BJOS
Brazilian Journal of Oral Sciences

Original Article

Volume 22
2023
e239079

# Use of scanning electron microscope to evaluate the marginal fit of protocol bars obtained through benchtop or intraoral digital scanners

Renês Augusto Parizotto[1,*], Vanessa Cavalli[2], Rafael Lacerda Zandoná[1], Geraldo Alberto Pinheiro de Carvalho[1], Aline Batista Gonçalves Franco[1], Elimario Venturin Ramos[1], Sérgio Candido Dias[1]

[1] São Leopoldo Mandic Dental School, Campinas, SP, Brazil.

[2] Piracicaba Dental School, University of Campinas, Piracicaba, SP, Brazil.

**Aim:** To evaluate the marginal fit of protocol bars milled from digital models obtained by conventional molding followed by bench scanning or digital molding with an intraoral scanner. **Methods:** Four morse-cone implants and the mini-pillars were installed in a 3D printed mandible model (master model). Digital models of the master model were obtained by (n=10): (Group A - Conventional) conventional (analog) molding of the master model followed by bench scanning or (Group B - Digital) molding of the master model with an intraoral scanner. All-on-four protocol bars were designed and milled from the digital models for both groups and screwed into the master model. Scanning electron microscopy (SEM) images from the distal, central, and mesial regions of each implant were obtained and the implant-protocol bar marginal fit was measured in an image software (Image J). The mean misfit of each region was analyzed by two-factor ANOVA, Tukey test, and Student's t-test (0,05 = 0.05). **Results:** The digital approach (B) showed higher misadaptation than the conventional approach (A, $p < 0.05$), regardless of the region evaluated. In group A, the central region showed higher maladjustment than the mesial region ($p<0.05$), however, there were no differences among regions of group B ($p>0.05$). **Conclusion:** The conventional method of acquiring digital models using the bench scanner produced bars for the All-On-Four protocol with better marginal fit than the digital models obtained with an intraoral scanner.

**Keywords:** Dental implants. Computer-aided design.

**Corresponding author:**
Renês Augusto Parizotto
São Leopoldo Mandic – Campinas, SP, Brazil
renesaugusto@hotmail.com

**Editor:** Dr. Altair A. Del Bel Cury

**Received:** April 22, 2022
**Accepted:** October 16, 2022

## Introduction

Studies show that patients undergoing partial or total rehabilitation with dental implants have a predictable and favorable success rate[1-3]. Nevertheless, after completion of the surgical procedure, the success of the treatment occurs only with the proper installation of the definitive prosthesis. However, the prostheses need to be made using a correct sequence and high-quality standard so that a passive and precise adjustment of the connection with the implant occurs[3], as the lack of adaptation of the prosthesis on the implant can generate minor consequences such as distortion and loosening of the fixation screw, to serious problems, as crown fractures or implant failure[4].

Passive fit is achieved by simultaneous contact between the structure and the implant or abutment surface. Therefore, this adaptation is essential to avoid stress accumulation at the bone/implant interface, preserving osseointegration and ensuring the longevity of the treatment[4]. In the search for the perfect fit, producing dental molds and/or implants with excellent precision became necessary. Therefore, high-quality molding became critical to the treatment sequence and, consequently, to achieving success[5].

In protocol-type prostheses, commonly used in full-arch rehabilitation, the position and angulation of the implants have meaningful influence and importance at the time of molding[6]. These variables influence the decision for the material type and the geometric shape of the bars, and the use of a material capable of absorbing and dissipating the stresses applied to the implants during function[7]. In this sense, the evolution of materials and molding techniques along with the evolution of intraoral scanners has raised concerns about which technique would be the best for acquiring the final model. For some reasons, such as financial, the first option for clinicians is still the conventional method (molding). But the decision depends on several factors since it requires a significant number of materials and techniques, generating a grander number of steps, increasing the demand for digital systems[8].

To determine whether the seating of the protocol-type bar occurs passively and without misfits, accurate tests must be performed to measure the presence of gaps in different regions of the prosthesis-implant connection. In this sense, the scanning electron microscope (SEM) is the tool commonly used to measure the accuracy of the gap generated between the connection of the prosthetic element with the surface of the abutment or dental implant, due to the precision of the analysis generated by the magnification of the image obtained[9].

In the face of the existing doubts and lack of consensus in the literature regarding the effectiveness of the benchtop scanner or intraoral scanner to determine the seating accuracy and adaptation of all-on-four protocol-type bars milled from virtual models, studies that evaluate the marginal fit of bars milled by both methods are required. Thus, the aim of this study was to evaluate, by means of scanning electron microscopy, the adaptation of milled protocol-type bars obtained after scanning with a benchtop scanner or intraoral scanner. The null hypothesis was that there would be no significant difference between the adaptation of milled protocol-type bars obtained after scanning with a benchtop scanner or intraoral scanner.

