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A Literature Review on Vertical Adaptation Of Fixed Implant-Supported Prostheses: Conventional System Versus Cad/Cam System

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Authors' contributions

This work was carried out in collaboration among all authors. Author RRDL designed the study, managed the literature searches, performed the data analysis and interpretation, and contributed to writing the manuscript. Author JOJ designed the study, managed the literature searches, performed the data analysis and interpretation, and wrote the first draft of the manuscript. Author BMFD managed the literature searches and wrote the first draft of the manuscript. Author LSJ managed the literature searches and wrote the first draft of the manuscript. Author EFH managed the literature searches, performed the data analysis and interpretation, and wrote the first draft of the manuscript. Author FSL managed the literature searches, performed the data analysis and interpretation, and wrote the first draft of the manuscript. Author RRV designed the study and managed the critical review and final revisions of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The present study aims to review the literature on the vertical adaptation of fixed implant prostheses, made by the conventional system and the CAD/CAM system.
Place and Duration of Study: The study was carried out at a training center for dentistry specialists in Belo Horizonte, Brazil, during 2022.
Methodology: The methodology of this study consisted of a bibliographic search carried out in the main scientific databases in order to identify relevant publications on the vertical adaptation of implant-supported fixed prostheses. The search strategy employed keywords in both English and Portuguese, including *Dental implants*, *Dental prosthesis fixed implant*, and *Prostheses and implants*, combined through the Boolean operators AND and OR to optimize the retrieval of articles.
Results: The results revealed a better vertical adaptation in the use of CAD/CAM systems to obtain fixed prosthesis on implant when compared to conventional techniques and provided greater passivity for the fixed prosthesis/implant set, consequently better distribution of stresses on bone structures.
Conclusion: CAD/CAM systems for implant-supported fixed prostheses demonstrated superior vertical adaptation compared with conventional techniques, as well as greater passivity of the prosthesis–implant complex, resulting in improved stress distribution on the bone structures.

Keywords: Dental implants; dental prosthesis fixed implant; prostheses and implants.

1. INTRODUCTION

Since the development of osseointegration more than 40 years ago, missing teeth resulted from fracture mandible, oral lichan planus or any other causes have been replaced with dental implants with a high success rate (Mahdi, Ali, 2013**;** Barros *et al*., 2013; Mahdi, 2024). Many poeple prefer dental implant (Mahdi, 2025). For completely edentulous patients, according to Rocha *et al*. (2013), different designs of implant-supported fixed prostheses are available, and the choice of the most appropriate type primarily depends on the number of implants in the arch. The classical model is the “protocol-type” prosthesis defined by brånemark, characterized by the placement of 4 to 6 implants in the anterior region of the mandible, between the mental foramina, with distal cantilevers on both sides to replace the posterior teeth (Freitas et al., 2007). According to the authors, in the maxilla the placement of 6 to 8 implants is recommended.

The installation of the dental prosthesis represents the final stage of rehabilitation with osseointegrated implants and is integral to treatment success. Factors related to the transmission of functional loads to the bone, the distribution of stresses on prosthetic components, and the passive adaptation of the prosthetic framework to the implants have been considered crucial for the longevity of both the prosthesis and the implants (Barros *et al*., 2013). A metal framework retained by implants that adapts with the least possible marginal misfit and in a passive manner, without creating stresses on the implant itself or the surrounding bone tissue, demonstrates what is known as passive fit (Campi Junior *et al*., 2010).

The passive adaptation of the prosthetic framework to the implants is considered one of the mechanical parameters that can affect prosthesis longevity. The absence of passivity in the adaptation of the implant-supported prosthesis may lead to various failures.

The present study aims to conduct a literature review on the vertical adaptation of implant-supported fixed prostheses fabricated using both the conventional system and cad/cam (computer-aided design/computer-aided manufacturing) systems.

