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Luisa de Lanna Reis Rocha

Influência da distância de transferentes de escaneamento intraoral na adaptação marginal de estruturas fresadas: um estudo laboratorial in vitro.

Dissertação apresentada à Faculdade de Odontologia da Universidade Federal de Uberlândia como requisito parcial para obtenção do Título de Mestre em Odontologia na área de Clínica Odontológica Integrada.

2024

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Orientadora: Prof. Dra. Karla Zancopé

Banca Examinadora

Prof. Dra. Karla Zancopé

Prof. Dr. Carlos José Soares

Prof. Dr. Frederick Khalil Karam

Suplentes:

Prof. Dr. Flávio Domingues das Neves

Prof. Dra. Júlia Dantas Mazão

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UNIVERSIDADE FEDERAL DE UBERLÂNDIA

Coordenação do Programa de Pós-Graduação em Odontologia
Av. Pará, 1720, Bloco 4L, Anexo B, Sala 35 - Bairro Umuarama, Uberlândia-MG, CEP
38400-902

Telefone: (34) 3225-8115/8108 - www.ppgoufu.com - copod@umuarama.ufu.br



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Iniciando os trabalhos o(a) presidente da mesa, Dr(a). Karla Zancopé, apresentou a Comissão Examinadora e o candidato(a), agradeceu a presença do público, e concedeu ao Discente a palavra para a exposição do seu trabalho. A duração da apresentação do Discente e o tempo de arguição e resposta foram conforme as normas do Programa.

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Nada mais havendo a tratar foram encerrados os trabalhos. Foi lavrada a presente ata que após lida e achada conforme foi assinada pela Banca Examinadora.



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RESUMO

O desenvolvimento e utilização do sistema CAI/CAD/CAM (*Computer Aided Impression/ Computer Aided Design/ Computer Aided Manufacturing*) na Odontologia propiciou ao cirurgião dentista soluções rápidas e eficazes para diferentes reabilitações. Ao escanear implantes e/ou pilares, busca-se transferir o posicionamento tridimensional dos implantes da boca para o modelo virtual. Para isso, Transferentes de Escaneamento Intraoral (TEI) são utilizados. O objetivo do estudo foi identificar se a distância entre os TEIs influencia na adaptação marginal de estruturas fresadas obtidas por meio de um fluxo clínico-laboratorial digital. Para isso, três modelos inferiores com ausência dos elementos posteriores esquerdos foram preparados. Em um primeiro momento, foram instalados em cada modelo dois implantes (Helix GM 3.5 x 11.5, Neodent, Straumann) com as distâncias de 7, 14 e 21mm entre eles, medidas a partir do eixo central dos implantes. Em seguida, foram instalados Mini Pilares Cônicos (GM Conical Mini abutment 2.5, Neodent, Straumann) e os TEIs compatíveis com o sistema de implantes. Em um segundo momento, os escaneamentos foram realizados primeiramente utilizando scanner de laboratório (inEos X5, Dentsply Sirona) para o grupo controle. Os escaneamentos posteriores para os grupos testes foram realizados utilizando a câmera intraoral (Virtuo Vivo, Straumann). Os arquivos .STL (Standard Tessellation Language) foram exportados para o software (Geomagic Control X, 3D Systems, Version 2018.1.1) e as análises e comparações 3D dos grupos controle e teste foram realizadas. Os arquivos .STL foram enviados ao laboratório (D-Lab – Laboratório Digital), e um total de 5 estruturas de 3 elementos foram usinadas em liga de Cobalto-Cromo (Co-Cr) em cada grupo. Cada junção pilar-estrutura foi avaliada por meio de Microscopia Eletrônica de Varredura (Scanning Electron Microscope, Zeiss EVO MA10) e as desadaptações horizontais das faces mesial e distal de cada junção foram identificadas. Foram realizadas radiografias periapicais digitais padronizadas de todas as estruturas parafusadas nos mini pilares, o que permitiu uma comparação entre o nível de desadaptação visível nas radiografias e os resultados encontrados no MEV. As radiografias foram feitas com o Raio-X Digital Portátil (Diox, Micro Image), seguindo as instruções do fabricante. Os dados foram analisados (Rstudio, RStudio Team, 2024). Os testes estatísticos Shapiro-Wilk e Anova seguido de Tukey foram aplicados, admitindo $\alpha=0,05$ para comparação dos grupos estudados. Não houve diferenças estatísticas significativas entre os grupos estudados. Com as limitações do estudo, foi possível concluir que independente das distâncias testadas, os modelos virtuais foram precisos, as estruturas metálicas adaptaram-se adequadamente ao pilar protético e a radiografia digital pode ser um método confiável de análise da adaptação da estrutura.

PALAVRAS-CHAVE: Próteses e Implantes, Implantes Dentais, CAD-CAM.

