UNIVERSIDADE DE SÃO PAULO
FACULDADE DE ODONTOLOGIA DE BAURU

MILENA STELUTI MARQUES

**Complete-arch implant-supported frameworks produced by different
manufacturing techniques and materials: a stress deformation and internal
fit analysis**

**Infraestruturas para próteses totais sobre implantes confeccionadas por
diferentes métodos e materiais: análise das deformações geradas na região
peri-implantar e da adaptação interna**

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DEDICATÓRIA

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“Your work is going to fill a large part of your life, and the only way to be truly satisfied is to do what you believe is great work. And the only way to do great work is to love what you do.”

Steve Jobs

ABSTRACT

ABSTRACT

Complete-arch implant-supported frameworks produced by different manufacturing techniques and materials: a stress deformation and internal fit analysis.

Statement of problem: With the variety of materials and techniques available, the knowledge of which combination provides frameworks with a better biomechanical behavior and greater fit accuracy is essential for a planning aiming prosthesis longevity.

Purpose. To analyze which manufacture technique and material provides a better stress/strain and internal fit correlation.

Material and methods. The groups were divided according to framework material and fabrication method: Titanium milled (TiCAD), Zirconia milled (ZrCAD), Cobalt-Chromium alloy milled (CoCrCAD), one-piece casting CoCr alloy (CoCrCAS) and cast and welded CoCr alloy (CoCrWEL). Four external hexagon implants and their respective mini-abutments were placed parallel to each other in a polyurethane model. This model was duplicated, scanned, and a single framework design was created to be used for all milled groups. Casting was done from a wax milled pattern following the same framework design used for the other groups. In preload condition, the strains generated by each framework were recorded by strain gauges fixed around the implants. The internal fit was evaluated by micro-CT scanning.

Results. Regarding the uniformity of stress distribution, ZrCAD and CoCrCAD groups presented irregular stress distribution, while TiCAD presented the most uniform distribution. Regarding the internal fit, the TiCAD group presented values significantly better than the others, but not statistically different from ZrCAD. The three manufacturing methods associated to CoCr alloy presented no statistical differences among them. The correlation between the method was statistically significant.

Conclusion. The physical and mechanical properties of the complete-arch implant-supported frameworks materials influence the stresses distribution and internal fit. TiCAD presented the best framework stress/strain ratio and internal fit.

Key words: Implant-Supported Dental Prosthesis. Computer-Aided Design. Mechanical Stress. Dental Alloys. X-Ray Microtomography.

RESUMO

RESUMO

Infraestruturas para próteses totais sobre implantes confeccionadas por diferentes métodos e materiais: análise das deformações geradas na região peri-implantar e da adaptação interna.

Afirmação do problema. Diante da variedade de materiais e técnicas disponíveis, ter o conhecimento de qual combinação proporciona infraestruturas com um melhor comportamento biomecânico e maior precisão na adaptação é essencial para um planejamento visando a longevidade da prótese.

Finalidade. Analisar qual material e método de confecção das infraestruturas proporciona a melhor relação tensão/deformação e adaptação interna.

Material e métodos. Os grupos foram divididos de acordo com o material e forma de confecção das infraestruturas: fresado em Titânio (TiCAD), fresado em Zircônia (ZrCAD), fresado em Cobalto Cromo (CoCrCAD), CoCr fundido em monobloco (CoCrCAS) e CoCr fundido e com ponto de solda (CoCrWEL). Quatro implantes hexágonos externos e seus respectivos mini-abutments foram colocados paralelos entre si em um modelo de poliuretano. Este modelo foi duplicado, digitalizado e um único desenho de infraestrutura foi criado para todos os grupos fresados. Para fundição, foi utilizado um padrão de cera fresado a partir do projeto usado nos outros grupos. Na condição de pré-carga, as tensões geradas por cada infraestrutura foram registradas por *strain gauges* fixados ao redor dos implantes. A adaptação interna foi avaliada através de escaneamento por micro-CT.

Resultados. Quanto a uniformidade na distribuição das tensões, os grupos ZrCAD e CoCrCAD se apresentaram irregulares, sendo que o grupo TiCAD apresentou distribuição mais uniforme. Quanto à adaptação interna, o grupo TiCAD apresentou valores significativamente melhores que os demais, mas sem diferença estatística em relação ao grupo ZrCAD. As três formas de produção da infraestrutura usando a liga de CoCr não apresentaram diferenças estatísticas entre si. A correlação entre os métodos foi estatisticamente significativa.

Conclusão. As propriedades físicas e mecânicas dos materiais de confecção das infraestruturas influenciam na distribuição de estresses e na adaptação interna. O grupo que apresentou a melhor relação tensão/deformação e adaptação foi o grupo TiCAD.

Palavras chave: Prótese Dentária Fixada por Implante. Projeto Auxiliado por Computador. Estresse Mecânico. Ligas Dentárias. Microtomografia por Raio-X.

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1 INTRODUCTION

1 INTRODUCTION

Although titanium implants osseointegration was first described by Branemark in 1969¹, the techniques and researches related to implantology continue in constant progress, giving support to the growing number of clinical resolutions associated to this treatment.²

For total edentulous patients' rehabilitation, the mandibular implant-supported fixed complete denture is a highly predictable and favorable treatment.³ It consists in a complete-arch implant-supported prosthesis, with a framework cast or milled usually in a metal alloy, covered by acrylic resin or ceramic to replace teeth. In addition to restore the functional capacity and presenting a high clinical success rates⁴, this treatment can – based on patient perspective of satisfaction, oral and general health-related quality of life⁵ – be considered the best rehabilitation method for this clinical situation.

Nevertheless, although factors such as success, reliability and effectiveness of treatments with implants and implant-supported prosthesis were well elucidated in the literature, scientific investigations must be conducted in order to seek evolution both in the techniques and materials used, as in the treatment longevity.