2. METHODOLOGY

The methodology of this study consisted of a bibliographic search carried out in the main scientific databases in order to identify relevant publications on the vertical adaptation of implant-supported fixed prostheses. The search strategy employed keywords in both English and Portuguese, including *Dental implants*, *Dental prosthesis fixed implant*, and *Prostheses and implants*, combined through the Boolean operators *AND* and *OR* to optimize the retrieval of articles.

The selection process was guided by predefined inclusion and exclusion criteria. Studies were included if they addressed the adaptation of implant-supported prostheses using either conventional or CAD/CAM systems, and if they were available in full text in English or Portuguese. Exclusion criteria comprised case reports, letters to the editor, conference abstracts, and studies lacking direct relevance to the topic.

No restrictions were applied regarding the year of publication in order to ensure a comprehensive overview of the available evidence. Duplicated references were removed, and the remaining studies were screened based on title and abstract, followed by a full-text evaluation for eligibility.

3. LITERATURE REVIEW

When selecting the retention system for an implant-supported prosthesis, it is essential that the dentist understands the structural options available for framework fixation. Neves *et al*. (2003) classified implant-supported fixed prostheses into segmented and non-segmented types. Segmented prostheses are composed of three parts: the implant, the abutment (screwed to the implant), and the crown. Within this category, screw-retained prostheses are connected to the abutment by a gold or titanium screw, whereas cement-retained prostheses rely on cementation for fixation. In contrast, non-segmented prostheses consist of only two parts—the implant and the crown—with the abutment directly connected to the implant, such as the UCLA abutment after casting.

Stüker *et al*. (2005) carried out a literature review emphasizing the importance of metal framework passivity in implant-supported fixed prostheses. They discussed factors related to bone alterations, as well as clinical and laboratory procedures that may influence framework passivity. According to the authors, the degree of passivity appears to be a decisive factor for both the success and failure of this type of restoration. Their analysis revealed that multiple variables can affect the final restorative outcome. Among the laboratory techniques discussed, laser welding was consistently reported to offer advantages over conventional methods, particularly in terms of precision and reduced procedure time. However, its widespread application is limited by high costs and the lack of technical expertise in most dental laboratories.

According to Brånemark (1983), a precisely adapted prosthesis should present a discrepancy of around 10 μm, which would provide adequate stimulation for bone remodeling. This condition can be referred to as passive fit, since once the prosthesis is installed, the implants would no longer occupy exactly the same positions in which they were originally placed. Misfit, however, is multifactorial. Several factors may influence passive adaptation, including the impression technique, distortions of the materials used, the fabrication process of metallic frameworks, welding technique, porcelain firing cycles, framework design, and the clinician's experience in performing the procedures. Although distortions at each individual stage may appear clinically insignificant, the accumulation of such errors can lead to a misfit large enough to cause significant stress on the bone–implant–prosthesis complex.

Abduo *et al*. (2012) investigated the influence of misfit in titanium and zirconia frameworks on implants. Two implants were inserted into an epoxy resin mandibular model, positioned in the left second premolar and second molar regions. From this model, five titanium and five zirconia frameworks were milled. Strain gauges were attached around each implant to evaluate stress development resulting from misfit at the framework margins. In addition, vertical gaps at the implant–framework interface were measured with an optical microscope, both under the single-screw test and the two-screw test conditions. Vertical fit was further altered by inserting one to three nominal 30 μm steel shims under one of the implants. The results indicated that both framework materials generated similar levels of stress, with a direct relationship observed between peri-implant stress and the vertical gap. The authors concluded that titanium and zirconia frameworks produced comparable magnitudes of peri-implant strain.

Bernardes *et al*. (2012) conducted a clinical literature review addressing CAD/CAM systems, their working principles, advantages and disadvantages, and the current state of their application in the fabrication of prostheses and restorations. The authors concluded that the evolution of CAD/CAM technology in dentistry has made it possible to produce high-quality prosthetic restorations with a wide range of restorative materials and prosthesis types. However, they emphasized that the system itself is not solely decisive for treatment success. Instead, success depends on the integration of

several stages, including clinical procedures, digital scanning, computational design, manufacturing, quality control, material selection, prosthesis type, and laboratory finishing.