ABSTRACT

The development of the CAI/CAD/CAM (Computer Aided Impression/Computer Aided Design/Computer Aided Manufacturing) system in dentistry has provided dentists with rapid and effective solutions for various rehabilitations. When scanning implants and/or abutments, the aim is to transfer the three-dimensional positioning of the implants from the mouth to the virtual model. For this purpose, Intraoral Scanbodies (ISBs) are used. The objective of the study was to determine whether the distance between the ISBs influences the marginal fit of milled structures obtained through a digital clinical-laboratory workflow. To this end, three lower models missing the left posterior elements were prepared. Initially, two implants (Helix GM 3.5 x 11.5, Neodent, Straumann) were installed in each model with distances of 7, 14, and 21mm between them, measured from the central axis of the implants. Then, multi units (GM Conical MultiUnit 2.5, Neodent, Straumann) and compatible ISBs were installed. In the next phase, scans were first performed by using a laboratory scanner (inEos X5 dental laboratory scanner, Dentsply Sirona) for the control group. Subsequent scans for the test groups were performed using the Virtuo Vivo intraoral camera (Straumann). The partial scanning files in the .STL (Standard Tessellation Language) extension were sent to an image software (Geomagic Control X, 3D Systems, Version 2018.1.1) where intraoral scans were compared with the control group, in the condition of mesh overlap. Then, the .STL files were sent to D-Lab – Digital Laboratory, and a total of 5 structures with 3 elements each were milled in a Cobalt-Chrome (Co-Cr) alloy for each group. Each multi unit-structure junction was evaluated using Scanning Electron Microscopy (Scanning Electron Microscope, Zeiss EVO MA10) and the horizontal misfits of the mesial and distal faces of each junction were identified. Standardized digital periapical radiographs were taken of all structures screwed onto the multi units, allowing for a comparison between the level of misfit visible on the radiographs and the results found in SEM. The radiographs were taken with the Portable Digital X-Ray (Diox, Micro Image), following the manufacturer's instructions. Data were analyzed using Rstudio (RStudio Team, 2024). Shapiro-Wilk and ANOVA tests followed by Tukey's test were applied, with $\alpha=0.05$ for group comparisons. No statistically significant differences were found between the groups studied. Within the limitations of the study, it was concluded that regardless of the tested distances, the virtual models were accurate, the milled structures fit the implant abutments, and digital radiography can be a reliable method for analyzing structure fit.

KEYWORDS: Prostheses and Implants, Dental Implants, Computer-Aided Design.

1. INTRODUÇÃO E REFERENCIAL TEÓRICO

A tecnologia digital na Odontologia tem evoluído rapidamente desde a introdução do fluxo digital e sistema CAI/CAD/CAM (*Computer Aided Impression/ Computer Aided Design/ Computer Aided Manufacturing*), o que possibilitou aos cirurgiões-dentistas desempenhar etapas clínicas e laboratoriais com menor demanda de tempo.¹⁻⁶ Os escaneamentos intraorais são uma etapa crucial na Implantodontia e a tecnologia permite a fabricação de restaurações suportadas por implantes de forma digital e precisa. Este método deve reproduzir cópias tridimensionais precisas de implantes e/ou componentes protéticos para que se tenha êxito no planejamento digital de próteses implantadas. A precisão dos escaneamentos é fundamental para garantir o sucesso do tratamento reabilitador protético e para a confecção de restaurações protéticas bem adaptadas.^{1,3,7-9}

Os Transferentes de Escaneamento Intraorais (TEI) podem variar em relação ao material, forma, tamanho, superfície, conexão, reutilização, compatibilidade com o scanner e custo. Esses geralmente consistem em três componentes: a região de escaneamento, o corpo e a base.¹⁰ A precisão da posição e inclinação do TEI é crucial para a transferência precisa do implante.^{4,5,11-13} É incerto se a distância entre os TEI no momento do escaneamento influenciará a adaptação marginal de estruturas fresadas obtidas por meio de um fluxo totalmente digital.

Em busca de melhores resultados na adaptação marginal de estruturas fresadas, torna-se necessário identificar alguns fatores que poderiam influenciar negativamente nas etapas de aquisição, e consequentemente no planejamento e manufatura das estruturas. Não há consenso sobre a adaptação marginal clinicamente aceitável. Alguns estudos indicam que um ajuste marginal de 150 μm (micrômetros) é clinicamente aceitável.^{7,14,15} Ainda outros discutem que um ajuste clinicamente aceitável deve ser 75 μm .¹⁶ Entretanto, ao analisar estruturas de ligas áureas, a desadaptação é inferior a 70 μm ,¹⁷ valor que norteou os valores de referência desse trabalho.

O presente estudo buscou identificar se a distância entre os TEIs poderia causar desadaptação horizontal nas faces mesial e distal de estruturas fresadas de dois e três elementos, parafusadas sobre Mini Pilares Neodent utilizando o método de Microscopia Eletrônica de Varredura e radiografias periapicais digitais.