## Materials and Methods

The study was submitted to the Research Ethics Committee (CEP PROTOCOL 2018/0968) of the Faculty and Research Institute of São Leopoldo Mandic and was dismissed for not involving humans or animals.

### Master Model Fabrication

One (01) jaw mannequin (master model) was made using software (Exocad 2.2) and a 3D printer (Miicraft 125 Ultra - Smartdent)[6,10]. Four morse taper implants (3.5 diameter and 13 mm length, Unitite, SIN Implants System) were installed on the mannequin, by only one experienced operator[1]. A mini-abutment compatible with the morse taper system (SIN Implants system), with a standardized height of three millimeters, was installed on each implant.

### Preparation of the specimens

For the preparation of the specimens, protocol bars on the implants, digital models of the implants positioned in the master model were obtained by conventional molding (analog) followed by scanning with a benchtop scanner (Group A), and another digital molding was obtained by the intraoral scanner directly in the master model (Group B)[8] (n=10):

*Group A: Conventional*. Starting from the point after installation of the mini-abutments on the implants, the molding transfers (SIN Implants System) were installed and splinted with metal rods associated with self-curing acrylic resin (Pattern - GC)[6,3,11]. The open tray molding technique was used associated with polyvinyl siloxane impression material (Express XT - 3M Oral Care)[10,12,13] (Figure 1A and B). The impression material was handled according to the manufacturer's instructions and inserted into the open tray. After polymerization of the material, the set was removed from the mannequin and the analogs were installed by the same operator who installed the implants. The special plaster (FujiRock - GC) was poured and the time required for the plaster to crystallize, generating the working model, was allowed. This model was inserted into the benchtop scanner (Bioscan - Bioart) creating a digital STL file for drawing the protocol bar and milling (DM5 - Tecnodrill)[11].

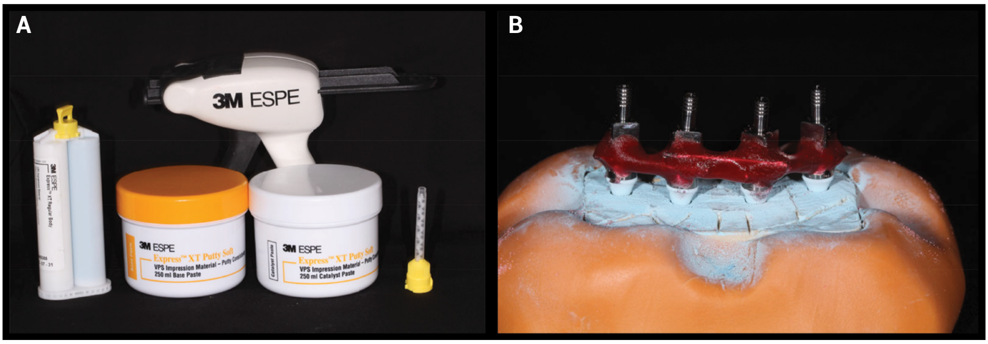


Figure 1. Impression material (A) used in the transfer molding of group A and transfers splinted on the working model (B).

*Group B: Digital.* The digital model was acquired after installing four standard scanning bodies (Scanning JIG JBMMA - SIN Implants System) for each mini-abutment and performing the scanning process with an intraoral scanner (Omnicam - Dentsply Sirona). The STL file went to the same responsible technician who designed the protocol bar and sent it to milling (DM5 - Tecnodrill)[11].

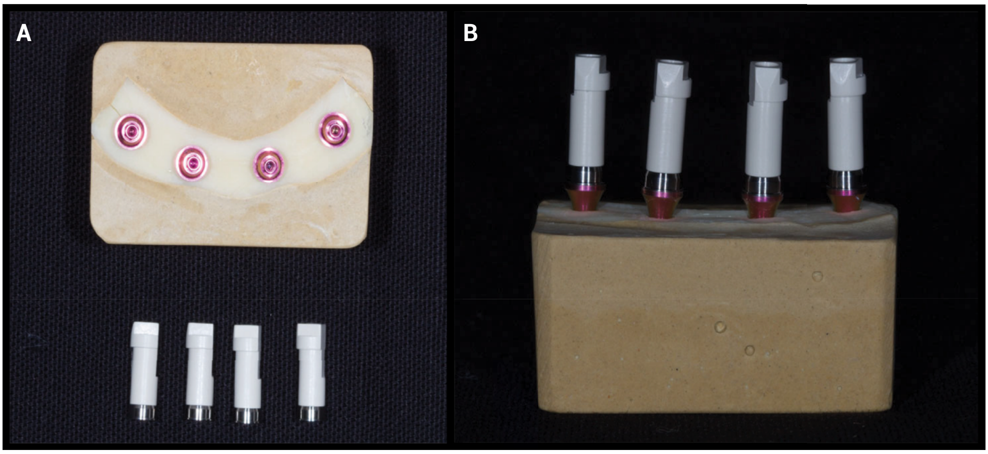


Figure 2. A master model with implants installed and scan bodies (Scan JIG) (A), is used to perform intraoral scanner scanning directly on the master model. A master model with specimens installed for intraoral scanning (B).

