UNIVERSIDADE DE SÃO PAULO
FACULDADE DE ODONTOLOGIA DE BAURU

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An approach on the use of CAD-CAM technology for the manufacture of removable partial dentures

Uma abordagem sobre o uso da tecnologia CAD-CAM para a confecção de próteses parciais removíveis

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Orientador: Prof. Dr. Vinicius Carvalho Porto

Coorientador: Prof. Dr. Joel Ferreira Santiago Junior

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“Toda a nossa ciência, comparada com a realidade, é primitiva e infantil- e, no entanto, é a coisa mais preciosa que temos."

Albert Einstein

ABSTRACT

The Removable Partial Denture (RPD) represents a specialty of great importance for Dentistry, being well indicated in many cases of Oral Rehabilitation. The purpose of this review was to investigate the use of CAD-CAM (computer aided design), as technologies for rapid updating and prototyping (RP) for the manufacture of PPRs. An electronic search was performed in the PubMed / MEDLINE, Web of Science, Cochrane Library and SciELO databases, according to the preferred report items for systematic analyzes and meta-analysis (PRISMA Statement) and was registered in the International Registry Prospective of Clinical Systematics (PROSPERO: CRD42020152197). A question about population, intervention, comparison, outcome (PICO) was "How do CAD-CAM structures perform similarly to those manufactured by specific techniques?" Clinical and in vitro studies were selected and analyzed selected and a total of 15 articles out of 358 were selected. A meta-analysis included clinical and in vitro studies based on the Mantel-Haenszel test with a 95% confidence interval (95% CI). For clinical studies, a quantitative analysis with a sample of 25 participants showed an average discrepancy between occlusal supports and niches of 184.91 μm (95% CI: 152.6 μm - 217.15 μm) and heterogeneity (I^2) of 0% , and considered the structures considered acceptable for the inheritance of the treatment. The predominant materials were Cobalt-Chromium (Co-Cr) and Polyetheretheretone (PEEK), the most recent being accepted for improved aesthetics. Quantitative data from in vitro studies revealed that the additive manufacturing technique (2,006 mm: 95% CI: -2,021 mm - 6,032 mm) was no different from the indirect technique (0.026 mm); (P = 0.329; random: I2: 94.34%). Conclude that clinical studies and in vitro research on planning and manufacturing of PPR infrastructures by CAD-CAM are still scarce. However, preliminary data can be adjusted and better aesthetic when compared to the conventional technique.

Keywords: CAD-CAM, Three-dimensional printing, removable partial denture

RESUMO

A Prótese Parcial Removível (PPR) representa uma especialidade de grande importância para a Odontologia, sendo bem indicada em muitos casos de Reabilitação Oral. O objetivo desta revisão sistemática foi investigar o uso de CAD-CAM (desenho auxiliado por computador), como tecnologias de fresamento e prototipagem rápida (PR) para fabricação de PPR's. Uma pesquisa eletrônica foi realizada nas bases de dados PubMed / MEDLINE, Web of Science, Cochrane Library e SciELO, de acordo com os critérios Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA Statement) e foi registrada no Registro International e Prospectivo de Revisões Sistemáticas (PROSPERO: CRD42020152197). Utilizou-se o quesito: população, intervenção, comparação, desfecho (PICO) e estruturou-se a questão principal da seguinte forma: "As estruturas de PPR confeccionadas por CAD-CAM têm desempenhos semelhantes as fabricadas pelas técnicas convencionais?". Estudos clínicos e in vitro foram selecionados e analisados separadamente e um total de 15 artigos de 358 foram selecionados. As metanálises incluíram estudos clínicos e in vitro baseados no teste de Mantel-Haenszel com intervalo de confiança de 95% (IC95%). Para estudos clínicos, a análise quantitativa com uma amostra de 25 participantes mostrou uma discrepância média entre apoios oclusais e nichos de 184,91 µm (IC 95%: 152,6 µm - 217,15 µm) e heterogeneidade (I^2) de 0%, e consideraram que as estruturas eram aceitáveis para a continuidade do tratamento. Os materiais predominantes foram Cobalto-Cromo (Co-Cr) e Polieterétercetona (PEEK), sendo as últimas amplamente aceitas pela estética aprimorada. Dados quantitativos dos estudos in vitro revelaram que a técnica de fabricação aditiva (2,006 mm: IC 95%: -2,021 mm - 6,032 mm) não foi significativamente diferente da técnica indireta (0,026 mm); (P = 0,329; aleatório: I^2: 94,34%). Constatou-se que estudos clínicos e pesquisas in vitro sobre planejamento e fabricação de infraestruturas de PPR's por CAD-CAM ainda são escassos. Concluiu-se que com base nos dados preliminares as estruturas de PPR confeccionadas por CAD-CAM apresentam ajuste semelhante e melhor estética quando comparados à técnica convencional.

Palavras-chave: CAD-CAM, Impressão Tridimensional, prótese parcial removível

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1 INTRODUCTION

1 INTRODUCTION

It is known that over the past few decades, there has been a considerable increase in the elderly population. This trend has widened over the years. Therefore, it should be considered that the number of elderly people will be much higher in future than that of some decades ago. In dentistry, it is known that the majority of users of removable prostheses are elderly and this is reflected in a great need for quality care for these individuals (CUNHA-CRUZ et al. 2007; EMAMI et al. 2013; DYE et al. 2012).

Tooth loss is result of several factors, mainly due to of caries and periodontal disease. The considerable absence of dental elements can result in difficulties in chewing, phonation, aesthetic consequences that affect general health, self-esteem and quality of life (HUGO et. Al, 2007). There are several treatment options for total or partially edentulous patients. Osseointegrated implants, fixed prostheses, partial and total removable dentures can be proposed to replace dental absences (COENYE et al. 2011; YASUI et al. 2012). Although the demand for dental implants has increased considerably, for various advantages, many toothless patients are still treated with removable prostheses, which have numerous clinical indications (YASUI et al. 2012; ETMAN et al. 2012; HUGO et al. 2007). In addition, there are many reasons for a patient to use a removable prosthesis, such as anatomical, physiological and financial factors (VAN DER ZEL et al. 2001; DURET et al. 1996; GOODACRE, CJ; BERNAL, G .; RUNGCHARASSAENG, 2003) .