Many aspects have been studied relative to implant biomechanics, that is, the way by which stresses are transferred to the system and related factors, for example: means to optimize the functional stresses transmission to the bone, improving the strain distribution on implants/abutments/prosthesis; and the importance of the frameworks passive fit. The lack of control of these factors have been considered the reason for failures of this treatment type.⁶

Frameworks marginal fit and their passivity seat are considered essential prerequisites to prosthesis success and longevity.⁷ The combination of horizontal and vertical misalignments lead to nonuniform distribution of compressive and tensile forces to bone-implant-prosthesis system, resulting in several complications.^{8,9}

Such complications can be specified in two categories: technical and biological. The first is a collective term for mechanical damage that can affect implants, abutments and prosthesis. Torque loss, loosening or fracture of prosthetic fixation or abutment screws and veneering material chipping or fracture are the most frequent examples of technical or mechanical complications.^{4, 10, 11, 12}

Biological complications refer to disorders that affect peri-implant bone support, as adverse reactions to hard and soft tissues.^{9, 12} From the biological point of view, the microgap

between implant and abutment, or abutment and prosthesis, can serve as a septic reservoir that initiate and perpetuate an inflammatory response with mucositis development potential, or even advancement to peri-implant bone loss. Also related to restoration misfit and a possible trauma, the hyperplasia or hypertrophy of the soft tissues is frequently reported.^{4, 10, 12, 13}

Such complications may not result in implant loss or prosthesis replacement, however, a significant amount of repair and maintenance becomes necessary, as well as the clinical time and costs spent by both patient and dentist increase. The dentist should then give due attention to these consequences.¹²

Passive fit is defined by several authors as the simultaneous circular contact of the prosthesis and their respective abutments, not inducing any tension on these and surrounding bone in the absence of an applied external force.^{8, 14, 15}

However, other studies have reported that this does not seem to be possible, since besides an unavoidable imprecision due to the frameworks manufacturing process and material dimensional changes^{16, 17}, there is the preload – the force responsible to keep the parts together that results from the torque applied to the screws.^{18, 19} Therefore, deformation levels close to zero do not necessarily represent a desirable condition, since it would indicate that the system components are completely separate, not transmitting any force between them and overloading the screws.

Nevertheless, a specific range of marginal fit that may be considered clinically acceptable has never been established in the literature²⁰, leaving to the professionals the task to obtain the best possible fit of their prosthesis.

The material used to produce the prosthetic framework is essential to the clinical success, since it influences biomechanics and stress levels propagation during use.^{16, 21, 22, 23}

For each situation, properties such as elastic modulus, tensile strength, ductility and Vickers hardness should be considered for the most appropriate material choice.²⁴ Over the years, different materials have been used to prosthesis framework manufacturing. Among them are noble metal alloys, basic metal alloys and ceramic materials.^{24, 25}

At first, noble metals as gold, silver, palladium and platinum were chosen.²⁴ However, considering that factors as cost (a new material have the same function that the old one, but at a lower cost), performance (new material performs better in some desirable aspect such as physical properties or processing method), and aesthetics (the new material has better aesthetic characteristics) stimulate innovations in dental prosthetic materials, several materials as the basic metal alloys and ceramics have gained their space.²⁶

With significantly lower cost and improved mechanical properties, alloys composed of basic metals combinations like nickel, chromium, cobalt, iron and others begun to be used. Compared to noble alloys, they have higher hardness and elastic modulus, which means that they deflect less than the first. The disadvantage of high hardness is related to laboratorial difficulties in casting and adjustment procedures.²⁵

Regarding the basic alloys, although patients allergies related to nickel are documented²⁷, Nickel-Chromium alloys casting is still widely done. A viable alternative for its biocompatibility and for having the options of casting or milling blocks by a CAD/CAM system, is the use of Cobalt-Chromium alloys.^{28, 29}

Another alloy that allows both casting and milling is Titanium. In addition to its relative low cost, it also presents properties that makes it ideal for dental use. When in contact whit air a titanium dioxide protective layer is created that is responsible for its excellent biocompatibility and high resistance to corrosion. This makes titanium very stable in the human body.^{25, 30}

The pressure for highly aesthetic restorations, associated to the CAD/CAM technology advent, led to the use of Zirconia structures in implantology.^{31, 32} Approximately 3% mol of yttrium oxide are added in order to stabilize Zirconia in its tetragonal phase and maintain its superior properties at ambient temperature.³³ For this reason, tetragonal zirconia polycrystalline (Y-TZP) is a possible alternative to metal alloys.³⁴ In addition to the mechanical properties as high flexural strength, hardness and elastic modulus comparable to stainless steel^{35, 36}, it still has advantages as excellent biocompatibility, chemical and dimensional stability and low biofilm adhesion.³⁷ However, because of lacking long-term clinical studies, caution is advised regarding extensive restorations planning.³²

Relative to fit, to seek a framework with a greater precision some techniques have been proposed.¹⁷ One technique basically consists on steps addition – for example in conventional lost wax technique – in which sectioning, replacement and welding are performed aiming at a better piece refinement.³⁸ Or on the contrary, eliminating steps by the use of CAD/CAM (computer-aided design e computer-aided manufacturing) system³⁹ or other prototyping methods – which avoid or eliminate some clinical and laboratory procedures as waxing, inclusion and casting, thus having less influence of materials dimensional changes.^{17, 40}

The literature has reported that CAD/CAM – which was initially designed to optimize the prosthetic structures production⁴¹ – produces restorations with greater precision than those made by conventional techniques as casting.^{34, 42, 43} Such results can be attributed to the fact that casting pieces go through a larger number of steps, which in addition to being more

vulnerable to human bias and dental technician skill, are also more susceptible to the materials dimensional changes.²⁵

Since adaptation depends both on material and framework manufacturing method, added to the fact that the prosthesis misfit influences the pattern and magnitude of stress distribution on bone-implant-prosthesis system⁴⁴, this study aims to analyze and compare the peri-implant bone region deformations and their correlation with the complete-arch frameworks internal fit produced by different materials through CAD/CAM or conventional lost wax technique.

Electrical linear strain gauges analysis added to micro-CT scanning were used to verify which manufacture technique and material provide better stress/strain and internal fit relation.

The null hypothesis is that there is no difference between the stresses amount developed from installation, neither of frameworks internal fit produced by different materials and manufacturing procedures.

2 ARTICLE

2 ARTICLE

The article presented in this Dissertation was written according to The Journal of Prosthetic Dentistry instructions and guidelines for article submission (Annex A).

COMPLETE-ARCH IMPLANT-SUPPORTED FRAMEWORKS PRODUCED BY DIFFERENT MANUFACTURING PROCESSES AND MATERIALS: A STRESS DEFORMATION AND INTERNAL FIT ANALYSIS

ABSTRACT

Statement of problem: With the variety of materials and techniques available, the knowledge of which combination provides frameworks with a better biomechanical behavior and greater fit accuracy is essential for a planning aiming the prosthesis longevity.

Purpose. To analyze which manufacture technique and material provide a better stress/strain and internal fit correlation.