The files were sent to the laboratory and an experienced CAD operator designed the twenty bars (Groups A and B) in square format[7] in CAD software (Exocad 2.2), and the bars were milled in titanium (DM5, Tecnodrill).

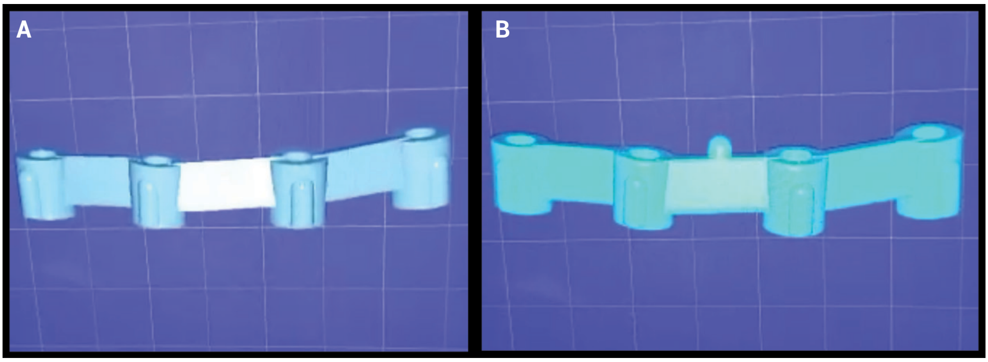


Figure 3. Digital drawing of bars. (A) Drawing of the bar of group A (conventional) and B) drawing of the protocol bar of group B (digital).

An experienced operator inserted each bar into the original master model, screwing each connection with a torque of 15N, measured with a calibrated torquemeter.

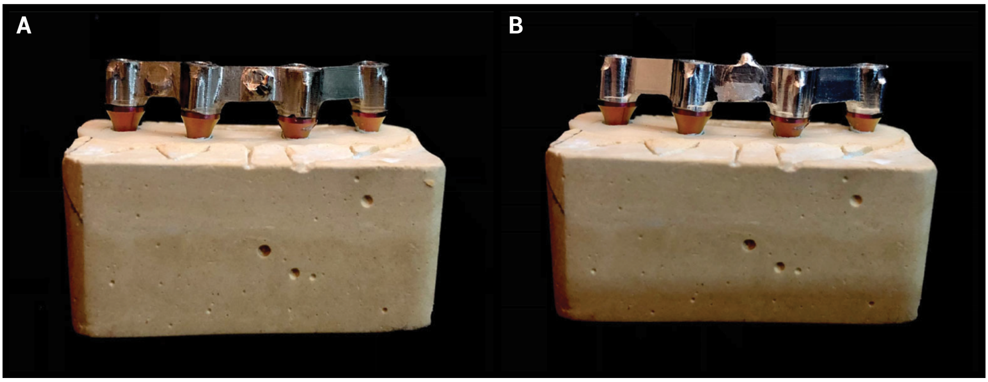


Figure 4. Milled bars on the master model. (A) Milled bars of group A (conventional) and (B) Milled bars of group B (digital) adapted in the master model.

## Scanning Electron Microscopy (SEM) and Marginal Fit Analysis

The SEM analysis (JEOL-JSM, 6460LV, Tokyo, Japan) was performed on each of the protocol-type bars[4], in the distal, central, and mesial regions, generating twelve images of each protocol-type bar specimen. The SEM operated at 15kV in high vacuum mode and 45 Pa. This method was selected because it allows measuring the adaptation of the milled bar/mini-pillar interface using electrons that create images with a high degree of magnification and resolution[14].

The images obtained were transferred to the imaging software (ImageJ software, US National Institutes of Health, Bethesda, Maryland, USA) to determine the length of each gap segment. The SEM image scale bar, at ×500 magnification, was used for distance calibration. The width of the gap was defined as the straight-line distance between the milled bars and the implants[15]. In the Image J software program, a line between two points of known distance (the scale bar of the SEM) was set as the measurement scale (pixel: length relationship known). Three linear measurements were made (in μm) of the vertical gap between the milled bars and the implant in each of the regions evaluated (distal, central, and mesial), and the mean values obtained from these three regions were submitted to statistical analysis.