The Removable Partial Denture (RPD) is a prosthesis indicated for partially edentulous patients, as it allows the replacement of several missing teeth at once (CAMPBELL et al. 2017). RPD is the option of choice for many patients for its varied advantages, among them, its conservative nature, low cost, easy access and speed. Therefore, it can be widely indicated and used from transitional procedures to definitive treatments (HARB et al. 2019; CAMPBELL et al. 2017; VAN DER ZEL et al. 2001; DURET et al. 1996).

This type of prosthesis conventionally has a metallic structure, previously designed in study models, which contains several components of the prosthesis: connectors, clasps, supports and saddle mesh. After making the metallic structure, the acrylic resin is inserted into the frame mesh, subsequently replacing teeth, soft tissue and bone (HARB et al. 2019; ETMAN et al. 2012).

For the correct framework planning, it is necessary that the dentist carry out an accurate planning. Firstly, the maxillary arches are molded and then study models are made. In the next step, it is possible to observe and plan the design of the new RPDs. This study is performed on a device called survayor (ARNOLD et al. 2018; SAITO et al. 2002). This device is handled and future guide plans and retentive areas are found to execute the correct design of the metal framework.

The study of the model is an important step in the planning of RPDs, as it allows the correct design of the structure, the position of the niches, the most appropriate type of clasps, the removal of retentive areas that can retain food, the creation of retention and parallelism of the abutments (WU et al. 2017; WILLIAMS et al. 2004). Therefore, it is crucial to identify changes in oral structures to accommodate the placement of the partial denture components in their designated ideal position in the abutment teeth, necessary to manufacture a RPD that has a successful prognosis.

In the dental clinic, it is common to find poorly planned and poorly designed prostheses, which probably did not carry out any previous planning, since most professionals, even those who offer treatment with RPDS, do not know how to execute a correct planning, much less use the survayor, and many who do, do not do it correctly. This function is very commonly delegated to the dental technician. Thus, it can cause irreversible consequences to the patient and lead to treatment failure (ETMAN et al. 2012; SAITO et al. 2002; DULA et al. 2015).

After studying the models in the survayor, planning the frame design and preparations in the mouth, a new model is made, this time copying the changes previously made in the remaining teeth. Then, the metal frame design in this model is followed and then it is sent to the dental laboratory for making the structure (traditional method). Then the technician proceeds to wax the drawing on the plaster for later casting in metal.

Typically, metal structures for RPDs are manufactured using cobalt-chromium (Co-Cr) alloys using coating / casting techniques due to their ease of manufacture, good strength and low cost. These manufacturing procedures have been successfully performed in dentistry for years and, as long as a correct study and planning are carried out, satisfactory treatments are obtained with good longevity.

On the other hand, it is known that one of the greatest advances in world technology in recent decades was the creation of CAD-CAM systems. The expression CAD-CAM refers to the design of a piece on a computer (Computer Aided Design) followed by its manufacture by a printing machine (Computer Aided Manufacturing). The CAD-CAM manufacturing process can include additive (rapid prototyping) or subtractive (milling) manufacturing. With technological developments over many years, current advances allow the use of various systems with CAD-CAM technology (GOODACRE et al. 2012; MIYAZAKI et al. 2009; BEUER et al. 2008).

Nowadays, an increasing number of companies from various sectors of the industry are researching ways to automate their processes. Many of them make use of CAD-CAM executing projects, with models idealized and designed on the computer in 3 dimensions, enabling the fabrication of faster and more efficient works, manufacturing the most varied objects and materials all over the world, in different areas of knowledge such as engineering and medicine, producing high quality parts, facilitating and automating manufacturing processes.

This innovation had its introduction in dentistry, at the end of the 70's with the aim of automating and improving production (CORREIA et al. 2006). CAD-CAM technology has revolutionized the area of oral rehabilitation, with an increasingly comprehensive demand for the treatment of patients. Obtaining digital dental prostheses using the CAD-CAM system, both on natural teeth and on implants, is now also a reality in dental clinics (MOURA and SANTOS, 2015). The system is basically composed of three components: a scanning scanner, which performs the virtual reading of the arcade, teeth, mold or model; CAD software, which carries out the design project for the future restoration on a computer; and a CAM unit, responsible for the manufacture of the restoration or structure.

This process is faster and more accurate than the conventional manufacture of RPDs, which depends on impressions, plaster models, wax sculptures, among other steps that prolong the treatment and sometimes require repetition of some steps. When discussing CAD-CAM and dental prostheses, it is noticed that this technology is highly inserted in the reality of dentistry to manufacture works such as inlays, onlays, fixed crowns, implant prostheses, maxillofacial prostheses, veneers, dental contact lenses (DARTORA et al. 2014; BERNARDES et al. 2012). In oral rehabilitation with fixed partial dentures, it is possible to finalize the cases in a single consultation, eliminating the stages of provisional crowns and subsequent consultations. (NISHIYAMA et al. 2019). However, when referring to RPDs, few studies report the use and effectiveness of CAD-CAM for its manufacture.

Although conventional techniques have already established advantages, it is important that research advances not only in fixed partial dentures, but also in other areas of rehabilitation, so that it is also applied in new research and technologies (WU et al 2017; CHEN et al. 2011; CAMPBELL et al. 2017). Possible advantages of the digital flow in PPR include reproducibility, fabrication of the structure in aesthetic materials, automatic determination of the insertion direction and rapid recognition of the retentive areas, eliminating the need to use the survayor (YE et al. 2017; CAMPBELL et al. 2017; ARNOLD et al. 2018). Thus, faster and more accurate planning is possible than with conventional techniques. In addition, the scanned models and structure design can be stored in a digital library for future use.