Material and methods. The groups were divided according to framework material and fabrication method: Titanium milled (TiCAD), Zirconia milled (ZrCAD), Cobalt-chromium alloy milled (CoCrCAD), one-piece casting CoCr alloy (CoCrCAS) and cast and welded CoCr alloy (CoCrWEL). Four external hexagon implants and their respective mini-abutments were placed parallel from each other in a polyurethane model. This model was duplicated, scanned, and a single framework design was created to be used for all milled groups. Casting was done from a wax milled pattern following the same framework design used for the other groups. In preload condition, the strains generated by each framework were recorded by strain gauges fixed around the implants. The internal fit was evaluated by micro-CT scanning.

Results. Regarding stress distribution uniformity, ZrCAD and CoCrCAD groups presented irregular stress distribution, while TiCAD presented the most uniform distribution. Regarding the internal fit, the TiCAD group presented values significantly better than the others, but not statistically different from ZrCAD. The three manufacturing methods associated to CoCr alloy presented no statistical differences among them. The correlation between the method was statistically significant.

Conclusion. The material and manufacturing procedure that provided the best stress/strain ratio and internal fit was Titanium CAD/CAM milled.

Key words: Implant-Supported Dental Prosthesis. Computer-Aided Design. Mechanical Stress. Dental Alloys. X-Ray Microtomography.

CLINICAL IMPLICATIONS

Material and manufacturing procedure of complete-arch frameworks influence on their passivity seat and internal fit. Titanium milled framework showed superiority in both aspects, and may be the best alternative for that treatment.

INTRODUCTION

For total edentulous patient's rehabilitation, the implant-supported fixed complete denture is a high predictability and favorable treatment¹ which in addition to restore the functional capacity and presenting a high clinical success rate², can – based on patient perspective of satisfaction, oral and general health-related quality of life³ – be considered the best rehabilitation method for this clinical situation.

Although factors such as success, reliability and effectiveness of treatments with implants and implant-supported prosthesis were well elucidated on literature, scientific investigations must be conducted in order to seek evolution both in the techniques and materials used, as in the treatment longevity.

Many aspects have been studied relative to implant biomechanics such as means to optimize the functional stresses transmission to bone/implant/abutments/prosthesis system, and the importance of the frameworks passive fit.⁴

Frameworks marginal fit and their passivity seat are considered essential prerequisites to prosthesis longevity.⁵ A non-passive framework leads to nonuniform distribution of compressive and tensile forces to bone-implant-prosthesis system, resulting in several complications.^{6, 7}

Such complications can be divided in two categories: technical and biological. The first is a collective term for mechanical damage that can affect implants, abutments and prosthesis. Biological complications refer to disorders that affect peri-implant bone support, as adverse reactions to hard and soft tissues.^{7, 8}

Such complications may not result in implant loss or prosthesis replacement, however, a significant amount of repair and maintenance becomes necessary, as well as the clinical time and costs spent by both patient and dentist increase. The dentist should then give due attention to these consequences.⁸

The material or alloy type used to produce the prosthetic framework is essential to the clinical success, since it influences biomechanics and stress levels propagation during use.^{9, 10, 11}

Relative to manufacturing procedures, to seek a framework with greater precision, some techniques are proposed.¹² One technique basically consists on steps addition – as in conventional lost wax technique – in which sectioning, replacement and welding are performed aiming at a better piece refinement.¹³ Or on the contrary, eliminating or avoiding

steps like waxing, inclusion and casting by the use of a CAD/CAM (computer-aided design e computer-aided manufacturing) system.^{12, 14, 15}

The literature has reported that CAD/CAM method produces restorations with greater precision than those made by conventional techniques.^{5, 16, 17, 18} Such results can be attributed to the fact that casting pieces go through a larger number of steps, which in addition to being more vulnerable to human bias and dental technician skills, are also more susceptible to the materials dimensional changes.¹⁹

Since adaptation depends both material and framework manufacturing method, added to the fact that the prosthesis misfit influences on pattern and magnitude of stress distribution on bone-implant-prosthesis system²⁰, this study aims to analyze and compare the peri-implant bone region deformations and their correlation whit the complete-arch frameworks internal fit produced by different materials through CAD/CAM or conventional lost wax technique.

Electrical linear strain gauges analysis added to micro-CT scanning were used to verify which manufacture technique and material provide better stress/strain and internal fit relation.

The null hypothesis is that there is no difference between the stresses amount developed from installation, neither of frameworks internal fit produced by different materials and manufacturing procedures.

MATERIALS AND METHODS

Division of test groups:

The specimens were divided into 5 groups according to framework material and fabrication methods, as shown in table 1. (Figure 1)

Experimental model

An experimental polyurethane model was made (F16 resin; Axson) to simulate a human mandible. Polyurethane was the material of choice for being isotropic and for having an elastic modulus similar to human bone marrow.^{21, 22} For its manufacture, a U-shaped metal matrix was used to simulate the mandibular arch.

With the aid of a parallellometer, four external hexagon implants measuring 3.75mm x 11.5mm (SCW 3711 Strong SW; S.I.N. Sistema de Implante) were fixed on an acrylic plate, 14mm apart from each other considering their central point.

This set was positioned on the metal matrix where liquid polyurethane was poured to remain in intimate contact with the implants. The matrix was placed in a 20-pound pressure device while setting of the material (Bubble eliminator; Essence Dental VH) to ensure homogeneity. Mini abutments - regular platform 4.1mm; 4.8mm diameter (MA 4102 S.I.N. Sistema de Implante) were tightened to the implants at 20Ncm torque.

Test specimens obtainment

1- Master cast duplication

An implant transfer impression was performed in order to obtain an experimental model replica. Open tray transfer copings (S.I.N. Sistema de Implante) were tightened onto the abutments and splinted with dental floss and autopolymerized acrylic resin (Duralay; Realiance Dental Co). In order to minimize the dimensional changes, the resin was sectioned between the copings with a carborundum disc (Dentorium) and reunited with the same material (Figure 2).^{23, 24}

Transfer impression was performed with a plastic tray (n° 1; Morelli) previously opened in the regions of the implants, filled with polyvinyl siloxane material (Express XT; 3M) using the double impression technique.^{25, 26} After polymerization, abutment analogs (ANMA 4800; S.I.N. Sistema de Implante) were attached and Type IV dental stone (Durone IV; Dentsply)

was mixed according to the manufacturer's instructions and poured to obtain the working cast.

2- Specimens fabrication

2.1 – CAD/CAM technique

The model was scanned (Optimet Scanner DS6000; Optime Phototonics) and, after digitalized, sent to Exocad DentalCAD (Exocad) for frameworks design creation – the same for all specimens – according to the following measurements: 3.5mm (height) x 6mm (width) x 15mm of cantilever from the center of terminal implants. (Figure 3a)

In the CAM WorkNC (SKA) system, the framework's design and the material to be milled were selected (Figure 3b). The software itself established the milling strategy and drills that should be used. As soon as the material block and drills were positioned in the determined sequence by the software, the milling could be started (DM5, Technodrill milling machine).