2. CAPÍTULO 1 ARTIGO

Influence of intraoral scanning distance on marginal adaptation of milled structures: an in vitro laboratory study.

Artigo a ser enviado para o periódico The Journal of Prosthetic Dentistry

**INFLUENCE OF INTRAORAL SCANNING DISTANCE ON MARGINAL
ADAPTATION OF MILLED STRUCTURES: AN IN VITRO LABORATORY
STUDY.**

Rocha LLRR; Peixoto ACC; Santos FHPC; Neves FD; Zancopé K

Luisa de Lanna Reis Rocha, DDS^a, Ana Carolina Candelas Peixoto, DDS^b, Fabio Henrique de Paulo Costa Santos DDS, MS^c, Carlos José Soares, DDS MS PhD^d, Flávio Domingues das Neves, DDS MS PhD^e, Karla Zancopé, DDS MS PhD^f

^a MSc student. Department of Occlusion, Fixed Prosthodontics and Dental Materials, School of Dentistry, Federal University of Uberlândia, Uberlândia, MG, Brazil. Av. Pará, 1720, Bloco 4LA sala 4LA-42, Campus Umuarama, +55(34)3225-8105, Zip Code: 38405-320, Uberlândia, Minas Gerais, Brazil. ORCID: 0000-0003-1567-8001.

^b MSc student. Department of Occlusion, Fixed Prosthodontics and Dental Materials, School of Dentistry, Federal University of Uberlândia, Uberlândia, MG, Brazil. Av. Pará, 1720, Bloco 4LA sala 4LA-42, Campus Umuarama, +55(34)3225-8105, Zip Code: 38405-320, Uberlândia, Minas Gerais, Brazil. ORCID: 0000-0001-7973-5365.

^c PhD student. Department of Occlusion, Fixed Prosthodontics and Dental Materials, School of Dentistry, Federal University of Uberlândia, Uberlândia, MG, Brazil. Av. Pará, 1720, Bloco 4LA sala 4LA-42, Campus Umuarama, +55(34)3225-8105, Zip Code: 38405-320, Uberlândia, Minas Gerais, Brazil. ORCID: 0000-0001-5192-4690.

^d Professor. Department of Dentistry and Dental Materials, School of Dentistry, Federal University of Uberlândia, Uberlândia, MG, Brazil. Av. Pará, 1720, Bloco 4LA sala 4LA-42, Campus Umuarama, +55(34)3225-8105, Zip Code: 38405-320, Uberlândia, Minas Gerais, Brazil. ORCID: 0000-0002-8830-605X.

^e Professor. Department of Occlusion, Fixed Prosthodontics and Dental Materials, School of Dentistry, Federal University of Uberlândia, Uberlândia, MG, Brazil. Av. Pará, 1720,

Bloco 4LA sala 4LA-42, Campus Umuarama, +55(34)3225-8105, Zip Code: 38405-320, Uberlândia, Minas Gerais, Brazil. ORCID: 0000-0002-8676-302X.

^f Professor. Department of Occlusion, Fixed Prosthodontics and Dental Materials, School of Dentistry, Federal University of Uberlândia, Uberlândia, MG, Brazil. Av. Pará, 1720, Bloco 4LA sala 4LA-42, Campus Umuarama, +55(34)3225-8105, Zip Code: 38405-320, Uberlândia, Minas Gerais, Brazil. ORCID: 0000-0002-2205-9842.

Corresponding author:

Karla Zancopé

Department of Occlusion, Fixed Prosthodontics and Dental Materials, School of Dentistry, Federal University of Uberlândia, Uberlândia, MG, Brazil. Av. Pará, 1720, Bloco 4LA sala 4LA-42, Campus Umuarama, +55(34)3225-8105, Zip Code: 38405-320, Uberlândia, Minas Gerais, Brazil.

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ABSTRACT

Statement of problem: The precise position and inclination of the intraoral scanbodies (ISBs) are crucial for the accurate transfer of the implant. It is uncertain whether the distance between the ISBs at the time of scanning will affect the marginal adaptation of milled structures obtained through a fully digital workflow.

Purpose: The purpose of the study was to identify factors that may cause horizontal misfit of milled structures of three elements, screwed onto Conical Multi Unit using Scanning Electron Microscopy.

Material and Methods: The experimental setup comprised three partially edentulous Typodonts (MOM Manequins Odontológicos Marília) with three different distances—7, 14, and 21 mm—between the implant analogs, serving as the oral cavity model. The multi unit-structure interface was analyzed using Scanning Electron Microscopy (SEM) on 2 faces of the junction: mesial and distal. This allowed the identification of the degree of horizontal misfit present in the multi unit-structure junction. Digital periapical radiographs of all structures screwed onto the multi units were taken for a comparison between the level of misfit visible on the radiographs and the misfit results found in SEM. The data were analyzed (RStudio software, RStudio Team, 2024). The Shapiro-Wilk and ANOVA tests, followed by the Sidak post-hoc test, were applied with a significance level of $\alpha = 0.05$ for comparing the studied groups.