Although PPR's manufactured by CAD-CAM technology are under development, new studies may offer guidance to clinicians. However, there is a lack of consensus on its applicability and indication. Therefore, the purpose of this review systematic and meta-analysis was to evaluate and compare different techniques and possibilities involving CAD / CAM and conventional techniques, in addition to advantages and disadvantages, indications, quantitative data of marginal adaptation and longevity for different types of prostheses. The null hypothesis formulated was that there would be no significant difference in the internal discrepancy obtained in PPR infrastructures obtained by the CAD-CAM method when compared to the conventional method or by diversifying the technique in the CAD-CAM system.

2 ARTICLE

2 ARTICLE

JPD-19-1110

SYSTEMATIC REVIEW

Computer-aided technology for fabricating removable partial denture frameworks: A systematic review and meta-analysis

ABSTRACT

Statement of problem. A consensus that establishes the indications and clinical performance of removable partial denture (RPD) frameworks designed and manufactured with computer-aided design and computer-aided manufacturing (CAD-CAM) systems is lacking.

Purpose. The purpose of this systematic review and meta-analysis was to evaluate the currently published literature investigating different CAD-CAM methods and techniques for RPD manufacturing and their clinical performance.

Material and methods. A comprehensive search of studies published up to September 2019 was performed in PubMed/MEDLINE, Web of Science, Cochrane Library, and SciELO databases according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA Statement) criteria and was registered and approved in the International Prospective Register of Systematic Reviews (PROSPERO: CRD42020152197). The population, intervention, comparison, outcome (PICO) question was “Do the CAD-CAM frameworks have similar performances to those fabricated by conventional techniques?” The meta-analysis included clinical and in vitro studies based on the Mantel-Haenszel test with

95% confidence interval (95% CI). Clinical and in vitro studies were selected and analyzed separately.

Results. A total of 15 articles out of 358 were selected. For clinical studies, quantitative analysis with a sample of 25 participants showed a mean discrepancy between occlusal rests and rest seats of 184.91 μm (95% CI: 152.6 μm – 217.15 μm) and heterogeneity (I^2) of 0%. Clinical data considered that frameworks were acceptable for continuity of treatment. The predominant materials were cobalt-chromium (Co-Cr) and polyetheretherketone (PEEK), and studies using Co-Cr reported that the structure required adjustments. In addition, it has been reported that the indirect technique was time-consuming and selective laser melting (SLM) can be costly. PEEK structures have been more widely accepted because of improved esthetics. Quantitative data from the in vitro studies revealed that the additive manufacturing technique (2.006 mm: 95% CI: -2.021 mm – 6.032 mm) was not significantly different than the indirect technique (0.026 mm); (P=.329; random: I^2: 94.34%).

Conclusions. Clinical studies and in vitro research on CAD-CAM planning and manufacturing of removable prosthesis frameworks are still sparse. However, preliminary data indicate a similar fit and esthetic improvement when compared with the conventional technique.

CLINICAL IMPLICATIONS

The use of computer-aided technology for RPD frameworks presented substantial potential for patient oral wellness and research. RPDs made with CAD-CAM technology are similar or superior to those made with the conventional technique.

INTRODUCTION

Computer-aided design and computer-aided manufacturing (CAD-CAM) technology has been successfully applied in many fields of dentistry,[1-5] with promising applications for removable partial denture (RPD) framework production.[6-8] This technology provides construction of a 3D digital framework with accurate designs, using software programs with geometric analysis tools.[9] The definitive framework can be manufactured by using either subtractive or additive CAD-CAM techniques with different materials, including cobalt-chromium (Co-Cr) and polyetheretherketone (PEEK).[6,10]

Possible advantages of this digital workflow include an improvement in planning[11,12] with automatic determination of the insertion and removal path and practical recognition and control of undercuts.[13-15] In addition, the digital cast and component design can be stored in a digital library for future use, allowing for faster digital planning than in conventional techniques.[16] It also provides inherent reproducibility, thus circumventing interoperator inconsistencies and improving quality standards in the dental prosthetic laboratory.[11,13,17-19]

Although CAD-CAM RPDs are under development, new studies may offer guidance to clinicians. Nonetheless, there is a lack of consensus for their applicability and clinical indication. Therefore, the purpose of this systematic review and meta-analysis was to evaluate and compare different techniques and possibilities involving CAD-CAM and conventional techniques, as well as advantages and disadvantages, indications, quantitative data of marginal adaptation, and longevity for different types of prostheses. The null hypothesis was that different techniques do not influence the internal discrepancy of RPD frameworks designed with CAD-CAM technology.

MATERIAL AND METHODS

This project was conducted under the criteria established by the Cochrane Collaboration (Cochrane Handbook for Systematic Reviews of Interventions - Handbook 5.1.0)[20] and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA Statement) recommendations for the development and elaboration of systematic reviews with meta-analysis.[21-23] This systematic review was registered and approved in the International Prospective Register of Systematic Reviews (PROSPERO) database (Registration: CRD42020152197) to allow evaluation of the proposed methodological design.

Analyses were based on the population, intervention, comparison, and outcome (PICO) index: patients undergoing prosthetic treatment involving digital systems (population), patients who received RPDs (intervention), patients who received RPDs using digital and conventional methods (comparison), and quantitative adaptation and longevity data for both types of prostheses (outcome). Studies were selected according to the following inclusion criteria: English language, studies involving scanning (intraoral or laboratory), planning, manufacturing of frameworks for RPDs with CAD-CAM technology, and clinical and in vitro studies. Articles that did not present a complete framework and systematic reviews were excluded.

Multiple databases, including Medline/PubMed, Cochrane Library, SciELO, and Web of Science, were used to search for articles published until September 24, 2019. The following MeSH/PubMed-based Boolean operators were used: “Removable partial Denture”, “Metal free,” “Polyetheretherketone,” “CAD-CAM,” and “Titanium.” The related search within PubMed is presented in Supplementary Table

1. A manual search of specific journals and related studies in the field of dental prosthesis and digital technology was conducted (Supplementary Table 2).