França *et al*. (2015) compared the fit accuracy between implants and components of three-unit screw-retained fixed dental prostheses (FDPs) fabricated using CAD/CAM technology with zirconia and Co-Cr alloys, as well as conventionally manufactured Co-Cr alloy prostheses, including both pre-machined Co-Cr abutments with castable components and castable abutments. Adaptation was assessed under two conditions: when only a single screw was tightened (passive fit) and when all screws were tightened (definitive fit). Sixteen frameworks were fabricated (n = 4 per group): zirconia frameworks produced by CAD/CAM (ZirCAD group), Co-Cr frameworks produced by CAD/CAM (CoCrCAD group), conventionally fabricated Co-Cr frameworks with pre-machined abutments and castable bases (CoCrUCci group), and conventionally fabricated Co-Cr frameworks with castable abutments (CoCrUCcl group). The conventional casting groups served as controls. Vertical misfit at the implant–framework interface was measured using scanning electron microscopy under both single- and multiple-screw conditions. Data were analyzed with the Kruskal–Wallis and Mann–Whitney tests (α = .05). Results showed mean vertical misfit values, under the all-screws condition, of 5.9 ± 3.6 µm for CAD/CAM zirconia, 1.2 ± 2.2 µm for CAD/CAM Co-Cr, 11.8 ± 9.8 µm for conventionally fabricated Co-Cr with pre-machined abutments, and 12.9 ± 11.0 µm for conventionally fabricated Co-Cr with castable abutments. The authors concluded that CAD/CAM frameworks demonstrated superior fit accuracy compared with conventionally manufactured frameworks.

Fontoura *et al*. (2018) evaluated the vertical misfit of screw-retained implant frameworks made of grade 5 titanium alloy (Ti6Al4V, ASTM) and yttria-stabilized tetragonal zirconia (Y-TZP), both fabricated using CAD/CAM technology. A mandibular master model in aluminum was created with four equidistant perforations corresponding to the positions of the mandibular canines and second premolars. Four regular straight titanium alloy abutment analogs (Regular CrossFit multibase, Institut Straumann) were placed into these perforations at 90° angles and fixed with autopolymerizing acrylic resin. The master model was then scanned with an S600 ARTI scanner (Zirkonzahn). Digital scan abutments were positioned to ensure precise three-dimensional mapping in the virtual model, which was subsequently used for framework design. Milling was performed using blocks of Y-TZP zirconia and grade 5 titanium alloy on an M5 heavy milling unit (Zirkonzahn).

Vertical misfit between frameworks and abutments was measured with a scanning electron microscope (SEM) (FEI). Readings were taken at three points on the buccal, lingual, and mesial surfaces of each abutment. Torque values were standardized at 15 N·cm using a manual Straumann key in a clinical simulation sequence. Measurements were processed using ImageJ software (version 1.48, NIH), with lines drawn across framework–abutment interfaces to determine the vertical discrepancy in micrometers. Data were analyzed in SPSS (version 20.0). Results showed no statistically significant difference in vertical misfit between the titanium frameworks (6.011 ± 0.750 µm) and zirconia frameworks (9.055 ± 3.692 µm). SEM analysis revealed occasional milling defects in zirconia frameworks, but overall, both materials achieved clinically acceptable vertical adaptation. The authors concluded that CAD/CAM frameworks demonstrated adequate fit regardless of the material used.

