulism has often intensified without proper critical judgment of the situation to be rehabilitated and the role of available materials. Presently, many prostheses are often connected directly to the implants, without abutments and higher preload forces could be expected because the screwdriver torque recommended for such prostheses is much higher. As a consequence, a higher stress is achieved in the periimplant tissues for comparable gap distances when tightening the frameworks on the implant level. In addition, new and less flexible materials than the earlier commonly used gold alloys, such as cobalt-chromium and zirconia, may introduce even higher stress levels. Thus, the focus fit and prostheses fabricated at abutment level are essential in order to minimize strain generated by these high elasticity modulus materials.

Statistically significant results were obtained from this study. A possible limitation of the results, however, is related to the number of specimens and number of measuring points in each abutment. Inclusion of more measurement points would involve practical difficulties because of the framework form. The sample size and number of measurement points was similar to those of other studies of accuracy fit and microgap (11,20,23-25) and the compelling correlation between manufacturing technique and microgap is an applicable result of this study. Normal distribution and statistically significant results were obtained from this study. The possible limitation of the results, however, is related to the number of specimens. The inclusion of more specimens would have posed significant practical and financial difficulties. The sample size was similar to other studies of passivity and tension (11,20,23-25) and the compelling correlation between manufacturing technique and passivity is an applicable result of this study.

Thus, there is a need for more studies to evaluate different CAD/CAM systems, evaluating if these distinctions influence in vertical gap and in generating tensions around the implants.

Within the limitations of this *in vitro* study, it may be concluded that CAD/CAM-fabricated frameworks exhibited better passivity compared with conventionally fabricated frameworks. CAD/CAM-fabricated Co-Cr frameworks may exhibit better passive fit compared with CAD/CAM-fabricated zirconia frameworks. Even so, similar levels of stress were achieved for CAD/CAM-fabricated frameworks. CAD/CAM may be used to achieve accurate passivity in implant-supported fixed denture prosthesis.

Resumo

O objetivo desta pesquisa foi avaliar a passividade através da medição da tensão induzida e adaptação passiva em infra-estruturas parafusadas sobre pilares, confeccionadas por tecnologia CAD/CAM, e comparar estas amostras com peças fabricadas por fundição convencional. Usando a tecnologia de CAD/CAM, quatro amostras foram feitas em zircônia (ZirCAD) e quatro amostras foram fabricados em cobalto-cromo (CoCrcad). Os grupos controle foram quatro espécimes de cobalto-cromo, feitos por fundição em monobloco (CoCrci), totalizando 12 infra-estruturas. Para avaliar a adaptação passiva, a diferença vertical entre a infraestrutura e o pilar protético foi medido em microscopia eletrônica de varredura (250 ×) quando apenas um parafuso foi apertado. A tensão média nestas infraestruturas foi analisada através do teste de fotoelasticidade. Foi observada uma diferença significativa na passividade entre os grupos controle e demais amostras. CoCrcad exibiu melhor valor de adaptação passiva (48,76±13,45 mm) e CoCrci o pior (187,55±103,63 mm), Zircad apresentou um valor intermediário (103,81±43,15 µm). Quando comparado com os outros grupos, CoCrci apresentou a maior tensão média ao redor dos implantes (17,19±7,22 kPa). Concluiu-se que a tecnologia CAD/CAM exibiu maior passividade em comparação com as infraestruturas confeccionadas pela técnica convencional. Infraestruturas confeccionadas em Co-Cr através do CAD/CAM apresentaram maior adaptação passiva em comparação com as amostras confeccionadas por CAD/CAM em zircônia. Entretanto, níveis de estresse similares foram obtidos para as estruturas fabricadas por CAD/CAM.

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Received July 2, 2014
Accepted March 16, 2015