Results: No significant discrepancies were noted in the misfit averages of the models when comparing mesial and distal faces. Despite the absence of statistically significant differences between the averages, higher misfit values were evident in structures with a 21mm inter-implant distance. The absence of a significant difference between the means in the 3D comparisons between the control and test groups indicates that the precision of the intraoral scanner remained consistent, regardless of the variation in the distance between the implants. Digital radiography can be a reliable tool for assessing the adaptation of the milled structure to the implant abutment, providing valuable insights into the quality of implant-supported restoration.

Conclusion: Despite the study's limitations, it can be concluded that irrespective of the tested distances, the virtual models were accurate, the milled structures adapted well to

the implant abutment, and digital radiography proved to be a reliable method for analyzing structure adaptation.

Clinical Implications: The study supports the adoption of a fully digital workflow for rehabilitations with implant-based prostheses, which can enhance efficiency in clinical practice. Digital impressions and CAD/CAM technology streamline the process from scanning to manufacturing, potentially reducing chair time and improving patient comfort. Recognizing that the distance between ISBs does not significantly impact the accuracy of the digital workflow can simplify treatment planning and scanning procedures.

Introduction

Digital technology in dentistry has rapidly evolved since the introduction of digital workflows with the CAI/CAD/CAM system, allowing dentists to perform clinical and laboratory procedures with less time and effort.¹⁻⁶ Furthermore, intraoral scanners remove the need for impression materials, tray selection, and the process of shipping impressions to the dental laboratory, thereby enhancing patient comfort and reducing the time required for processing indirect restorations.^{4,5}

Additionally, intraoral scanning plays a crucial role in implant dentistry, enabling the digital and precise fabrication of implant-supported restorations. This method should accurately reproduce three-dimensional copies of implants and prosthetic components for successful digital planning of implant-based prostheses. The accuracy of scans is vital to ensure the success of prosthetic rehabilitation treatment and the fabrication of well-fitted indirect restorations.^{1,3,7-9} Intraoral scanbodies (ISBs) may vary in material, shape, size, surface, connection, reusability, compatibility with scanners, and cost. The precise position and inclination of the ISB are crucial for the accurate transfer of the implant. It remains uncertain whether the distance between ISBs at the time of scanning will affect the marginal adaptation of milled structures obtained through a fully digital workflow.^{4,5,11-14}

The passive fit of prostheses is essential to prevent adverse stress on the implants. Continuous uneven forces can cause biomechanical issues within the implant system, leading to component fatigue and bone strain. This can result in prosthetic and biological complications such as restoration loosening, bone loss around the implant,

premature failure of components, or peri-implantitis.^{8,11,15-18} In pursuit of improved results for the marginal adaptation of milled structures, it becomes essential to identify factors that may negatively influence the acquisition stages, thereby affecting the planning and manufacturing of the structures. Despite extensive research, there remains no consensus on clinically acceptable marginal adaptation, and the impact of inter-implant distances on the marginal adaptation of milled structures obtained through a fully digital workflow remains unclear.

While previous studies have primarily focused on the accuracy of intraoral scanners in implant dentistry,^{4,6-9,11,14} there is limited mention of studies investigating inter-implant distances. Numerous factors could influence the accuracy of this procedure, including scanning technology, clinician experience, scanning technique, the design and material of scan bodies, and the distance between them.^{1,2,12} Additionally, in vivo factors such as limited mouth opening, oversized tongue, and hypersalivation should be considered, as they can also influence accuracy.^{2,8}

Consequently, this study aimed to evaluate the impact of the distance between two implants on the surface distortion of models generated by ISBs, the misfit of milled structures, and to compare the level of misfit visible on radiographs with those found in Scanning Electron Microscopy (SEM). The null hypothesis posits that the distance between the ISBs during scanning does not influence the marginal adaptation of milled structures. The alternative hypothesis suggests that the distance between ISBs during scanning does influence the marginal adaptation of milled structures, potentially leading to treatment failures due to misfit.

Material and Methods

The present study followed a 1x3 factorial design. The study factor was the distance between the implants at three levels: 7mm, 14mm, and 21mm. Trueness, the response variable, was assessed using 3D analysis software (Geomagic Control X, 3D Systems, Version 2018.1.1). The sample size consisted of 30 specimens (N=5).