## Statistical Analysis

The normality of the data was confirmed by the Shapiro-Wilk test, and an outlier was removed from Group A, in the mesial region. Data were submitted to two-way Analysis of Variance (ANOVA, factors: *group* and *region*) and Tukey HSD Test. Additionally, Student's t-test was performed for independent samples (comparison among groups). All analyzes were performed using the Statplus software: mac (AnalystSoft, v.6), with a significance level of 5%.

## Results

Table 1 describes the mean values (in μm) and standard deviation of the measurements performed on each implant, and on each protocol bar, according to the regions of the protocol bar and implant connection (distal, central, and mesial) and groups (A: conventional and B: digital).

**Table 1.** Mean (in μm) and standard deviation of the measurements performed on each implant of each protocol bar, in the distal, central and mesial regions, according to the methods for obtaining the metallic structure (Group A: conventional and B: digital).

| Regions | Groups | |
|---|---|---|
| | Group A Conventional | Group B: Digital |
| Distal | 18.7 (7.6) Bab | 40.1 (10.8) Aa |
| Central | 28.8 (10.5) Ba | 46.1 (13.1) Aa |
| Mesial | 13.1 (2.9) Bb | 38.4 (8.6) Aa |

Caption: Means followed by distinct letters are statistically different according to two-way ANOVA and Tukey's HSD test ($p < 0.05$). Capital letters compare groups A and B in each region (rows), and lowercase letters compare regions in each group (columns).

The results indicate that group B showed greater misadaptation than group A ($p<0.05$), regardless of the region evaluated. In group A, the central region showed greater misadaptation than the mesial region ($p = 0.0116$), but the central and mesial regions did not differ from the distal region ($p>0.05$). Group B exhibited no differences among the evaluated regions ($p>0.05$).

Additionally, the overall mean of each group was compared, regardless of the region evaluated. It was observed that treatment B presented greater misadaptation than group A (Table 2).

**Table 2.** Overall mean (µm) and standard deviation (sd) marginal fit measurement of each implant, regardless of the region evaluated.

| Groups | Overall mean (sd) | *p value* |
|---|---|---|
| A (Conventional) | 21.6 (7.7) B | *0.000474* |
| B (Digital) | 39.2 (11.9) A | |

Caption: Mean values followed by distinct letters indicate statistically significant differences according to the t test ($p < 0.05$).

The SEM images of the protocol-type bar interface on implants (Fig. 5) obtained using a benchtop scanner (A, B, and C) or intraoral scanner (B, D, E), illustrate the regions evaluated and measured for misfit (distal - A and D; central B and E; mesial C and F). The central region (B and E) indicates the existence of a gap, observed in all specimens for both groups. Image D (Group B) demonstrates, in addition to gap formation, overcontour of the metal bar, while in F (Group B) an undercontour is associated with gap formation. Representative images were obtained at × 500 magnification.

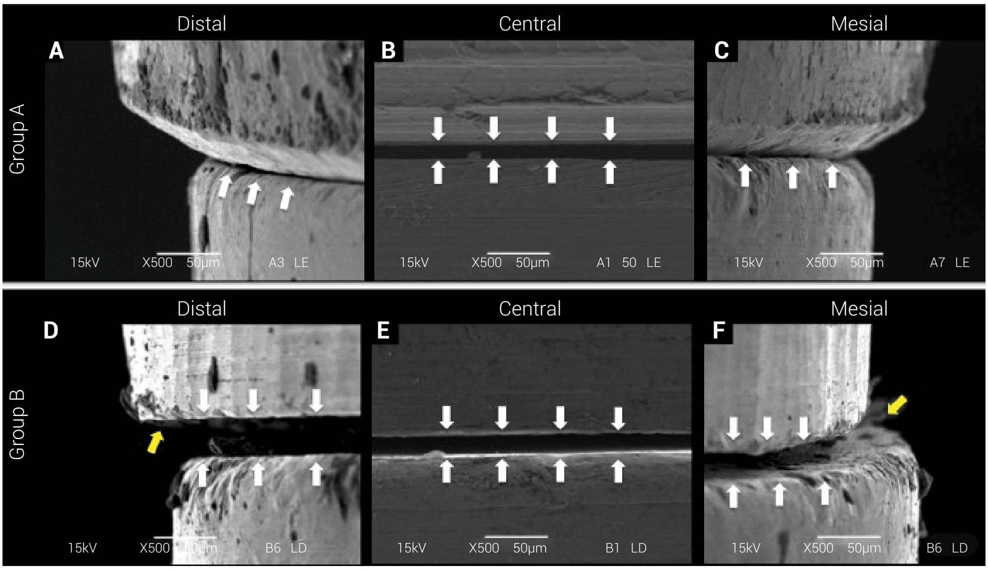


**Figure 5.** Representative scanning electron microscopy (SEM) images of the all-on-four protocols on implant attachments, produced by a benchtop scanner (A, B, and C) or intraoral scanner (D, E, F), according to the regions evaluated (distal - A and D; central B and E; mesial C and F). White arrows indicate the gap regions measured in the Image J software, and yellow arrows correspond to the over- (D) or under-contour (F) region of the metallic structure. (Magnification: ×500)