For the Zirconia framework, due to the use of a pre-sintered block, the design dimensions on software were intentionally increased, predicting a 20% contraction from the sintering process. After milled, the specimen was sintered at approximated 1530°C in an automated oven, where the final shape, physical properties and resistance were achieved.¹⁹

2.2 Conventional one-piece casting technique

In order to present the same shape as the other specimens, the one-piece casting framework was first milled from a wax block (Vipi Block Wax; Vipi) and then invested and cast in CoCr alloy (Fit Cast Cobalto; Talmax) by the conventional lost wax technique.²⁷

After testing, this same framework was used for the next test group (welding).

2.3 Welding

Sectioning was made by a vertical cut in the framework middle region using a carborundum disc (Ninja 1; Talmax). The disc thickness itself created an approximately 0.6mm of space between the two fragments. Then, the parts were correctly positioned and fixed on the master cast, and stabilized with metal rods and autopolymerized acrylic resin (Pattern Resin LS; CG).

For the welding procedure, after placing the weld flow (Fluxo Fit; Talmax) on the sectioned area, the framework was uniformly heated by the torch flame (Draeger; Labor

Dental) and the solder (Solda Flex; Talmax) was applied, melt and flowed into the joint, filling the entire space. Cooling to ambient temperature occurred naturally.

Strain Gauges

When tensioned, every material undergoes a proportional elongation or deformation to the force applied to it (Hooke's Law). The strain gauge is an electrical device capable of measuring that deformation and to qualify the tension in traction (+) or compression (-).

To prepare the electric circuit, configured in $\frac{1}{4}$ of Wheatstone bridge, strain gauges (KFG -02-120-c1-11 Strain Gauges; Kyowa Electronic Instruments) were bonded on the polyurethane model to the mesial, distal, buccal and lingual sides of each implant^{28, 29, 30}, totalizing 16 linear strain gauges (Figure 4a)

The stress around the implants on the polyurethane indicates the stress induced by the framework to the peri-implantar bone.³⁰ These numerical values, recorded in microstrains ($\mu\epsilon$), are transmitted to a data acquisition board (Three modules NI9237; National Instruments) that, connected to a chassis (NIcDAQ-9172; National Instruments), receive the information as electrical signals and convert it to digital signals to be sent to a computer by USB 2.0 connection. These data were viewed on the screen through LabVIEW 8.1 software (National Instruments), which keep up with all the deformation values computed by each sensor during the experiment.

Performing the tests

To perform the tests, the specimens were positioned on the master model and titanium screws were manually tightened with a hexagonal key 1.2mm (S.I.N. Sistema de Implante) until there was resistance (Figure 4b). News screws were used for each specimen to avoid fatigue or wear interference.

Although it has been proved that changes on the tightening sequence of prosthetic retaining screw have no influence on final preload^{32, 33}, after the specimen was properly fixed, a manual torque controller (S.I.N. Sistema de Implante) was used to tighten each screw to 10Ncm torque, following the 1-4-2-3 implant sequence.

Data collection was initiated at screwing and finished 5 minutes later. At this time, the strain values measured by each strain gauge went through three distinct phases:

- Initial phase: Period in which the equipment is connected and the framework is positioned; a low magnitude variation occurs, with values equivalent to the sensitivity limit of sensors.
 - Intermediate phase: period between the tightening of screws and torque achievement; the
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deformation increases as a function of time.

- Final phase: the values stabilize and remain on a standard level.

For greater fidelity results, each specimen was tested four times.

Data analysis

Approximately 400 deformation readings were taken by each strain gauge per test, but only the last 100 - which represent the third phase (stabilization) - were taken into account and tabulated in Microsoft Excel 2010 to calculate the average values of each strain gauge.

The data were initially recorded in traction (positive values) and compression (negative values). However, considering that the research intention was to perform a quantitative analysis, and not a qualitative one, the tension signal was eliminated, and only absolute values were used.^{34, 35, 36}

Micro-CT scanning

By allowing a three-dimensional, non-destructive and non-invasive evaluation^{37,38}, the x-ray microtomography was the method of choice to measure the frameworks internal fit.

The quantitative and qualitative fit analysis was made through the volumetric measurement of the space between the internal connection areas of the frameworks to the abutments and the external face of the mini-abutments. It was assumed that the smaller the volume, the better the adaptation.

To reproduce that interface, the inner side of each framework was filled with a light body silicone (Express™ VPS Impression Material; 3M ESPE Dental) and the specimen was seated on the master cast analogues, providing a silicone filled interface (Figure 5a and b). The same tightening and torque sequence of the previous test was done. After polymerization, the light body silicone pellicles were carefully removed from analogues and mounted on a support (Figures 5c and d) to facilitate microtomography scan.

At the desktop X-ray microfocus CT scanner (SkyScan 1174v2; SkyScan), the light body silicone pellicles were scanned using 50kV X-ray tube voltages, 800μA anode current and voxel size of 14 μA, over 360° degrees (1 complete rotation).

After scanning, the image files acquired were reconstructed using NRecon v1.6.10 (SkyScan) software, and the volume of each pellicle was quantified through CTscan v1.11.10.0 (SkyScan) software.

A 3D image of the pellicles and their visualization on coronal, sagittal and transaxial planes were possible with the SkyScan DataViewer 1.5.1.2. software. (Figure 6)

Statistical analysis

The variables tension and fit were grouped into tables and, after verifying data normality (Shapiro Wilk test), were submitted to statistical analysis at a 5% significance level.

- Strain values analysis: Two-way analysis of variance (ANOVA) followed by the Tukey test.
 - Pellicles volume analysis: Kruskal Wallis test followed by Tukey test.
 - Dependent variables correlation: Pearson correlation coefficient.
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RESULTS

Table 2 shows the strain values averages in each studied group. Analyzing the stress distribution uniformity provided by each framework to the system, it can be observed that ZrCAD and CoCrCAD groups (both with implants 2 and 4 with divergent letters) distribute stresses in a lesser uniform pattern than TiCAD (^{abcd} coincident), CoCrCAS (^a coincident) and CoCrWEL (^d coincident) groups.

Although not statistically relevant, TiCAD group presents the largest number of coincident letters (abcd), which is an indication of a more uniform strain distribution to the system.

Regarding the strains on peri-implant area, by the sum of mean values of each implant, it can be noticed that the group with the largest total was the ZrCAD (152,50µε), followed by CoCrWEL (135,60µε), TiCAD (102,21µε), CoCrCAD (95,11µε), and CoCrCAS (70,88µε) groups in decreasing order.