Data collection was performed by 2 previously calibrated reviewers (M.P., J.F.S.Jr.). In case of disagreement, consensus meetings were held to evaluate the titles and abstracts selected. Subsequently, a definitive consensus meeting (including researchers H.S.V., A.P.C.C., R.M.B.C.) was held, in order to evaluate selected articles, data collection, and risk of bias. Finally, further clarification of doubts and technical support was offered by an additional advisor (V.C.P.). The included clinical studies were evaluated and classified according to the type of study performed.[24] Because of their different methodologies, the in vitro studies, including studies with computer simulations, were analyzed according to the parameters of their various methodologies.[25] All data in the tables were extracted by 2 investigators (A.P.C.C., R.M.B.C.) and checked by a third (J.F.S.Jr.).

For bias risk analysis, different types of methodologies were compared, and a detailed analysis of the employed system and manufacturing type milling (MI) or additive manufacturing (AM) was performed. The internal discrepancy of the frameworks manufactured with CAD-CAM was evaluated by using the Mantel-Haenszel test with a 95% confidence interval (95% CI). For the in vitro studies, the analysis was performed considering the fit and overlap in the anterior palatal major connector in frameworks produced with the indirect technique and the occlusal rest in frameworks produced with the direct and indirect techniques and stereolithography (SLA). Quantitative data from clinical studies were used on rest seat fit in Co-Cr frameworks produced with SLA combined with conventional and selective laser melting (SLM). Meta-analysis was performed by using a software program (Comprehensive Meta-Analysis Software v3.0; BioStat Inc).[26] The number of participants was considered as a statistical unit, and heterogeneity (I^2) was used as a percentage for evaluation between studies. I^2 values greater than 75 (0-100) indicated high heterogeneity.[22,27-29]

RESULTS

A total of 358 articles were found, and 30 were selected based on their titles. After reading the abstracts, articles that used the CAD-CAM technique for RPD framework fabrication were selected for full text reading. Eventually, 15 articles were selected: 7 in vitro studies, 2 clinical study, and 6 clinical reports (Fig. 1).

Clinical studies were subclassified as longitudinal and cross-sectional, totaling 25 participants who received removable prostheses with Co-Cr frameworks processed with the CAD-CAM system through the SLM technique[6] or indirect techniques (SLA + conventional casting)[15] (Table 1). Both studies indicated that CAD-CAM frameworks were acceptable; however, it should be noted that Ye et al[6] reported significant differences in internal discrepancy between frameworks made with the digital system and those made with the conventional technique and reported that the conventional technique group showed the lowest average values ($P<.05$) (Table 1). It was possible to consider an analysis of the internal discrepancy of CAD-CAM frameworks[6,15] in rest seat adaptation, having in one of these studies 3 analysis subgroups.[6] The average observed discrepancy was estimated at 185 μm (95% CI: 153 μm - 217 μm) (Fig. 2). No heterogeneity was identified in the performed analysis ($P=.420$; $I^2=0\%$, fixed effect) (Fig. 2). The results are presented in Tables 1 and 2.

Women predominated in all patient report studies.[7,8,11,30-32] The manufacturing techniques included SLM, MI, and SLA+conventional casting, and the relevant software included FreeForm (Geomagic Freeform; 3D Systems), Geomagic Studio

6.0 (Geomagic Studio 6.0; 3D Systems), 3Shape Dental System (3Shape Dental System; 3Shape A/S) and Dental System D 810 (Dental System D 810; 3D Systems) [7,8,12,30-32] Regarding the materials used, Co-Cr and PEEK were most commonly used, while one study used titanium and 2 used combined materials.[8,32]

Considering the in vitro studies, 2 using the indirect AM technique, were selected for quantitative analysis for the accuracy of the frameworks.[33,34] For the anterior palatal strap, a mean accuracy fit of 0.1 mm (95% CI: 0.067 mm – 0.133 mm) (Fig. 3) was observed and heterogeneity between analyses (P =.239; I^2=28, fixed-effects model) (Fig. 3) was identified. In addition, posterior palatal straps analyses showed a mean accuracy fit of -0.297 mm (95% CI: -0.483 mm – -0.111 mm) (Fig. 4) and significant heterogeneity was observed between analyses (P<.001; I^2=94.23, random-effects model) (Fig. 4). Three studies,[33-35] which applied indirect AM, were selected for the comparison of fit accuracy between rest seats. The mean fit accuracy was 0.026 mm (95% CI: -0.042 mm – 0.093 mm) (Fig. 5) and heterogeneity was significant between analyses (P<.001; I^2=98.402, random-effects model) (Fig. 5). A comparison of fit accuracy between rest seats involving 2 studies[33,35] that applied indirect AM was performed. Mean accuracy was -0.008 mm (95% CI: -0.085 mm – 0.070 mm) (Fig. 6) and significant heterogeneity between analyses was observed (P<.001; I^2=99.71, random-effects model) (Fig. 6). Fit accuracy of framework rest seats produced with the direct AM technique was compared between 2 studies.[33,35] The mean fit accuracy was 2.006 mm (95% CI: -2.021 mm – 6.032 mm) (Fig. 7). No statistically significant differences between groups (P=.329) were observed; however, significant heterogeneity was observed between analyses (P <.001; I^2=94.34, random-effects model) (Fig. 7). The results of the in vitro studies are presented in Tables 3 and 4.

DISCUSSION

The results observed in this systematic review and meta-analysis supported the null hypothesis, which stated that the internal discrepancy of Co-Cr frameworks generated with the indirect technique was similar to the conventional technique. Considering the internal discrepancy between digital techniques, analysis of the literature revealed reduced discrepancy in frameworks manufactured with SLM compared with the indirect technique.[6,15] Based on these results, frameworks generated with SLM appear to be more precise than those generated with the indirect technique, although additional studies are required to confirm this finding.[36] Clinical reports[30,31] have also evaluated these groups. Bibb et al[30] used the indirect technique for fabrication of frameworks and reported a longer manufacturing time and the need for adjustments in the manufactured frameworks. Williams et al[31] used the SLM technique for manufacturing frameworks; they indicated that the frameworks required certain adjustments and underscored their higher manufacturing cost.