Typodont Preparation

Three partially edentulous Typodont (MOM Manequins Odontológicos Marília) with 3 different distances between implant analogs were used as the mouth model. For the

study, rehabilitation through implant-supported prostheses consisting of 2 and 3 elements, splinted together, and screwed onto two implants was chosen among various treatment options. Initially, 2 implants (Helix GM 3.5 x 11.5, Neodent, Straumann) were placed in each model with distances of 7mm, 14mm, and 21mm between them. The distance between implants was measured and confirmed using a digital caliper (Mitutoyo, Tokyo, Japan). The implants were secured with self-polymerizing acrylic resin (Acrylic Resin Pattern Bright Red, Kota) to stabilize the system and prevent implant movement during testing. Subsequently, abutments (GM MultiUnit 2.5, Neodent, Straumann) compatible with this implant system were installed with the recommended torque by the manufacturer (32N/cm).

Intraoral scanning

Intraoral scanbodies compatible with multi unit for the Neodent system were installed (see Figure 1). The bevel features of the implant scan bodies were deliberately positioned misaligned, as determined in a pilot study to be the preferred configuration.



Figure 1. Respectively, models and distances between implants: model 1 (7mm), model 2 (14mm) and model 3 (21mm).

The image acquisition stage was conducted in 2 phases. Initially, a dental laboratory scanner (inEos X5, Dentsply Sirona) was used for the control group. Subsequently, scans for all test groups were performed using an intraoral scanner (Virtuo Vivo, Straumann). Two transfers were scanned 10 times in each lower quadrant, with variations in the distance between each group (n=10). The scans were alternated between the groups. The scanning was performed according to the manufacturer's guidelines, starting from the posterior region of the right quadrant, following the arch along the occlusal surface, and performing zig-zag movements in the anterior teeth region. The process continued by scanning the buccal region and subsequently the lingual region. The resulting .STL files from the scanning were saved in a digital folder and sent to a dental laboratory (D-Lab Digital Excellence – Curitiba BR). This facilitated analysis to determine whether the distance between transfers influenced scan

quality and, consequently, the assembly of the virtual model and manufacturing of the structures.

Image analysis

After scanning all clinical situations, the partial scanning files in the .STL extension were sent to image software (Geomagic Control X, 3D Systems, Version 2018.1.1) for analysis, comparing intraoral scans with the control group under the condition of mesh overlap. The analysis followed these steps:

Initially, the main model was imported and segmented to create a partial model, which served as a reference. Each digital model was aligned with the reference model using the initial alignment tool. Sections approximately 2 mm below the gingival margin were removed from the digital models to improve the accuracy of measurements. These modified files were then aligned using the best fit tool, with the surrounding areas of the ISBs being clipped to reduce potential discrepancies. This procedure was performed consistently by an experienced software operator. The ISBs were compared in 3D using a color scale threshold of 0.5. The resulting data averages (AVG) were extracted and organized into tables using Microsoft Excel for further analysis.

Manufacturing of structures

After scanning all clinical situations, the arch files in the .STL extension were forwarded to DLab Digital Excellence in Curitiba, Brazil, for the manufacturing of structures. Five .STL files from each group were sent to the digital laboratory. Randomization was performed using the Random Integer Generator (Random.ORG) to select these five files from the ten scans conducted for each group.

A total of 15 Cobalt-Chromium (Magnum splendidum, MESA) structures were manufactured (Milling Machine Ultrasonic 20 Linear, DMG MORI), divided into 3 groups (n=5), each differing by the distance between the transfers. Following the CAI/CAD/CAM stages (Figure 2), the structures were secured onto the abutments (Figure 3) with a torque of 10N/cm, in accordance with the manufacturer's recommendations.



Figure 2. Digital planning of the milled structures.



Figure 3. Respectively, milled structures screwed onto the implant multi unit in the models with distances between the implants: model 1 (7mm), model 2 (14mm) and model 3 (21mm).

Microscopy Analysis

The multi unit-structure interface was examined by using a Scanning Electron Microscope (SEM, Zeiss EVO MA10) on two faces of the interface: mesial and distal, at 500x magnification and extra high tension of 10.00kV. This allowed for the identification of horizontal misfit present in the multi unit-structure junction. When analyzing gold alloy structures, the misfit is typically less than 70 μm ,¹⁷ a value that serves as a reference point in this study.

Radiographic Analysis

After the microscopic analysis stage, standardized digital periapical radiographs of all structures screwed onto the multi units were taken. This allowed for a comparison between the level of misfit visible on the radiographs and the misfit results found in SEM. The radiographs were taken with the Portable Digital X-Ray (Diox, Micro Image), following the manufacturer's instructions, ensuring that the portable X-ray device was perpendicular to the digital sensor, which was positioned behind the structures. The X-ray exposure time was 0.30 seconds, and the radiographs were taken in the same manner and position for all the structures.

To conduct the analysis in this study, the data was exported to the RStudio program (RStudio Team, 2024), where all statistical procedures were executed. Descriptive statistics were used to summarize and present the data in the form of box plots. Analysis of variance (ANOVA) was employed to compare the data obtained from the 3D comparison of the test and control groups, as well as the misfit measurements in micrometers (μm) obtained from the SEM images (on the mesial and distal faces for the 7, 14 and 21mm models).