The volume means values of the scanned silicon pellicles are shown in Table 3. The Tukey test showed that the TiCAD group pellicles volume was significantly lower than the CoCrCAD, CoCrCAS, CoCrWEL groups, but not different when compared to ZrCAD. The ZrCAD volume values were statistically lower only when compared to CoCrCAS – which demonstrated the worst result.

The three manufacturing techniques used in combination with the CoCr alloy – CoCrCAD, CoCrCAS and CoCrWEL – did not show significant differences among each other.

In order to analyze which framework provides the best strain/deformation ratio and internal fit, Pearson's correlation coefficient was performed on the obtained values of strain and microCT tests (Table 4). In general, the correlation between the methods was statistically significant ($p < 0.033$) and negative (-0.238), which means that the variables were inversely proportional. In other words, as higher the strain values, the lower are the pellicles volume, with the reverse being true as well.

Analyzing the groups individually, among those with a significant correlation, TiCAD (-0.551) presented a moderate correlation, while ZrCAD (-0.835) presented a strong correlation, both being also negative.

DISCUSSION

Considering that both material and frameworks manufacturing methods had an influence on internal fit and on strain quantity and uniformity developed on system, it was concluded that the null hypothesis was rejected.

Several studies have reported that when load is applied to the system, independently of the bone type ³⁹, implant design ⁴⁰, restoration type ⁴¹ and type of load ⁴², the highest stress concentration and deformations occurs at bone crest region – the cervical area of implants. ^{28,29,43,44} For this reason, this area was chosen for strain gauges fixation.

Although the strain gauges were positioned on mesial, distal, buccal and lingual implant regions, as already described in previous studies ^{14, 28, 29, 30}, this study considered the average of strain values obtained by the 4 sensors. This analysis seems more relevant, since the purpose was to analyze the stress distribution uniformity and correlate it with fit. The same reasoning was used to frameworks misfit, since the pellicle total volume was considered.

Regarding the study method, the strain gauge analysis has been widely used to correlating the misfit effect on peri-implant deformations, and to elucidate the deleterious implications that the absence of framework passivity causes in bone tissue around the implants. ^{9, 35, 45} In addition to this methodology, photoelasticity and finite elements analysis can also be used as alternatives, with studies indicating agreement between the results obtained by these three analysis types. ^{46, 47}

The load transfer and strain distribution among the implants, abutments, prosthesis and bone structure depend on each components mechanical properties. ¹¹ The materials mechanical properties study is based on strains and their consequences, that is, tension and deformation properties.

The elastic modulus (E) - the ratio of tensile stress to deformation - justifies why different materials respond differently to load application. Which means that, under a given load, the different elastic modulus and rigidity of the frameworks result in distinct amount and pattern of tensions distributed by the system. ^{48, 49}

Regarding the stress distribution uniformity, finite element studies ^{20, 50} show that when an ideal fit is assumed, stresses are evenly distributed throughout the system, producing a minimum effort on each component. Analyzing this study results, the frameworks milled in Ziconia (ZrCAD) and Cobalt Chromium alloy (CoCrCAD) presented the highest values of peri-implant deformations, and a nonuniform strain distribution among implants. In both

groups, the settlement achieved on implants 1 and 3 were statistically different from those found on implants 2 and 4. Both results corroborate with other studies^{49, 51}, which also demonstrated higher intensity and worse stress distribution in CoCr milled frameworks.

Such results may be associated with materials mechanical properties. The sintered Zirconia has the highest E - 200GPa, Vickers hardness of 1200Hv and density 6,05g/cm³⁵², followed by CoCr alloy, with respectively 183 GPa, 273Hv and 8,5g/cm³.⁵³

The high rigidity of both materials result in low rates of deformation. Therefore, at the slightest misfit, the frameworks made by these materials do not bend to seek a better fit during the prosthesis tightening. Then, part of the tensions are transmitted to other structures (screws, abutments) with a higher intensity, ultimately being directed to the bone tissue.

Considering the conventional lost wax technique frameworks, the CoCrCAS group followed by CoCrWEL group presented the lowest peri-implant deformation values. Associating the fact that they presented the worst internal fit values, and that their E is about 663MPa (Talmax), it is supposed that the large space found between the framework and the abutment compensates for its low rate of deformation resulting in less stress transmission. However, this apparent advantage is undermined by the fact that it results in a poorly fit framework that allows washing into its components and prosthesis fixing screws overload.

The Titanium milled framework (TiCAD) presented the best fit values, greater uniformity in stress distribution and intermediate amounts of tension transmitted to peri-implant area. These better results can also be justified by the alloy mechanical properties. With elastic modulus of 114GPa and density of 4,43g/cm³ - considerably lower than the other materials, the milling by CAD/CAM system becomes easier, resulting in a better internal fit and consequently in a better strain transmission and distribution. Other studies^{54, 55} also reported better Titanium framework strain distribution and passivity when compared to other metal alloys.

Although several studies of implant-supported prosthesis biomechanics have been performed, a consistent definition of passivity, considering the stress amount and fit quality, has not yet been established. What is known is that passivity is related to the prosthesis fit, and that passivity absence can jeopardize the treatment success. Abutments failures, peri-implant tissue changes and screw loosening or fracture are possible consequences of a higher misfit.^{50, 56}

However, an acceptable fit does not necessarily means that the prosthesis have a passive fit, once when all screws are tightened, the marginal fit is naturally achieved. The passivity is

more related to the system stress induction, and a bad fit ends up directing strain unevenly about the system components, overloading some of them.⁵⁷

Since that passive fit usually refers to assessments of framework's vertical axis fit⁵⁵ this study correlated the strain gauge analysis with the different materials internal misfit volume of abutment-frameworks interface.

Distinct methods are used to evaluate implant-supported prosthesis internal fit. The x-ray microtomography methodology⁵⁸ is the more recent and has been cited as the most appropriate method for internal fit restorations evaluation allowing a three-dimensional, non-destructive and non-invasive evaluation.^{37, 38, 59}

In this study, the tension tests and x-ray microtomography tests presented a positive correlation, showing that as higher the peri-implant deformation, the better the framework fit, with the opposite being true, that is, the worse the fit, less stress will arrive on bone. Other studies also reported this relationship^{60, 61}, concluding that the misadjustment may be responsible to the magnitude and distribution of stresses.

The Titanium milled framework (TiCAD) presented the best adaptation values. This result can be associated with the easiness to milling and finishing presented by this material for being less rigid and less dense when compared to other basic alloys. Other studies comparing material and manufacturing procedures of complete-arch implant-supported frameworks^{16, 62, 63} also show superiority of milled titanium frameworks.