Some studies evaluated milled PEEK clasps[7,8,32] and reported higher patient satisfaction regarding esthetic outcomes,[37] concluding that this material can be considered as an alternative to overcome the esthetic limitations of conventional frameworks. However, such clasps facilitate plaque accumulation, probably because of their porosity and roughness,[8] common characteristics of polymers.[38]

Intraoral scanners were used in the manufacturing of titanium structures designed with the aid of SLM.[11] The authors reported that intraoral scanners were a viable alternative for patients with limited mouth opening, as they allowed 3D reconstruction of intraoral structures with high precision in a short time. This was because the CAD software package could automatically seal unwanted cuts, select appropriate components from the library, and drag them over the dental mold, thus minimizing working time and eliminating variability between operators.[11]

The in vitro studies presented in this systematic review and meta-analysis tested different manufacturing techniques. The conventional casting technique was included as a control group in 4 studies.[10,33,36,39] For CAD-CAM-assisted manufacturing, additive and subtractive techniques were included. In addition, some studies considered the influence of direct and indirect workflows.[10,33-35] Arnold et al[10] reported superior adaptation of the modified clamps produced by direct and indirect grinding ($P<.05$), most likely because of the contraction of the Co-Cr alloy combined with the polishing procedures. Although high melting range alloys such as Co-Cr have greater solidification shrinkage and polishing procedures may produce a metal loss of 127 μm,[40] it is still not clear why the indirect MI group showed better results compared with the conventional group, which is a limitation of the study. However, Soltanzadeh et al[33] reported better precision adjustment of structures produced with conventional casting compared with AM groups. The disparity between these results is probably because of differences in the study methodology, including sample size, techniques evaluated, and the measurement methods used.

Among the different CAD-CAM methods evaluated, the direct subtractive technique appeared to produce the best fit.[10,34,39] This technique enables better surface finish that facilitates polishing, thus reducing the need for adjustments. Similarly, Soltanzadeh et al[33] reported poorer general adaptation of the structures produced with AM, in addition to inadequate adjustment of the anterior palatal strap. They suggested that this finding was probably a consequence of errors during digitization procedures or during stereolithography processing by the software; however, satisfactory adaptation was still observed.[13,33]

Arnald et al[10] did not observe a statistically significant difference between milled modified clasps generated directly or indirectly. However, the authors reported worse vertical adjustment ($P<.05$) in the direct AM group compared to the indirect group. Some factors, such as different measurement methods, areas, arch, and techniques may explain these contrasting results.

Regarding the evaluation method used for the adaptation of the prostheses in in vitro studies, a few studies used low viscosity silicone in their analyses.[36,39] Others used a digital overlay, which will likely be used in the future to standardize adaptation verification, thus avoiding material distortions.[10,33,34] Some studies investigated PEEK as a new alternative to metal RPD frameworks.[7,8,10,39,41] However, a standard structure design has not been established with respect to framework planning: clasp choice, depth of support, thickness or biomechanics. Additional clinical studies with this material are required for accurate planning and rehabilitation using RPDs.

The results of the meta-analysis of in vitro studies showed a discrepancy between studies, but it was not statistically significant (P=.329). As these values are minimal and restricted to digital simulation, it is likely that these results are not clinically relevant. Therefore, further studies are necessary to validate these findings. Considering the meta-analysis carried out in clinical studies involving 25 patients, an average mismatch of 185 μm was identified for occlusal seats. After adaptation and polishing, the discrepancy in structure adjustment can be reduced and controlled. This further emphasizes the need for more clinical studies, generating data to enable comparison with the conventional technique.

Regarding acquisition of the resin and teeth base, the procedures followed a conventional protocol, recording all stages from assembly on the articulator to final molding.[7] One study indicated that the union of the clasp surface and connectors manufactured using PEEK with the resin base was carried out through previous treatment of this surface with airborne-particle abrasion (50-μm Al_20_3 particles). In addition, this study did not indicate clinical complications related to the resin part after a 2-year follow-up. Therefore, it is suggested that the lower modulus of elasticity of PEEK and acrylic resin compared with that of metal and resin, may help to reduce interface problems.[8]

One study reported a complete technique for obtaining RPD by using CAD-CAM, the major and minor connectors (Ceria stabilized zirconia and alumina (Ce-TZP/A; Yamakin), the clasps (PEEK; Evonik), and the artificial teeth (composite resin, Vita Enamic; Vita Zahnfabrik) by the milling machine.[32] However, some studies did not report the resin component (teeth and gingiva).[6,11,15,30,31] There are still important challenges in the use of PEEK, such as the difficulty of polishing and adjusting the retention capacity .[8]

There have been few published studies on the subject to date, with variations in the sample size, way of obtaining the casts, use of different software programs, infrastructure manufacturing techniques, and methodology used to verify the fit and type of materials, making data analysis and comparison between conventional and digital methods difficult. Of note, most studies identified did not include a control group for comparison.

CONCLUSIONS

Based on the findings of this systematic review, the following conclusions were drawn:

1. The software used and the level of experience of the professional possibly influence the quality of RPD structures.
2. The use of CAD-CAM technology for the manufacture of RPD frameworks can be a viable alternative.