Yilmaz *et al*. (2018) conducted an in vitro study with the aim of assessing the marginal discrepancy of screw-retained, full-arch fixed prosthetic frameworks fabricated from high-density polymers (HDP resin) using CAD/CAM, and statistically comparing them with titanium (Ti) and zirconia (Zir) frameworks through industrial computed tomography (CT) scanning. An acrylic resin prototype of a screw-retained full-arch framework was fabricated on a typodont model with two straight anterior implants and two distally inclined posterior implants at 30 degrees, supported by multiunit abutments. A three-dimensional (3D) laboratory laser scanner was employed to digitize the typodont model with scan bodies and the resin prototype, generating a virtual CAD 3D framework design. A CAM milling unit was then used to manufacture five frameworks for each material (HDP, Ti, and Zir). A one-screw test was performed by tightening the prosthetic screw at the left maxillary first molar abutment (terminal position) while the frameworks were mounted on the typodont model. Marginal discrepancies were evaluated using an industrial CT scanner and volumetric 3D software. The 3D marginal discrepancy at the

abutment–framework interface was measured at the left canine (L1), right canine (L2), and right first molar (L3). Mean 3D discrepancy values were calculated for each location within groups, with 95% confidence intervals. Data were analyzed using two-way repeated measures ANOVA with restricted maximum likelihood estimation and Satterthwaite's approximation for degrees of freedom, accounting for material as the between-subject factor, location as the within-subject factor, and their interaction. Tukey's tests were applied for pairwise comparisons when overall significance was detected. Results indicated that 3D marginal discrepancy measurements could only be reliably obtained for L2 and L3, as L1 values were too small to be detected. At L2, mean discrepancies were 60.0 µm for HDP, 74.0 µm for Ti, and 84.0 µm for Zir. At L3, mean discrepancies were 55.0 µm for HDP, 102.0 µm for Ti, and 94.0 µm for Zir. The authors concluded that, when fabricated with CAD/CAM, HDP frameworks exhibited lower 3D marginal discrepancy compared with titanium or zirconia frameworks.

Similarly, Al-Meraikhi *et al*. (2018) carried out an in vitro study aimed at comparing the marginal fit and discrepancy of screw-retained, full-arch fixed dental prostheses (FDPs) fabricated from titanium and zirconia using CAD/CAM, based on a standardized all-on-4 implant distribution model. An edentulous maxillary cast with four multiunit abutment replicas positioned at the maxillary canines and first molars was employed. The abutments were digitized using scan bodies and a laboratory scanner, and the frameworks were designed in CAD software and milled using CAM. Titanium (n=5) and zirconia (n=5) frameworks were fabricated and scanned with an industrial CT scanner during the one-screw test. CT datasets were reconstructed into standard tessellation language (STL) files and analyzed using volumetric analysis software to obtain measurements. Marginal discrepancy was evaluated at the left maxillary canine (LMC), right maxillary canine (RMC), and right maxillary first molar (RMFM). Additionally, color maps were generated to visualize discrepancies, applying a color scale interval of ±0.500 mm. The authors reported that material type (zirconia vs. titanium) did not significantly influence 3D discrepancy values ($P = 0.904$). However, significant differences were found between implant locations, particularly between RMC and RMFM, within both material groups ($P < 0.001$). For titanium frameworks, the mean ± SD 3D discrepancies were 48.2 ± 2.6 µm (LMC), 74.0 ± 15.0 µm (RMC), and 102.0 ± 26.7 µm (RMFM). For zirconia frameworks, the mean values were 84.4 ± 12.1 µm (RMC) and 93.8 ± 30.0 µm (RMFM). All values remained below 135 µm.

Mello *et al*. (2019) conducted a systematic review and meta-analysis of *in vitro* studies comparing the vertical marginal misfit of implant-supported frameworks fabricated using CAD/CAM systems versus the conventional lost-wax casting technique. The review followed PRISMA guidelines. An electronic search was independently performed by two reviewers in MEDLINE (PubMed), Embase, Web of Science, and the Cochrane Library to identify studies published up to April 2018. The initial search yielded 507 references; after removal of duplicates, 384 studies remained, and 11 *in vitro* studies met the eligibility criteria. Across these studies, nine different CAD/CAM systems were used to fabricate 172 frameworks from various materials, including zirconia, monolithic lithium disilicate, and metallic alloys. The pooled analysis revealed that frameworks produced by CAD/CAM systems exhibited smaller marginal discrepancies compared with those manufactured by the conventional casting method. However, no significant difference was observed between cement-retained and screw-retained frameworks. The authors concluded that CAD/CAM technology demonstrated superior marginal fit compared with conventional lost-wax casting techniques for implant-supported prosthesis fabrication.