Although presenting statistical superiority only when compared to the one-piece casting framework – which presented the worst result – the Zirconia framework presented the 2nd best adaptation. The sintering process may have influenced this result. The pre-sintered Y-ZTP blocks are milled 20 to 25% larger than the final dimensions and, after this step, sinterization is done to reach appropriate physical properties.¹⁹ At this phase, the framework shrinkage to the required dimension is still hard to control, with the dimensional changes being possible to occur in different directions^{64, 65}, thus resulting in poor fit accuracy.

Despite of showing good adaptation, the clinical success of Zirconia frameworks is confirmed by studies only in unitary and partial prosthesis.⁵⁷ Knowing that a systematic review verified that long and curved structures are subject to higher sintering distortion than short and straight ones⁶⁶, the results presented by Zr frameworks must be confirmed by further studies.

As for the CoCr alloy frameworks, the three manufacturing methods did not present statistical differences among them. Numerically, the best fit values were presented by CoCrWEL followed by CoCrCAD and finally, the one-piece casting CoCrCAS.

The worst result of milled CoCr framework compared to other machinable materials may be associated to the CoCr alloy properties. Its hardness (273Hv) and density (8,5g/cm³) can hamper the milling procedure, resulting in longer time for machining, more intense milling burs wear, and difficulties in the finishing procedures.

Analyzing the conventional lost wax casting method, the framework sectioning and welding promoted a better fit and higher strain values. Although the purpose of welding is precisely to overcome the casting imprecisions, welding benefits are not yet fully established. While one study show substantial improvements in adaption and strain distribution⁶⁷, others do not show a statistically significant difference after welding.^{45, 68}

In general, this study corroborates the literature, which has shown superiority or at least equivalence in CAD/CAM made frameworks when compared to the conventional method.⁶⁹ One possible explanation for this result is that the greater control and accuracy of procedures, besides the exclusion of steps vulnerable both to human bias and to materials dimensional changes, result in a better adaptation and settlement between the components.^{69, 70}

For future studies, it is suggested that strain gauges be applied not only in peri-implant area but also on the framework body. Thus, it would be possible to verify to which part of the system strains are being directed. Finite element analysis can also elucidate the framework's strain location.

Furthermore, stresses were recorded in preload condition, which means that if the frameworks were submitted to functional loads, significantly higher tensions could have been generated.²⁰ Therefore, axial and oblique load applications are needed to understand the biomechanical behavior of frameworks produced by each material/production method.

CONCLUSIONS

According to the present in vitro study, it can be concluded that:

- Material and manufacturing procedure both influence strains and internal fit of the frameworks; the welding procedure in a CoCr casting framework did not promote significant improvement these variables.

- Analysis method: strain gauge analysis and microCT scanning are appropriate methodologies to evaluate strain and internal fit association; a correlation was found between the two methods.

- Tension distribution was more uniform among the implants in the TiCAD group, followed by CoCrCAS and CoCrWEL; the ZirCAD and CoCrCAD groups distributed the stresses in a non-uniformly.

- Internal fit: the TiCAD framework exhibited better fit than all CoCr groups, and an insignificant difference when compared to Zirconia framework; ZirCAD presented a significant better fit only when compared to CoCrCAS; all CoCr alloy frameworks presented a similar internal fit, which means that for this alloy, the manufacturing procedure did not have an influence on that variable; therefore, CAD/CAM frameworks accuracy was superior or at least equivalent to the conventional techniques.

- In general, the material and manufacturing procedure that provided the best stress/strain ratio and internal fit was Titanium CAD/CAM milled.

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LEGENDS FOR ILLUSTRATIONS

Figure 1 - From left to right: TiCAD, ZrCAD, CoCrCAD and CoCrWEL.

Figure 2 - Implants transfer impression for the experimental model replica.

Figure 3 - a) Framework design creation in the Exocad DentalCAD; b) Milling strategy in the CAM WorkNC (SKA) system.

Figure 4 - a) Strain gauges position; b) Specimen (CoCrCAD) on the master model

Figure 5 - a) Framework inner side filled with light body silicone; b) Specimen seated on master cast analogues; c) Light body silicone pellicles removal; d) Pellicles ready for micro-CT scanning

Figure 6 - 3D image pellicle visualization in the SkyScan DataViewer 1.5.1.2. software.

Fig 1

Fig 2

Fig 3a

Fig 3b

Fig 4 a and b

Fig 5 a, b, c and d

Fig 6

Table 1. Groups division

Group	Fabrication technique	Material	Brand name
TiCAD	Copy/mill	Titanium	Ti-Gr5; Zirwell
ZrCAD	Copy/mill	Zirconia $ZrO_2(3\%Y_2O_3)$	Vipi Block Zirconn; Vipi
CoCrCAD	Copy/mill	Cobalt-Chromium alloy	Magnum Splendium; MESA
CoCrCAS	One-piece casting	Cobalt-Chromium alloy	Fit Cast Cobalto; Talmax
CoCrWEL	Secction and welding	Cobalt-Chromium alloy	Fit Cast Cobalto; Talmax Solda Flex; Talmax

Table 2. Strain values analysis: Two-way analysis of variance (ANOVA) followed by the Tukey test.

Material	Implants			
	1	2	3	4
TiCAD	32.97 ± 2.15^{abcde}	30.64 ± 12.98^{abcde}	18.52 ± 5.54^{abcd}	20.06 ± 10.71^{abcd}
ZrCAD	39.05 ± 10.23^{bcde}	54.44 ± 3.14^e	41.06 ± 12.92^{bcde}	17.93 ± 1.41^{abcd}
CoCrCAD	19.83 ± 8.47^{abcd}	42.58 ± 17.12^{cde}	21.01 ± 8.18^{abcd}	11.69 ± 13.16^a
CoCrCAS	7.07 ± 2.72^a	33.06 ± 12.36^{abcde}	14.61 ± 7.51^{ab}	16.12 ± 8.46^{abc}
CoCrWEL	21.76 ± 11.04^{abcd}	41.00 ± 3.84^{bcde}	43.98 ± 18.02^{de}	28.84 ± 13.06^{abcde}

Stress ($\mu\epsilon$) means and standard deviation of each site per group. Values with the same superscript letter are not significantly different ($p < 0.05$).