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TABLES

Table 1. Clinical studies of RPDs processed with CAD-CAM systems

Author	Year	Level of evidence	Study type	Number of patients	Number of measurements	Fit measuring procedure	Manufacturing	Framework material	Planning Software	Kennedy class	Areas evaluated	Follow-up	Results
Lee et al	2017	III-2	Longitudinal (III-2)	10	348	Silicone registration + analysis in stereomicroscope and image program.	Stereolithography (acrylic resins) + Conventional casting	Co-Cr	Sensable f reeForm; 3D Systems	I II III	Rests Clasps Minor connector Major connector Proximal plates Edentulous area	2 years and 8 months	No failed dentures were observed during the period evaluated. RPD digitals varied in accuracy of fit. In the analysis of the discrepancies under the cingulum rest, the accuracy of the periphery was higher than that of the center.
Ye et al	2017	IV	Cross-sectional (IV)	15	NR	Silicone registration + analysis in stereomicroscope and software ZoomBrowser;Canon	AM/SLM Conventional technique	Co-Cr Co-Cr	Dental System; 3Shape A/S	I (8) II (3) III (3) IV (1)	Occlusal rests Zone closest to the occlusal center (Zone C). Zone closest to the marginal ridge (Zone R). Zone between Zone C and R (Zone M).	NR	The RPD framework designed by SLM technique may meet the clinical requirements with satisfactory retention, stability and no undesired rotation. The average gap between the occlusal rest and the corresponding rest seat of the CAD-CAM frames was slightly larger than that of the investment casting frameworks.

Co-Cr, cobalt-chromium; NR, not reported; AM, additive manufacturing; SLM, selective laser melting; RPD, removable partial denture; CAD-CAM, Computer-aided design/computer-aided manufacturing

Table 2. Clinical reports of RPDs processed with CAD-CAM systems

Author	Year	Number of patients	Level of evidence	Gender	Kennedy class	Arch	Manufacturing	Software for planning	Framework material; Thread made	Results
Bibb et al	2006	1	IV	Female	I	Mandible	Stereolithography (acrylic resin) + conventional casting	FreeForm; 3D Systems	Co-Cr	The RPD frame requires adjustments. The manufacturing time was long. The frame was considered “acceptable” to continue with the next stages.
Williams et al	2006	1	IV	Female	I	Mandible	SLM	FreeForm; 3D Systems	Co-Cr; Sandvik Osprey	The frame demanded some adjustments representing a great cost.
Harb et al	2019	1	IV	Female	I	Mandible	Milling machine	Dental System; 3Shape A/S	PEEK; Invibio	Patient demonstrated satisfaction with esthetics and function. Patient reported lower retention force when comparing with the old Co-Cr structure.
Wu, Li, Zhang	2017	1	IV	Female	IV	Maxilla	SLM	Dental System; 3 Shape A/S	Titanium	RPD can be used in patients with mouth opening limitations. This technique decreases interoperator variability. Provides greater precision when compared with conventional techniques Reduces treatment time and cost.
Ichikawa et al	2019	1	IV	Female	I	Mandible	Miling (only clasps)	Geomagic Freeform; 3D Systems	PEEK; Invibio CoCr	The clasps accumulated microbial plaque. RPD was considered satisfactory by the patient.
Nishiyama et al	2019	2	IV	Female Female	III I	Maxilla Mandible	Milling	Dental System D-810 ;3Shape A/S Freeform (denture base);3D Systems	Ce-TZP/A (major and minor connectors);Yamakin PEEK (retention clasp);Evonik	No clinical complications or denture fractures were reported. The scores of patient satisfaction were improved after delivery of prostheses. This technique reduced treatment time.

Co-Cr, cobalt-chromium; NR, not reported; SLM, selective laser melting; RPD, removable partial denture

Table 3. Data summary of in vitro articles selected

Author/ Year	Sample size (n)	Arch	Kennedy class	Groups	Manufacturing	CAD-CAM technique	Framework material	Software for planning	Fit measuring procedure
Eggbeer et al 2005	NR	Mandible	III	SL Thermojet Solidscape Prefactory	CAD-CAM + LWT	AM	Co-Cr Not casted Not casted Co-Cr	Sensable freeform;3D Systems	NR
Ye et al 2018	15	Mandible	II	PEEK	CAD-CAM Conventional casting	Milling	PEEK NR	3Shape Dental System (2015); 3Shape A/S and Geomagic Studio (2012); 3D Systems	Silicon impression and digital analysis
Soltanzadeh et al 2018	10	Maxilla	III	LWT CAD-Printing CAD-Printing from stone model LWT from resin model	Conventional casting CAD-CAM CAD-CAM CAD-CAM + LWT	AM (NR) AM(NR) AM (SL)	Co-Cr - NR NR Co-Cr	NR	Digital superimposition
Arnald et al 2018	3	Maxilla	III	Ami AMd MIi MId LWT	CAD-CAM + LWT CAD-CAM CAD-CAM + LWT CAD-CAM Conventional casting	AM (NR) AM (SLM) Milling Milling	Co-Cr Co-Cr Co-Cr PEEK Co-Cr	3Shape Dental Designer (2013); 3Shape A/S	Light microscopy
Tasaka et al 2019	5	Mandible	II	AM-Cast SLS	CAD-CAM + LWT CAD-CAM	AM (NR) AM (SLS)	Co-Cr NR	Digistell; Digilea	Digital superimposition
Negm et al 2019	10	Maxilla	I	Direct CAD-CAM technique Indirect CAD-CAM technique	CAD-CAM CAD-CAM + thermopress technique	Milling AM	PEEK PEEK	3Shape Dental System; 3Shape A/S	Digital superimposition
Bajunaid et al 2019	15	Mandible	III	LWT SLM	Conventional casting CAD-CAM	AM (SLM)	Co-Cr Co-Cr	3Shape Dental System; 3Shape A/S	Silicon impression and digital microscopy

Co-Cr, cobalt-chromium; NR, not reported; AM, additive manufacturing; SLM, selective laser melting; LWT, lost-wax technique; SL, stereolithography; SLS, selective laser sintering; PEEK, polyetheretherketone; AMi, indirect additive manufacturing; AMd, direct additive manufacturing; MIi, indirect milling; MId, indirect milling.