Oteiza-Galdón *et al*. (2020) investigated the degree of passive and vertical fit achieved in implant-supported fixed partial dentures (FPDs). Their study evaluated cobalt–chromium (Co-Cr) and titanium (Ti) frameworks fabricated using CAD/CAM milling. A total of 33 three-unit FPDs were analyzed, of which 17 Co-Cr frameworks formed the test group and 16 Ti frameworks the control group. All prostheses were fabricated over two implants using copy-milling technology. Passive fit (PF) and vertical fit (VF) were assessed through optical microscopy. For vertical fit, prosthetic screws were tightened to 20 Ncm, while passive fit was evaluated using the single-screw test. Descriptive and inferential analyses were performed to assess statistically significant differences between groups for each type of fit. Brunner–Langer models were applied to evaluate potential effects of material and implant area, and ANOVA was used to estimate main effects and interactions. The findings indicated that passive fit did not differ

significantly between the two groups. However, the control group (Ti) exhibited significantly better vertical fit compared with the test group (Co-Cr) ($p = 0.046$) in the screwed implant, whereas no differences were observed in the non-screwed implant. Vertical fit was superior in the lingual area compared to the buccal area. The authors concluded that both Co-Cr and Ti alloys achieved clinically acceptable passive and vertical fit. Moreover, three-unit implant-supported FPDs fabricated with Co-Cr alloys using CAD/CAM milling demonstrated dimensional accuracy comparable to that of titanium frameworks.

Tonin *et al*. (2021) evaluated vertical misfit, passive fit, and stress distribution after screw tightening in different prosthesis types. Two implants were used to simulate rehabilitation of a partially edentulous mandibular space from the second premolar to the second molar. Forty three-unit screw-retained fixed dental prostheses with distal cantilevers were fabricated and divided into four groups according to the fabrication method (n = 10): G1 = conventionally cast one-piece framework, G2 = conventionally cast sectioned framework with laser welding, G3 = conventionally sectioned framework welded with inert gas tungsten (TIG), and G4 = CAD/CAM-fabricated framework. Vertical misfit (all screws tightened) and passive fit (single screw tightened) were measured under an optical comparator microscope. Data were analyzed using the Shapiro–Wilk test to allow for ANOVA, followed by Tukey post-hoc tests with Bonferroni correction ($\alpha = 0.05$). Stress distribution was qualitatively assessed using photoelastic analysis. Vertical misfit was 24 µm in G2 and 27 µm in G3, both significantly higher than G4 (10 µm). Passive fit values were 64 µm in G1 and 61 µm in G3, also significantly higher than G4 (32 µm). Photoelastic analysis revealed higher stress between implants in G1 and lower stress in G4. The authors concluded that CAD/CAM frameworks resulted in reduced vertical misfit, greater passive fit, and consequently better stress distribution to the bone.

Peixoto *et al*. (2024) conducted an in vitro study to analyze vertical misfit in cantilever-type partial fixed prostheses. The prostheses were divided into five experimental groups (n = 8) according to framework material: LAS Co-Cr (conventional casting with laser welding), TIG Co-Cr (conventional casting with TIG welding), OP Co-Cr (conventionally cast one-piece), CAD Co-Cr (CAD/CAM technology), and CAD Zr (CAD/CAM technology with zirconia). Vertical misfit was measured at three stages: before porcelain application (T1), prior to (T2) and after (T3) thermomechanical cycling using stereomicroscopy. Results indicated that CAD/CAM-fabricated frameworks exhibited lower vertical misfit compared with other fabrication methods, although sectioning and subsequent welding of metal frameworks remains a viable alternative.