## Discussion

The objective of this study was to evaluate, by means of scanning electron microscopy, the marginal fit of milled protocol bars after the acquisition of the scan with a benchtop or intraoral scanner in models acquired from conventional moldings. The results indicate that the All-on-Four protocol bars obtained by benchtop scanning showed greater adaptation than those obtained by intraoral scanning. Thus, the null hypothesis that there would be no difference between the groups evaluated was rejected.

In recent years, authors have reported the difficulty in rehabilitating patients with protocol-type prostheses, especially the challenge of obtaining passive seating, since the materials used during the process produce uncontrollable variations that directly reflect the result. Since then, the evolution of techniques involving implant-prosthesis is constant, and technology has a fundamental role in the current form of All-on-Four rehabilitations[2]. In this sense, the main challenges of CAD/CAM systems are to reproduce the quality of products and compete with analog techniques[6].

It is known that for an All-on-Four rehabilitation to be successful in the long term, one of the fundamental factors is the adaptation of the bar that supports the entire dental structure. Balouch et al.[16] compared the three-dimensional accuracy between moldings with open tray and closed tray and concluded that the closed tray technique exhibited superior performance. Nakhaei et al.[17] compared the three-dimensional accuracy of moldings with open and closed trays. After generating a total of 42 models, the authors observed that the impression technique with an open tray showed greater precision compared to a closed tray, and this information was confirmed in a literature review carried out with more than 417 articles[12]. Thus, to select the most accurate impression technique, transfer molding with an open tray was selected for Group A. Although it has been demonstrated that the open-tray molding technique presented greater accuracy[12], the authors indicated that intraoral scanning for 3D model acquisitions was a reality and that its use by clinicians was on the rise. According to these authors, intraoral scanning could promote better results than moldings with closed trays and compatible with results with open trays.

The present study confirms previous observations in which researchers[18] compared intraoral scanning as an alternative technique to conventional molding with an open tray associated with polyvinyl siloxane, an addition-reaction silicone elastomer. According to the results[18], conventional impression promoted better marginal fit than intraoral scanning, confirming that conventional impression is superior to intraoral scanning. These results were corroborated by Alsharbaty et al.[19], in which the authors compared conventional molding with polyvinyl siloxane to intraoral scanning techniques and confirmed that conventional molding promotes more accurate clinical results than intraoral 3D image acquisition.

In another research, Huang et al.[20] evaluated the accuracy of intraoral and benchtop scanning methods, similar to the methodology used herein. A mannequin with four implants and four mini abutments installed on the implants was used. After acquiring the master models files through scans with an intraoral scanner or with a benchtop scanner on the models generated through conventional molding with an open tray and polyvinyl siloxane, the researchers showed that conventional moldings with open trays are more accurate than the intraoral scan. Besides, it should be noted that acquisition methods also influence the accuracy of implant-supported All-on-Four rehabilitations. Stimmelmayr et al.[11] compared the discrepancy between two different impression techniques of All-on-Four implants and concluded that the splinted pick-up technique should be used for impressions. The authors also stated that clinicians need to choose a technique that they feel capable, confident in, and safe to perform.

Contrarily to these findings, a previous research[8] evaluated the performance of conventional moldings and digital acquisitions of implant-supported prostheses in 25 patients treated with the All-on-Four technique associated with immediate loading for one year. The authors concluded that it is possible to manufacture satisfactory accurate prostheses on implants using digital impression techniques[8].

Pesce et al.[21] evaluated the gaps of printed protocol bars with the images acquired through an intraoral scanner and concluded that these protocol bars are reliable for a passive adaptation point. However, the authors reported that the experience of the intraoral scanner operator is critical to the clinical outcome[22]. Therefore, it is important to note that some studies that do not report whether the operator has experience in handling intraoral scanners may have their real data masked by this crucial factor. Conversely, others reinforce that the scanning pattern for digital acquisition does not significantly influence the clinical results obtained[23].

These studies were important to confirm the growing tendency to rehabilitate patients with the digital workflow. Nevertheless, even with scientific evidence, the number of dentists who have an intraoral scanner available is small, so to facilitate the choice of clinicians who have no experience with intraoral scanners, the best indication is the use of conventional molding with an open tray with splinting transfers[1,10,12,17,24,25] and addition silicone as molding material[13], which even promotes greater adaptation of the milled protocol bars, as shown by the results of this study.