Table 4. Summary of each in vitro study selected

Study	Summary	Model
Eggbeer et al 2005	Only stereolithography group presented satisfactory results, with good accuracy	Not reported
Ye et al 2018	PEEK RPDs presented better fit than cast RPDs ($P<.01$)	Silicon impression analysis and digital analysis
Soltanzadeh et al 2018	Conventional frameworks showed better fit and accuracy in comparison with additive manufacturing frameworks ($P<.05$). However, all methods reached the clinical accepted parameters. Rests and reciprocal plates showed the highest accuracy and fit, for all methods tested. Major connectors presented the poorest fit, particularly for additive manufacturing technique	Digital superimposition
Arnald et al 2018	The CAD/CAM direct and indirect milling group showed better fit in comparison with conventional LWT group. The additive manufacturing groups presented highest discrepancies. CAD/CAM techniques can provide accurate RPDs	Light microscopy analysis
Tasaka et al 2019	The accuracy of the two techniques varied according to the framework component evaluated. The SLS group presented smaller overall misfit than additive manufacturing plus LWT group.	Digital superimposition analysis
Negm et al 2019	The RPDs obtained directly from milled PEEK blanks showed better overall fit when compared to the indirectly produced RPDs. Both CAD/CAM techniques produced RPDs with acceptable fit.	Digital superimposition analysis
Bajunaid et al 2019	The overall misfit between the techniques did not differ. SLM can be applied in order to produce RPD frameworks	Silicon impression and microscopy analysis

SLM, selective laser melting; LWT, lost-wax technique; SLS, selective laser sintering; PEEK, polyetheretherketone.

FIGURES

Figure 1. Data of article selection according to PRISMA diagram.

PRISMA 2009 Flow Diagram

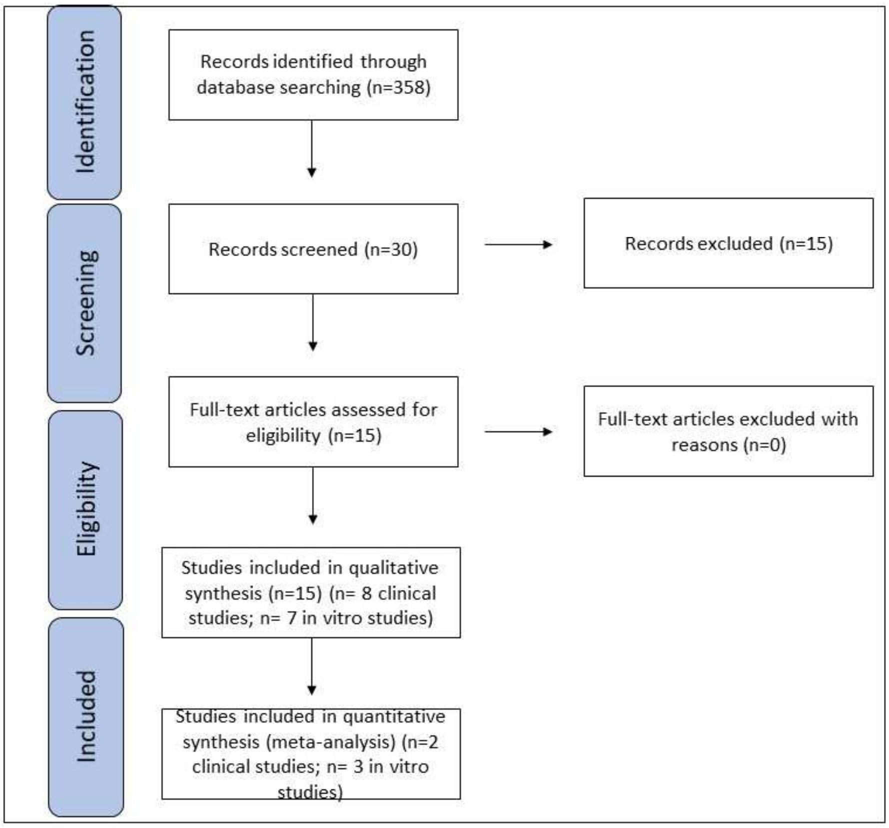
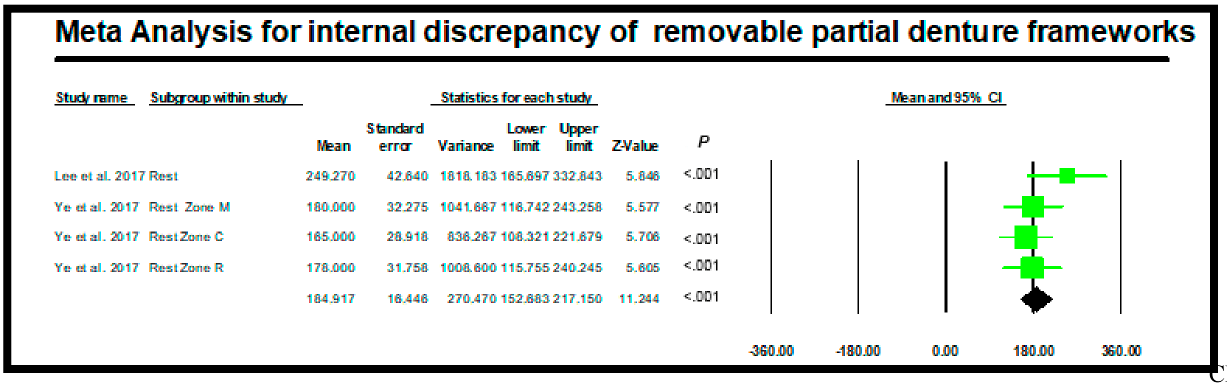
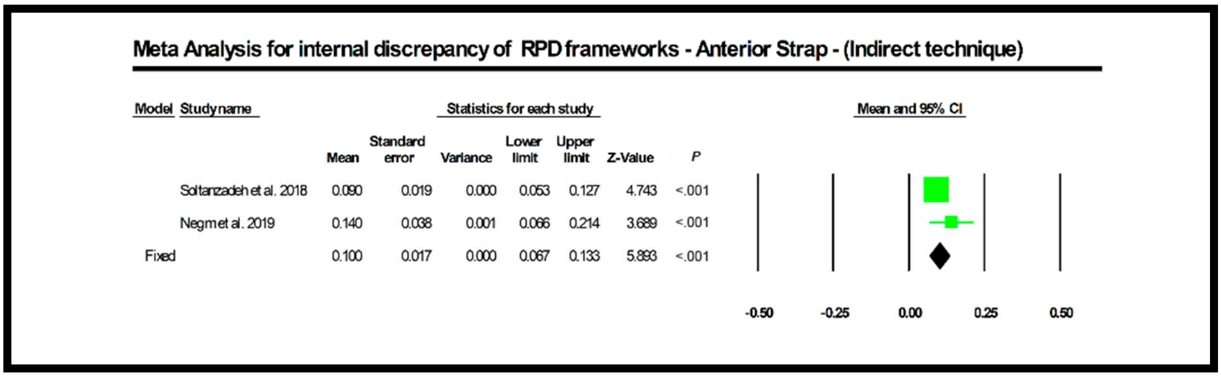