Tonin *et al*. (2024) performed an in vitro study using confocal laser scanning microscopy to assess marginal misfit in various implant-supported frameworks. The study simulated the posterior region of a partially edentulous mandible using three-unit screw-retained frameworks supported by two implants, distributed into five experimental groups (n = 10 each): OP = conventionally cast Co-Cr one-piece framework (control), LAS = sectioned Co-Cr framework laser-welded, TIG = sectioned Co-Cr framework TIG-welded, Co-Cr CAD/CAM = milled Co-Cr framework, and Zir CAD/CAM = milled zirconia framework. Horizontal (X) and vertical (Y) misfits were measured with one or both screws tightened. Data were analyzed using two-way repeated-measures ANOVA with Bonferroni correction ($\alpha = 0.05$). The greatest horizontal misfit was observed in the OP group with both screws tightened (290 µm), and with one screw tightened, values were 388 µm and 340 µm, respectively. Across all conditions, vertical misfits remained below 53 µm; however, milled frameworks exhibited higher vertical misfit compared with conventional casting. The authors concluded that both cast sectioned frameworks with laser welding and milled Co-Cr frameworks present higher marginal misfit but improved passive fit compared with other fabrication methods.

4. DISCUSSION

According to Stüker *et al*. (2005), an implant-supported prosthesis should exhibit a vertical misfit of approximately 10 µm to be considered a passive fit, allowing for adequate stimulation of bone remodeling. However, it is difficult to achieve complete adaptation across all surfaces. A passively fitting implant-supported prosthesis can be screwed into place without generating stresses. Passive fit has thus been defined as the level at which no clinical complications are expected (Campi Junior, 2010). The long-term success of implant-supported restorations is closely related to the ability of the implant–

prosthesis system to withstand occlusal forces without inducing stress or strain in the peri-implant bone, thereby avoiding screw loosening and prosthetic failures. A key factor in this success is the passivity of the prosthetic framework on the implants (Oteiza-Galdón *et al*., 2020).

Yilmaz *et al*. (2018) reported that many authors consider a marginal misfit of 120 µm for indirect fixed dental restorations to be a clinically acceptable threshold, although this value is not fully supported by scientific evidence. Regarding the objective of achieving passive fit in implant-supported superstructures, two studies suggested that the acceptable misfit for clinically acceptable restorations ranges between 10 µm and 150 µm, indicating that absolute passive fit is likely unattainable. For Fontoura *et al*. (2018), passive fit is synonymous with an "ideal fit" and is considered essential for maintaining the bone–implant interface. Therefore, the concept of passive fit establishes that, in the absence of external load, the prosthesis should not induce stress in the implant components or surrounding bone.

The consequences of lacking passivity can be mechanical, such as screw loosening or fracture, or biological, including potential bone resorption due to stress on peri-implant tissues or the development of bacterial biofilm within the microgap, which is often present when passive adaptation between the implant and prosthetic component is not achieved (Silva *et al*., 2011; Toro *et al*., 2020).

The success of passive fit in implant-supported prostheses depends on numerous factors, including the implant transfer impression technique, distortions of the impression materials used, inclusion and casting procedures for metallic frameworks, welding techniques for multiple-unit implant prostheses, porcelain sintering processes, structural design of the prosthetic framework, and, ultimately, the experience of the professionals involved in fabricating the implant-supported prosthesis, whether using conventional methods or CAD/CAM technology (Hamata *et al*., 2005; Campi Junior *et al*., 2010; Silva *et al*., 2011; Toro *et al*., 2020).