The accuracy of scanning electron microscopy was used for image acquisition[9] and later, the images were quantitatively evaluated for marginal fit. In addition to proving that the adaptation of the protocol bars of group A (digital models obtained by conventional molding followed by benchtop scanning) was superior to that of group B, in this group (intraoral scanner) overcontour and undercontour areas were observed in the distal and mesial regions. Although these misadaptations are observed, there are no statistical differences among the regions of group B (distal, central, and mesial). There were, however, differences among the regions evaluated in group A (central region with higher misadaptation than the mesial region). Even though this statistical difference was found, the primary outcome of the research was always the comparison among the groups. And in this context, regardless of the region, group A (conventional) always showed better adaptation than group B (digital).

Although the results of this study are important to guide the clinician's selection of the best technique for making the protocol bars, the acceptance, comfort, and time generated by the techniques must be considered during rehabilitation. Although the digital technique (B - intraoral scanner) has shown greater misadaptation than the conventional technique (group A), intraoral scanning is a well-accepted technique due to the comfort and agility in obtaining the images[26]. Besides, another advantage of digital workflow is the ability to produce three-dimensional (3D) meshes to generate a virtual patient, enhancing the virtual treatment planning, communication with patients[27], and predictability[26,28]. Considering that both methods promoted gaps that could generate biofilm accumulation and microleakage, and that the patient must maintain adequate control of oral hygiene, the use of intraoral scanner cannot be ruled out.

For CAD-CAM crowns and short-span fixed partial dentures, intraoral scanning has been shown to be more accurate than conventional impressions[29-31]. These studies describe marginal gaps of approximately 60 μm for CAD-CAM dental crowns produced by intraoral scanning, while conventional impressions exhibited gap values up to 183 μm[29]. In the present study, digital models obtained by conventional molding followed by benchtop scanning (group A) exhibited an overall marginal gap of 21.6 μm while the intraoral scanning produced an overall marginal gap of 39.2 μm, both significantly lower than those reported in the literature. The mean gap values differences among the studies are closely related to the type of rehabilitation, as it has been reported that the accuracy of intraoral scans is still challenging for extended rehabilitations[32]. Besides, authors have reported the differences among the software programs and methods for use in the digital design of dental prosthesis[33,34], and the influence of the operator's clinical experience and educational background. It has also been described that prosthodontists with basic CAD training were shown to outperform dental professionals who had CAD certificates but less clinical experience[34]. Therefore, one important limitation of this investigation is that the interpretation of results should be performed carefully, as the materials and methods vary considerably among the studies. According to Cortes 2022[35], the outcomes of CAD-CAM restorations and prostheses can be affected during image acquisition (intraoral scan device, operator, technique, or anatomy), CAD phases (software or operator), or CAM phases (device, manufacturing material, CAM protocol, or finishing)[35].

In conclusion, and considering the described limitations, this study corroborates previous findings that the conventional molding technique followed by benchtop scanning presented better marginal adaptation than the digital technique performed with an intraoral scanner. However, future studies should compare different software programs, devices, and operation modes, and clinical studies must be performed to validate the obtained results.

## Acknowledgments

The authors are grateful for Gabriel Matzembacher from Dental Scan lab, and his important contribution to producing the digital images and All-on-Four protocol bars.

## Conflict of interest

The authors have no conflicts of interest to declare.

## Data availability

Datasets related to this article will be available upon request to the corresponding author.

## Author contribution

- Renês Augusto Parizotto; methodology, investigation, data curation, writing (original draft, review, and editing).

- Vanessa Cavalli: methodology, formal analysis, data curation, writing (review and editing).
- Rafael Lacerda Zandoná: conceptualization, writing (review and editing)
- Geraldo Alberto Pinheiro de Carvalho: conceptualization, writing (review and editing)
- Aline Batista Gonçalves Franco: conceptualization, writing (review)
- Elimario Venturin Ramos: conceptualization, writing (review and editing)
- Sérgio Candido Dias: conceptualization, writing (review).

All authors actively participated in discussing the manuscript's findings and have revised and approved the final version of the manuscript.