Table 3. Pellicle volume analysis using micro-CT

Materials	Implants				Mean	Std. Dev
	1	2	3	4		
TiCAD	322.86	317.47	331.34	328.26	324.98	5.46
ZrCAD	336.73	321.32	340.59	352.15	337.70	11.38
CoCrCAD	350.60	343.67	342.90	350.60	346.94	3.79
CoCrCAS	337.50	345.21	371.41	365.24	354.84	14.38
CoCrWEL	328.26	339.82	362.16	348.29	344.63	12.77

Pellicles volume (mm³) means and standard deviation per group (p<0.05)

Table 4. Variables correlation

Group	Pearson's correlation	p
General	-0.238	0.033
TiCAD	-0.551	0.027
ZrCAD	-0.835	0.000
CoCrCAD	-0.475	0.063
CoCrCAS	-0.047	0.863
CoCrWEL	0.461	0.072

Results correlation between strain gauge and microCT tests. Pearson's correlation values and significance level ($p < 0,05$).

3 DISCUSSION

3 DISCUSSION

Considering that both material and frameworks manufacturing methods had an influence on internal fit and on strain quantity and uniformity developed on system, it was concluded that the null hypothesis was rejected.

The study of the load distribution on the peri-implant region is important to understand the biomechanical behavior of the prostheses and, consequently, for better treatment planning and longevity.^{45, 46}

Several studies have reported that when a load is applied to system, independently of the bone type⁴⁷, implant design⁴⁸, restoration type⁴⁹ and type of load⁵⁰, the highest stress concentration and deformations occurs in bone crest region – the cervical part of implants.^{51, 52, 53, 54} For this reason, this area was chosen for strain gauges fixation.

Although the strain gauges were positioned on mesial, distal, buccal and lingual implant regions, as already described in previous studies^{40, 52, 53, 55}, this study considered the average of strain values obtained by the 4 sensors. This analysis seems more relevant, since the purpose was to analyze the stress distribution uniformity and correlate it with fit. The same reasoning was used to frameworks misfit, since were considered the pellicle total volume was considered.

Regarding the study method, the strain gauge analysis has been widely used to correlating the misfit effect on peri-implant deformations, and to elucidate the deleterious implications that the absence of frameworks passivity causes in bone tissue around the implants.^{21, 31, 56} In addition to this methodology, photoelasticity and finite element analysis can also be used as alternatives, with studies indicating agreement among the results obtained by these three analysis types.^{57, 58}

The advantage of strain gauge analysis is the achievement of dynamic and static strains records, which can be used for quantitative and qualitative comparisons.^{57, 59}

Although this methodology provides the difference of compressive (negative signals) and traction forces (positive signals)^{57, 59} in this work only the absolute strain values were considered, since for our purpose, the amount of deformation undergone by specimens is more relevant than its type.^{31, 60}

The strains measurement can be made *in vitro*, *in vivo* or *ex vivo*.⁵⁸ The *in vivo* experiments are of extreme technical and biological difficulty. Besides having to incorporate

electrical sensors into intraoral devices, the bone physical properties vary according to the age, functional status and each patient's systemic factors.^{61, 62} Additional variables such as elastic modulus, bone density, implant stability and bone-implant contact (BIC) would also have to be considered.^{63, 64}

In *ex vivo* study, the use of fresh human cadaver mandibles becomes impracticable due to the difficulty to bond the strain gauges because of the bone humidity and oiliness.^{65, 66, 67}

Therefore, for this methodology, the use of a laboratory model it is possibly a more precise and standardized method to perform the tests and to achieve better results evaluation.⁵⁹

Aiming at this standardization, the polyurethane used in experimental model ensures uniform elastic properties (isotropic) and similar elastic modulus to human bone marrow, being appropriate for mandibular bone simulation.⁶⁸ Using a single model made with this material, it is possible to analyze how materials properties reflect on different frameworks performance and behavior.

The load transfer and strain distribution among the implants, abutments, prosthesis and bone structure depend of each components mechanical properties.¹⁶ The materials mechanical properties study is based on strain and their consequences, that is, tension and deformation properties.

Tension can be defined as the reaction of a given body to an external force or load by deformation (which can be elastic or plastic depending on the intensity/duration of the load).⁶⁹ According to Hooke's Law, such properties (tension/deformation) are proportional and have a cause-and-effect relation, which means that as higher the load, the greater the deformation.

The elastic modulus (E) is the ratio of tensile stress to deformation. As smaller the deformation suffered for a certain load, the higher the E, and thus more rigid is the material. In the same way, a low E material is more flexible, since the applied tension produces a more deformation.⁷⁰

This justifies why distincts materials responding differently to load application. Which means that, under a given load, the different elastic modulus and rigidity of the frameworks result in distinct amount and pattern of tensions distributed by the system.^{71, 72}

Another factor related to strain amount developed in the system from the implant-supported framework fixation is its level of accuracy. Any implant-prosthesis misfit may result in stresses on the restoration, the abutments, the retaining screws and/or bone tissue.^{44, 73, 74}

Regarding the stress distribution uniformity, finite element studies^{44, 73, 74} show that when an ideal fit is assumed, stresses are evenly distributed throughout the system, producing a minimum effort on each component. Analyzing this study results, the frameworks milled in Zirconia (ZrCAD) and Cobalt-Chromium alloy (CoCrCAD) presented the highest values of peri-implant deformations, and a nonuniform strain distribution among implants. In both groups, the settlement achieved on implants 1 and 3 were statistically different from those founded on implants 2 and 4. Other studies^{72, 75} also demonstrated higher intensity and worse stress distribution in CoCr milled frameworks.

Such results may be associated with materials mechanical properties. The sintered Zirconia has the highest elastic modulus - 200GPa, Vickers hardness of 1200Hv and density 6,05g/cm³⁷⁶ followed by CoCr alloy, with respectively 183 GPa, 273Hv and 8,5g/cm³.⁷⁷

The high rigidity of both materials result in low rates of deformations. Therefore, at the slightest misfit, the frameworks made by these materials do not bend to seek a better fit during the prosthesis tightening. Then, part of the tensions are transmitted to other structures (screws, abutments) with a higher intensity, ultimately being directed to the bone tissue.

Considering the conventional lost wax technique frameworks, the CoCrCAS group followed by CoCrWEL group presented the lowest peri-implant deformations values. Associating the fact that presented the worst internal fit values, and that their elastic modulus is about 145 GPa – 663MPa (Talmax), it supposed that the large space found between the framework and the abutment compensates for its low rate of deformation resulting in less stress transmission. However, this apparent advantage is undermined by the fact that it results in a poorly fit framework that allows washing into its components and prosthesis fixing screws overload.