The conventional technique for fabricating implant-supported prostheses essentially follows the same steps as a conventional prosthesis over natural teeth. This technique involves numerous clinical and laboratory stages, each of which may contribute to cumulative distortions in the final prosthesis (Barros *et al*., 2013). According to Hamata *et al*. (2005), the advent of osseointegrated implants and their prefabricated prosthetic components has provided clinicians with greater confidence compared to the marginal adaptation of restorations on natural tooth preparations, as these prefabricated implant components reduce the dependence on highly precise impressions required for natural teeth abutments. Mello *et al*. (2019) further note that conventional methods are more prone to procedural interferences, which are primarily associated with the clinician's manual skill and the laboratory technician's expertise.

The prosthetic material and fabrication technique can significantly influence the degree of misfit in the frameworks. Conventional casting methods involve multiple stages with substantial human intervention and material handling, which are inherently subject to contraction and/or expansion, potentially resulting in processing errors and inaccuracies. Although studies have generally shown better fit of implant-supported frameworks when using noble metal alloys compared with base metal alloys, the high cost of noble alloys has motivated the development of alternative metal alloys to overcome these limitations (Oteiza-Galdón *et al*., 2020).

Several techniques have been proposed to improve passive fit in implant-supported prostheses. One category focuses on incorporating steps to refine the adaptation of prosthetic components, including sectioning and welding frameworks, electro-erosion, and prefabricated cylinders fused to the metal framework. The other category aims to reduce fabrication steps, primarily through the use of computer-aided design and manufacturing (CAD/CAM) technologies and other prototyping methods (Barros *et al*., 2013; Fontoura *et al*., 2018).

According to Bernardes *et al*. (2012), these newer CAD/CAM-based workflows involve multiple components. Depending on the facility, they may include: (1) milling centers, (2) scanning centers, or (3) combined milling and scanning centers, each of which may operate at industrial, laboratory, or clinical levels. These components are interconnected, allowing for a wide range of tools and options when working with CAD/CAM technology.

For prosthesis fabrication using CAD/CAM techniques, gypsum models or even patients' dental arches can be digitized, generating digital files through scanning processes (Bernardes *et al*., 2012). França *et al*. (2015) emphasized that the method used to digitize and transfer implant positions can influence the accuracy of CAD/CAM-fabricated prostheses. Scanning can be performed directly, intraorally, or indirectly, in the laboratory on stone models obtained via conventional impression techniques.

In vitro studies by Barros *et al*. (2013) and Fontoura *et al*. (2018) employed aluminum master models with direct scanning to obtain monolithic or screw-retained frameworks over implants. These studies used metallic alloys and zirconia with the Neoshape and Zirkonzahn systems, respectively. The authors reported that rapid prototyping and computer-assisted milling (CAD/CAM) significantly improved vertical fit compared with traditional laboratory procedures.

Several studies have demonstrated that frameworks fabricated using CAD/CAM technology exhibit significantly lower vertical or marginal misfit compared with conventionally cast frameworks. França *et al*. (2015) reported mean vertical misfit values of 1.2–5.9 µm for CAD/CAM frameworks, significantly lower than the 11.8–12.9 µm observed in conventionally fabricated structures. Similarly, Mello *et al*. (2019), in a systematic review and meta-analysis, confirmed that CAD/CAM-fabricated frameworks consistently show superior marginal fit compared to the lost-wax casting technique. Tonin *et al*. (2021) and Peixoto *et al*. (2024) also observed reduced vertical misfit and improved passive fit in CAD/CAM frameworks relative to conventional casting, while Tonin *et al*. (2024) reported enhanced passive adaptation in CAD/CAM frameworks, although vertical misfit differences were not statistically significant. These findings highlight the advantage of digital manufacturing methods in achieving precise adaptation and potentially improving clinical outcomes for implant-supported prostheses.

This difference in vertical fit values can be attributed to the greater number of steps required to fabricate a cast metal framework, including waxing, investing, and casting. The main challenge lies in compensating for the shrinkage of the Co-Cr alloy, which is approximately 2.3% due to its high melting temperature (Barros *et al*., 2013).