For each model, 10 .STL files were obtained from the intraoral scans, and the mean distances were compared using ANOVA. From these files, five milled structures were fabricated for each model, analyzed by SEM on the mesial and distal junction faces, and compared by ANOVA.

In addition to the comparisons, the Spearman correlation coefficient was utilized to assess significant associations between the distances measured by the 3D comparison and the microscopic distances measured by the SEM. This coefficient not only identifies significant associations but also quantifies the strength and direction of the association. A positive correlation indicates that the variables follow the same linear trend, while a negative correlation indicates opposite trends. Correlation coefficients range from 0.00 to 1.00 and are denoted by the Greek letter ρ (rho). Typically, correlations are interpreted as follows: $\rho < 0.30$ indicates a weak correlation, $\rho > 0.31$ and < 0.50 suggests a moderate correlation, and $\rho > 0.70$ signifies a strong correlation.²⁰⁻²²

The significance level used in this study was $\alpha = 0.05$.

Results

The results of this study indicate that the comparison derived from the 3D comparisons of models with implants installed at distances of 7mm, 14mm, and 21mm, revealed no significant difference between the means (μm) ($F = 1.07$; $df = 2.00$; $p = 0.37$ and $\eta^2 = 0.15$), as depicted in Figure 4.

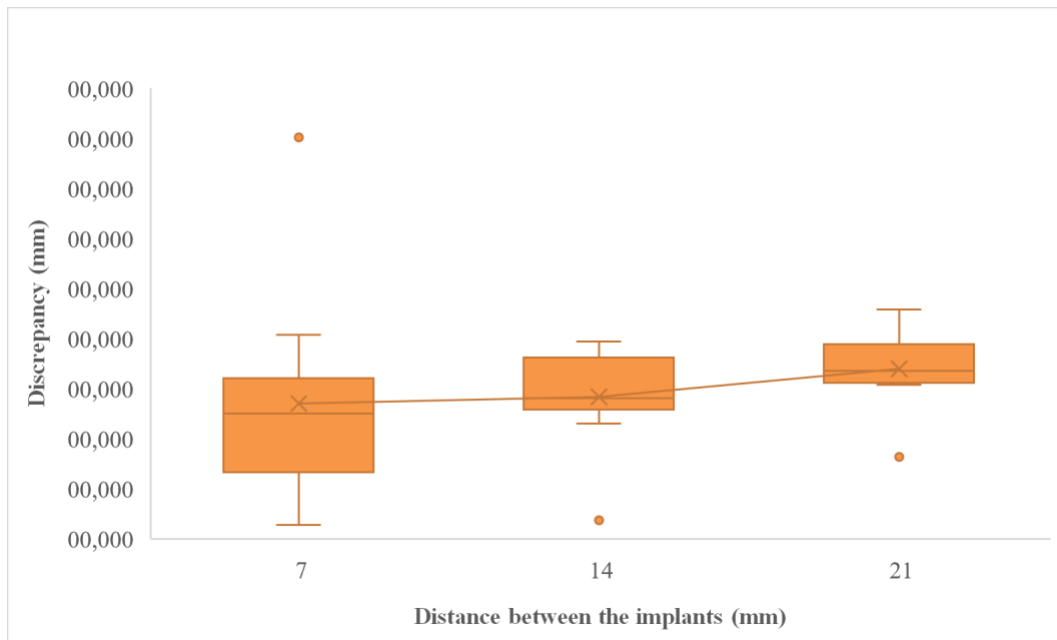


Figure 4. 3D comparisons and analysis of models by ANOVA.

Microscopy Analysis: The following comparisons pertain to the misfit values of the milled frameworks. No significant differences were detected in the model misfit averages in the comparisons between the mesial faces of tooth 34 of model 1 and 2 and 35 of model 3 ($F = 3.25$; $gl = 2.00$; $p = 0.07$ and $\eta^2 = 0.35$). However, the effect size can be considered large according to Figure 5. Similarly, the comparison in their distal measurements also revealed no significant differences ($F = 0.34$; $gl = 2.00$; $p = 0.72$ and $\eta^2 = 0.05$) in their mean misalignments, although the effect size is considered very small. Regarding mesial misfit measurements of the milled framework of tooth 35 in 7mm model, with tooth 36 in 14mm model and 37 in 21mm model, no significant differences were detected in their misfit means ($F = 2.76$; $gl = 2.00$; $p = 0.10$ and $\eta^2 = 0.32$), yet the observed effect size was large. Likewise, in the same measurement looking at the distal face, no significant difference was detected ($F = 0.93$; $gl = 2.00$; $p = 0.42$ and $\eta^2 = 0.13$), with a small effect size.