## References

1. Patil R, Kadam P, Oswal C, Patil S, Jajoo S, Gachake A. A comparative analysis of the accuracy of implant master casts fabricated from two different transfer impression techniques. J Int Soc Prev Community Dent. 2016 Mar-Apr;6(2):142-8. doi: 10.4103/2231-0762.178747.
2. WennerbergA, Albrektsson T. Current challenges in successful rehabilitation with oral implants. J Oral Rehabil. 2011 Apr;38(4):286-94. doi: 10.1111/j.1365-2842.2010.02170.x.
3. Selvaraj S, Dorairaj J, Mohan J, Simon P. Comparison of implant cast accuracy of multiple implant impression technique with different splinting materials: an in vitro study. J Indian Prosthodont Soc. 2016 Apr-Jun;16(2):167-75. doi: 10.4103/0972-4052.167937.
4. Araújo GM, França DG, Silva Neto JP, Barbosa GA. Passivity of conventional and CAD/CAM fabricated implant frameworks. Braz Dent J. 2015 May-Jun;26(3):277-83. doi: 10.1590/0103-6440201300145.
5. Patzelt SB, Lamprinos C, Stampf S, Att W. The time efficiency of intraoral scanners: an in vitro comparative study. J Am Dent Assoc. 2014 Jun;145(6):542-51. doi: 10.14219/jada.2014.23.
6. Stimmelmayr M, Güth JF, Erdelt K, Happe A, Schlee M, Beuer F. Clinical study evaluating the discrepancy of two different impression techniques of four implants in an edentulous jaw. Clin Oral Investig. 2013 Nov;17(8):1929-35. doi: 10.1007/s00784-012-0885-z.
7. Carvalho GAP, Franco ABG, Kreve S, Ramos EV, Dias SC, Amaral FLB. Polyether ether ketone in protocol bars: mechanical behavior of three designs. J Int Oral Health. 2017 Sept;9(5):202-6. doi: 10.4103/jioh.jioh_163_17.
8. Gherlone E, Capparé P, Vinci R, Ferrini F, Gastaldi G, Crespi R. Conventional versus digital impressions for "all-on-four" restorations. Int J Oral Maxillofac Implants. 2016 Mar-Apr;31(2):324-30. doi: 10.11607/jomi.3900.
9. Markarian RA, Galles DP, Gomes França FM. Scanning electron microscopy analysis of the adaptation of single-unit screw-retained computer-aided design/computer-aided manufacture abutments after mechanical cycling. Int J Oral Maxillofac Implants. 2018;33(1):127-36. doi: 10.11607/jomi.5588.
10. Siadat H, Alikhasi M, Beyabanaki E, Rahimian S. Comparison of different impression techniques when using the all-on-four implant treatment protocol. Int J Prosthodont. 2016 May-Jun;29(3):265-70. doi: 10.11607/ijp.4341.

11. Stimmelmayr M, Beuer F, Edelhoff D, Güth JF. Implant impression techniques for the edentulous jaw: a summary of three studies. J Prosthodont. 2016 Feb;25(2):146-50. doi: 10.1111/jopr.12305.

12. Moreira AH, Rodrigues NF, Pinho AC, Fonseca JC, Vilaça JL. Accuracy comparison of implant impression techniques: a systematic review. Clin Implant Dent Relat Res. 2015 Oct;17 Suppl 2:e751-64. doi: 10.1111/cid.12310.

13. Naumovski B, Kapushevska B. Dimensional stability and acuracy of silicone - based impression materials using different impression techniques - a literature review. Pril (MakedonAkadNaukUmet Odd Med Nauki). 2017 Sep;38(2):131-8. doi: 10.1515/prilozi-2017-0031.

14. Simamoto-Júnior PC, Cavalcante LAL, Miura FL, Resende LM, Fernandes Neto AJ. [Evaluation of the quality of the surface prosthetic in different systems: a comparative study]. Rev Odontol Bras Central. 2015;24(71):204-8. Portuguese.

15. Zhou Y, Li Y, Ma X, Huang Y, Wang J. Alternative method to evaluate the adaptation of implant-supported multi-unit prosthetic frameworks. J Prosthodont. 2019 Feb;28(2):e643-e648. doi: 10.1111/jopr.12644.

16. Balouch F, Jalalian E, Nikkheslat M, Ghavamian R, ToopchiSh, Jallalian F, et al. Comparison of Dimensional Accuracy between Open-Tray and Closed-Tray Implant Impression Technique in 15° Angled Implants. J Dent (Shiraz). 2013 Sept;14(3):96-102.

17. Nakhaei M, Madani AS, Moraditalab A, Haghi HR. Three-dimensional accuracy of different impression techniques for dental implants. Dent Res J (Isfahan). 2015 Sep-Oct;12(5):431-7. doi: 10.4103/1735-3327.166190.

18. Kim KR, Seo KY, Kim S. Conventional open-tray impression versus intraoral digital scan for implant-level complete-arch impression. J Prosthet Dent. 2019 Dec;122(6):543-9. doi: 10.1016/j.prosdent.2018.10.018.

19. Alsharbaty MHM, Alikhasi M, Zarrati S, Shamshiri AR. A clinical comparative study of 3-dimensional accuracy between digital and conventional implant impression techniques. J Prosthodont. 2019 Apr;28(4):e902-8. doi: 10.1111/jopr.12764.