CAD/CAM systems enhance the final strength of the metallic framework due to the absence of welding and offer the advantage of reduced dependence on operator skill, making the process less sensitive to human error (Mello *et al*., 2019). França *et al*. (2015) reported superior vertical fit for Co-Cr frameworks produced using CAD/CAM compared with those fabricated through conventional casting. These results are likely related to the precision and reproducibility of CAD/CAM procedures, which are faster and avoid errors associated with investing, wax elimination, casting, finishing, and polishing.

Mello *et al*. (2019) noted that for multi-unit implant-supported frameworks, vertical fit with CAD/CAM may differ slightly. They observed that while the precision of the casting technique for multi-unit prostheses depends on the same variables as single-unit restorations, milling these frameworks in a monolithic form is subject to more sources of interference. This reduces the ability to accurately reproduce areas with complex geometries, such as the implant platform and connection design.

According to Al-Meraikhi *et al*. (2018), fixed dental prostheses with fewer units are significantly more accurate than multi-unit prostheses. Bernardes *et al*. (2012) further highlighted that CAD/CAM technologies can be divided into different components, which directly influence the quality of the final product, the types of prostheses that can be produced, and the materials that can be used. Some milling units are unable to machine large frameworks with multiple units, while others have limitations when working with very hard metals, such as Co-Cr alloys.

According to Yilmaz *et al*. (2018), manufacturing technologies such as CAD/CAM and the introduction of new restorative materials have enabled the fabrication of complex and large-volume restorations with high precision. These frameworks can be produced using high-density polymer (HPD), titanium (Ti), or zirconia (Zi). HPD-based prostheses are suitable for provisional restorations. Both physical and virtual laboratory methods are commonly used to analyze misfit. The virtual method allows the digital framework and model to be superimposed to observe the minimal possible gap; however, scanning procedures may generate inaccurate values and inconsistent results, potentially leading to misinterpretation (França *et al*., 2015).

Hamata *et al*. (2005) reported that achieving an absolutely passive prosthesis is nearly impossible within the limitations proposed by Brånemark. Moreover, there is no consensus on the clinically acceptable level of misfit for multi-unit implant-supported prostheses, as clinical evaluations are subjective and dependent on the experience and judgment of each professional. The authors also noted that although the relationship between adaptation and adverse effects on bone tissue is not well established, poor fit may be associated with a higher incidence of mechanical failures due to stress accumulation. Therefore, passive fit should always be pursued, even recognizing the limitations of techniques and materials.

Bernardes *et al*. (2012) highlighted that current CAD/CAM systems in dentistry are capable of producing high-quality prosthetic restorations with a wide range of restorative materials and prosthesis types. However, they emphasize that the technique alone does not determine success, as the entire workflow involves multiple steps that must be carefully controlled to ensure proper outcomes. According to França *et al*. (2015), the rapid development and advancement of CAD/CAM processes will continue, making computerized techniques more cost-effective, flexible, and accurate, although high system costs remain a potential limitation.

França *et al*. (2015) also noted that there are numerous techniques and materials available for fabricating implant-supported frameworks, and currently no single combination of methods guarantees standardized results, reduced fabrication time, low cost, and precise fit. The authors stated that, with current materials and manufacturing methods, some degree of inaccuracy in the frameworks is inevitable. Nevertheless, Mello *et al*. (2019) emphasized that due to the inherent difficulty in achieving perfect fit between implants and their frameworks, well-controlled fabrication techniques are generally accepted as capable of providing successful long-term implant rehabilitation.

5. CONCLUSION

Based on the present study, the following conclusions can be drawn: 1 – CAD/CAM systems for the fabrication of implant-supported fixed prostheses demonstrated superior vertical fit compared to conventional techniques. 2 – CAD/CAM systems provided greater passive fit for the implant–prosthesis assembly, resulting in improved stress distribution across the surrounding bone structures.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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