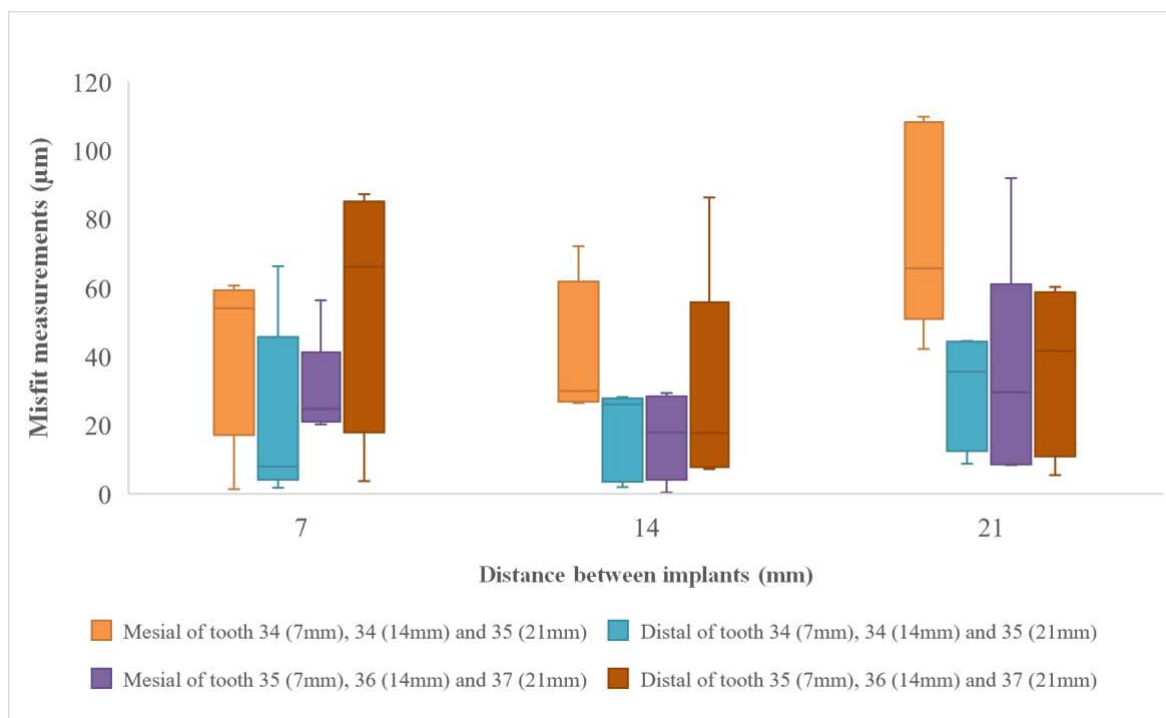


Figure 5. Comparisons of the mean mesial and distal misfit between the models by ANOVA ($p > 0.05$).

Radiographic Analysis: From the fifteen digital radiographs taken, it was feasible to correlate levels of misfit in five radiographic images of the milled structures screwed to the multi unit of the implants. The measurement of visible misfit in the radiographic image was correlated with the measurements of these respective structures obtained by SEM (Figure 6). The detection of misfit in the radiographs was done blindly by an observer different from the researcher. The measurements of misfit visible in the radiographs were performed using the ImageJ (ImageJ 1.x) software.²³ Pearson's correlation was conducted between the misfit values measured in the SEM and the radiograph of the same samples, revealing a strong positive relationship between the values (pearson's $r = 0.819$; $p = 0.045$). The misfit values in μm obtained by SEM and by radiographs of the structures are shown in Table 3.

Table 3. Misfit values in μm obtained by scanning electron microscopy (SEM) of the structures that were radiographically misfit.

Misfit MEV (μm)	Misfit Radio (μm)
87.26	5.29
82.91	3.3
8.,5	2.62
86.17	4.05
109.83	5.95