The Titanium milled framework (TiCAD) presented the best fit values, greater uniformity in stress distribution and intermediate amounts of tension transmitted to peri-implant area. These better results can also be justified by the alloy mechanical properties. With an elastic modulus of 114GPa and density of 4,43g/cm³ - considerably lower than the other materials, the milling by CAD/CAM system becomes easier, resulting in a better internal fit and consequently in a better strain transmission and distribution. Other studies^{78, 79} also reported a better Titanium framework strain distribution and passivity when compared to other metal alloys.

Although several studies of implant-supported prosthesis biomechanics have been performed, a passivity consistent definition considering the stress amount and fit quality has not yet been established. What is known is that passivity is related to the prosthesis fit, and

that passivity absence can jeopardize the treatment success. Abutments failures, peri-implant tissue changes and screw loosening or fracture are possible consequences of a higher misfit.^{74,}

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However, an acceptable fit does not necessarily means that the prosthesis have a passive fit, since when all screws are tightened, the marginal fit is naturally achieved. The passivity is more related to system stress induction, and a bad fit ends up directing strain unevenly about the system components, overloading some of them.^{81, 82}

Since that passive fit term usually refers to assessments of framework's vertical axis fit⁸³, this study correlated the strain gauge analysis results with the different materials internal misfit volume of abutment-frameworks interface.

Regarding stability, the May KB 1998⁸⁴ study reported that an implant-abutment misfit has no effect on prosthesis, however, the same misadjustment between abutment and gold alloy cylinders can produce significant restoration instability.

Taking into account that in this study the frameworks were milled in homogeneous blocks, and the casting was first milled in wax, the use of cylinders was not necessary. Therefore, the misfit volume corresponded to the space between abutment and framework material itself.

Distinct methods are used to evaluate implant-supported prosthesis internal fit. The replica technique⁸⁵ is a well established methodology in the literature. However, due to limitations as the specimen sectioning⁸⁶, possible pellicle lacerations in well adapted faces⁸⁷, and because fit is measured at predefined points, not being possible to calculate the volume as a whole, other methods evolved.

The x-ray microtomography methodology⁸⁸ is the more recent and has been cited as the most appropriate method for internal fit restorations evaluation⁸⁹ allowing a three-dimensional, non-destructive and non-invasive way of evaluation.^{90, 91}

In this study, the tension tests and x-ray microtomography test values presented a positive correlation, showing that as higher the peri-implant deformation, the better the framework fit, with the opposite being true, that is, as worse the fit, less stress will arrive on bone. Other studies also reported this relationship^{14, 19}, in which authors state that the misadjustment may be responsible for the magnitude and distribution of stresses.

The Titanium milled framework (TiCAD) presented the best adaptation values. This result can be associated with the easiness to milling and finishing presented by this material for being less rigid and less dense when compared to other basic alloys. Other studies

comparing material and manufacturing procedure of complete-arch implant-supported frameworks^{42, 92, 93} also show superiority of milled titanium adaptation.

Although presenting statistical superiority only when compared to the one-piece casting framework – which presented the worst result – the Zirconia framework presented the 2nd best adaptation. The sintering process may have influenced this result. The pre-sintered Y-ZTP blocks are milled 20 to 25% larger than the final dimensions and, after this step, sinterization is done to reach appropriate physical properties.²⁵ At this phase, the framework shrinkage to the required dimension is still hard to control, with the dimensional changes being possible to occur in different directions^{94, 95, 96}, thus resulting in poor fit accuracy.

Despite of showing good adaptation, the clinical success of Zirconia frameworks is confirmed by studies only in unitary and partial prosthesis.⁹⁷ Knowing that a systematic review verified that long and curved structures are submitted to a higher sintering distortion than short and straighter ones⁹⁸, the results presented by Zr frameworks must be confirmed by further studies.

As for the CoCr alloy frameworks, the three manufacturing methods did not presented statistical differences among them. Numerically, the best fit values were presented by CoCrWEL, followed by CoCrCAD and finally, the one-piece casting CoCrCAS.

The worst result of milled CoCr framework compared to other machinable materials may be associated to the CoCr alloy properties. Its hardness (273Hv) and density (8,5g/cm³) can hamper the milling procedure, resulting in a longer time for machining, more intense milling burs wear, and difficulties in the finishing procedures.

Analyzing the conventional lost wax casting method, the framework sectioning and welding promoted a better fit and higher strain values. Although the purpose of welding is precisely to overcome the casting imprecisions, the welding benefits are not yet fully established. While some studies show substantial improvements in adaptation and strain distribution^{99, 100, 101}, others do not show a statistically significant difference after the welding.^{56, 102, 103}

In addition, besides weld manipulation variables such as a penetration failure in the welding space, and porosity in the joint region¹⁰⁴, for being composed of a different and lower melting point alloy, there is a higher corrosive potential and a possible weld joint resistance reduction^{105, 106}, thus resulting in a weakened structure in the welded area.¹⁰⁷

In general, this study corroborates with the literature, which has shown superiority or at least equivalence in CAD/CAM made frameworks fit when compared to the conventional method.³⁷ One possible explanation for this result is that the greater control and accuracy of

procedures, besides the exclusion of steps vulnerable both to human bias and to materials dimensional changes such as waxing, investing, casting and finishing, result in a better adaptation and settlement between the components.^{34, 39, 42}

Although it is not possible to directly associate the differences observed in this *in vitro* study to the clinical success rates, it is a professional duty to be aware and have the knowledge of the techniques and materials that provide greater accuracy in order to seek the maximum quality fit for the prosthesis.

For future studies, it is suggested that strain gauges be applied not only in peri-implant area but also on the framework body. Thus it would be possible to verify to which part of the system strains are being directed. Finite element analysis can also elucidate the framework's strain location.

Furthermore, stresses were recorded in preload condition, which means that if the frameworks were submitted to a functional loads, significantly higher tensions could have been generated.⁴⁴ Therefore, axial and oblique load applications are needed to understand the biomechanical behavior of frameworks produced by each material/production method.

4 FINAL CONSIDERATIONS

4 FINAL CONSIDERATIONS

According to the present *in vitro* study, it can be concluded that material and manufacturing procedure both influence strains and internal fit of the frameworks. The strain gauge analysis and microCT scanning are appropriate methodologies to evaluate strain and internal fit association, exhibiting correlation between the methods. The framework that produced the most uniformity of tension and the best fit was the Titanium milled. In general, CAD/CAM frameworks accuracy is superior or at least equivalent to the conventional techniques.

Although it is not possible to associate the differences observed in this *in vitro* study to the rehabilitations clinical success rate, it is a professional duty to be aware and have the knowledge of the techniques and materials that provide greater accuracy in order to seek the maximum quality fit of the prosthesis.

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ANNEXES

ANNEX A – Guidelines for The Journal of Prosthetic Dentistry:

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