20. Huang R, Liu Y, Huang B, Zhang C, Chen Z, Li Z. Improved scanning accuracy with newly designed scan bodies: An in vitro study comparing digital versus conventional impression techniques for complete-arch implant rehabilitation. Clin Oral Implants Res. 2020 Jul;31(7):625-33. doi: 10.1111/clr.13598.

21. Pesce P, Pera F, Setti P, Menini M. Precision and accuracy of a digital impression scanner in full-arch implant rehabilitation. Int J Prosthodont. 2018 Mar/Apr;31(2):171-5. doi: 10.11607/ijp.5535.

22. Gimenez-Gonzalez B, Hassan B, Özcan M, Pradíes G. An in vitro study of factors influencing the performance of digital intraoral impressions operating on active wavefront sampling technology with multiple implants in the edentulous maxilla. J Prosthodont. 2017 Dec;26(8):650-5. doi: 10.1111/jopr.12457.

23. Mennito AS, Evans ZP, Lauer AW, Patel RB, Ludlow ME, Renne WG. Evaluation of the effect scan pattern has on the trueness and precision of six intraoral digital impression systems. J Esthet Restor Dent. 2018 Mar;30(2):113-8. doi: 10.1111/jerd.12371.

24. Saboury A, Neshandar Asli H, DaliliKajan Z. The accuracy of four impression-making techniques in angulated implants based on vertical gap. J Dent (Shiraz). 2017 Dec;18(4):289-97.

25. Nishioka RS, De Santis LR, De Melo Nishioka GN, Kojima AN, Souza FÁ. Strain gauge evaluation of transfer impression techniques of multiple implant-supported prosthesis. Implant Dent. 2018 Apr;27(2):188-92. doi: 10.1097/ID.0000000000000744.

26. Mangano A, Beretta M, Luongo G, Mangano C, Mangano F. Conventional vs digital impressions: acceptability, treatment comfort and stress among young orthodontic patients. Open Dent J. 2018 Jan;12:118-24. doi: 10.2174/1874210601812010118.

27. Mangano C, Luongo F, Migliario M, Mortellaro C, Mangano FG. Combining intraoral scans, cone beam computed tomography and face scans: the virtual patient. J Craniofac Surg. 2018 Nov;29(8):2241-6. doi: 10.1097/SCS.0000000000004485.

28. Markarian RA, da Silva RLB, Burgoa S, Pinhata-Baptista OH, No-Cortes J, Cortes ARG. Clinical relevance of digital dentistry during covid-19 outbreak: A scoped review. Braz J Oral Sci. 2021;19:e200201. doi: 10.20396/bjos.v19i00.8660201.

29. Morsy N, El Kateb M, Azer A, Fathalla S. Fit of zirconia fixed partial dentures fabricated from conventional impressions and digital scans: a systematic review and meta-analysis. J Prosthet Dent. 2021 Oct 22;S0022-3913(21)00496-0. doi: 10.1016/j.prosdent.2021.08.025.

30. Nedelcu R, Olsson P, Nyström I, Thor A. Finish line distinctness and accuracy in 7 intraoral scanners versus conventional impression: An in vitro descriptive comparison. BMC Oral Health. 2018 Feb;18(1):27. doi: 10.1186/s12903-018-0489-3.

31. Carbajal Mejía JB, Wakabayashi K, Nakamura T, Yatani H. Influence of abutment tooth geometry on the accuracy of conventional and digital methods of obtaining dental impressions. J. Prosthet. Dent. 2017 Sep;118(3):392-9. doi: 10.1016/j.prosdent.2016.10.021.

32. Schmidt A, Klussmann L, Wöstmann B, Schlenz MA. Accuracy of digital and conventional full-arch impressions in patients: An Update. J Clin Med. 2020 Mar;9(3):688. doi: 10.3390/jcm9030688.

33. Markarian RA, Vasconcelos E, Kim JH, Cortes ARG. Influence of gingival contour on marginal fit of cad-cam zirconia copings on implant stock abutments. Eur J Prosthodont Restor Dent. 2021 Feb;29(1):2-5. doi: 10.1922/EJPRD_2052Markarian04.

34. No-Cortes J, Son A, Ayres AP, Markarian RA, Attard NJ, Cortes ARG. Effect of varying levels of expertise on the reliability and reproducibility of the digital waxing of single crowns: A preliminary in vitro study. J Prosthet Dent. 2022 Jan;127(1):128-33. doi: 10.1016/j.prosdent.2020.10.007.

35. Cortes ARG. Digital versus conventional workflow in oral rehabilitations: Current status. Appl Sci 2022 Apr;12(8):3710. doi: 10.3390/app12083710.