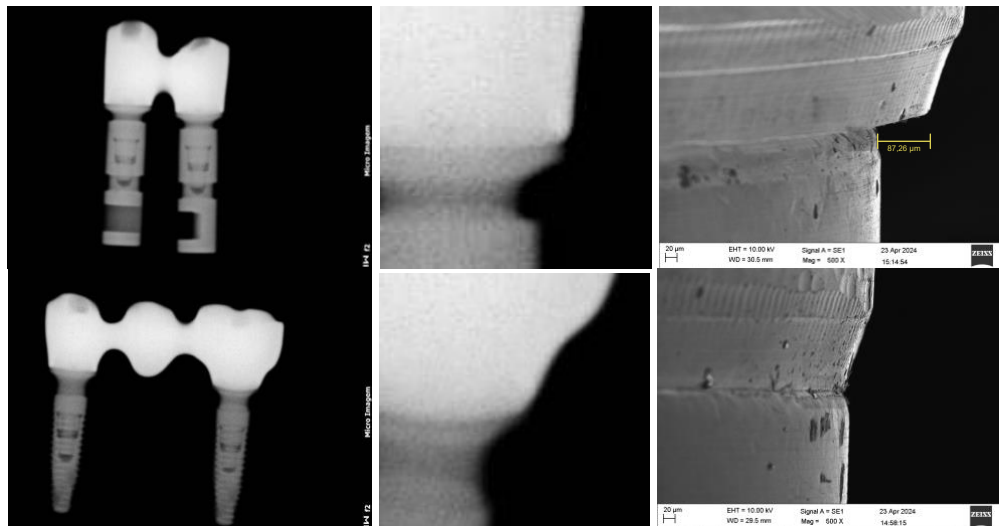


Figure 6. Respectively, in the radiograph and SEM image, example of milled structure misfit on the distal face of implant 35 (87.26 µm) and example of milled structure without misfit.

Discussion

The null hypothesis of this study was accepted. Despite some studies suggesting that the distance between scanbodies could affected the accuracy of virtual models and consequently the manufacturing of structures,^{4,5,11-14} the current investigation found that the distance between intraoral scanbodies during scanning have not influenced the marginal adaptation of milled structures in this study. Notably, one study concluded that the intraoral scanner tends to exhibit more error and less reproducibility at increased inter-implant distances.¹⁵ However, despite testing the same distances as the previously cited study,¹⁵ our findings indicate that there was no statistically significant difference in the accuracy of the scans and the adaptation of the milled structures.

To assess the accuracy of the intraoral scanner when scanning the three models with different distances, reference data were prepared using a high-precision scanner. The reference data were generated by the dental laboratory scanner (inEos X5, Dentsply Sirona). Precision measurement was conducted by aligning the test and reference models and superimposing the data. Incorrect model alignment indicates the translation error of the test objects compared to the reference objects.^{14,15} After aligning the models, 3D comparisons were performed between the control and test groups. Statistical analysis of these data revealed that there is no significant difference between the means. The absence of a significant difference between the means in the 3D comparisons between the control and test groups indicates that the precision of the intraoral scanner remained consistent, regardless of the variation in the distance between the implants.

In the microscopic examination of all milled structures conducted via Scanning Electron Microscopy (SEM), no significant discrepancies were noted in the misfit averages of the models when comparing the mesial and distal aspects. However, despite the absence of statistically significant differences between the averages, higher numerical misfit values were evident in structures with a 21mm inter-implant distance. This observation may be explained by prior research suggesting that increased scanning distances compromise the precision of the virtual model and consequently affect subsequent rehabilitation outcomes.^{4, 7, 11, 15, 18} Regarding the mesial misfit measurements, no statistically significant differences were observed, despite a notable effect size. This underscores the importance of meticulous analysis in discerning subtle variations and understanding the nuances of misfit in implant-supported restorations. Further investigation into the factors influencing misfit, such as scanning protocols and implant positioning, could provide additional insights into optimizing restoration accuracy and clinical outcomes.

In the radiographic analysis, it was observed that all misfits visible on the radiograph correspond to misfit values ranging between 81.5 and 109.83 μm (with a mean of 89.534 μm and a median of 86.17 μm). These values fall within a range described in the literature as clinically detrimental, as they can lead to complications in the gingival and osseous tissue, compromising peri-implant health and implant survival.^{16,17} These findings suggest that radiography can be a reliable tool for assessing the adaptation of the milled structure to the implant abutment, providing valuable insights into the quality of implant-supported restoration. This radiographic approach offers a non-invasive and widely accessible evaluation of prosthetic structure adaptation, complementing direct clinical measures and enabling a more comprehensive assessment of implant-supported restoration integrity.

This study has limitations. Firstly, a typodont was used for patient simulation, which differs from the actual conditions in a real patient's oral cavity and natural teeth. The in vitro design of this study introduces limitations compared to a clinical scenario. In a clinical setting, various factors can impact intraoral scanning results that are not replicated in an in vitro environment. For instance, patient movement, limited mouth opening, the presence of the tongue, and hypersalivation can significantly affect the accuracy of intraoral scans.^{2,8}

Furthermore, the radiographs were performed without adjacent teeth, which is a simplification when checking for misfits. In a real clinical scenario, adjacent teeth can

influence the seating and positioning of the prostheses, potentially leading to different outcomes in terms of fit and adaptation.

Therefore, while this study provides valuable insights, its findings should be interpreted with caution, considering the inherent differences between in vitro and in vivo conditions and the additional clinical factors that can impact intraoral scanning and prosthetic fit.

Conclusion

Despite the study's limitations, it can be concluded that regardless of the tested distances, the virtual models were accurate, and the milled structures adapted well to the implant abutments. Additionally, digital radiography emerged as a reliable method for analyzing structure adaptation.

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