Figure 2. Meta-analysis graph indicating internal discrepancy analysis for removable partial denture frame.



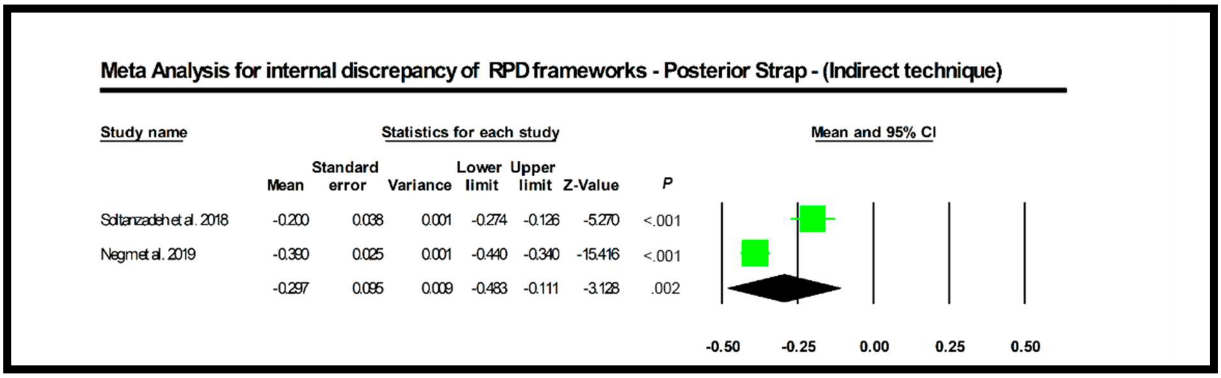
CI, confidence interval.

Figure 3. Meta-analysis forest plot showing the comparison of accuracy of RPD major connectors (anterior palatal straps) produced with indirect additive manufacturing.



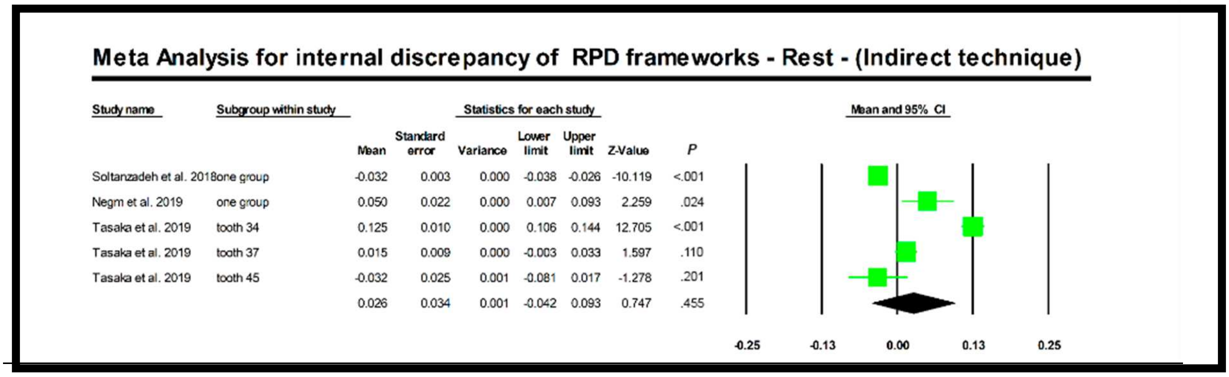
RPD, removable partial denture; CI, confidence interval.

Figure 4. Meta-analysis forest plot showing comparison of accuracy of RPD major connectors (posterior palatal straps) produced with indirect additive manufacturing.



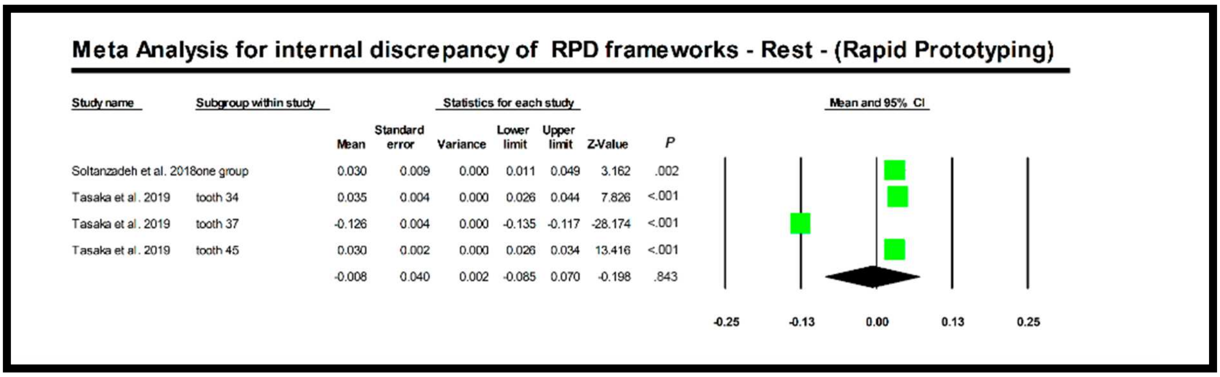
RPD, removable partial denture; CI, confidence interval.

Figure 5. Meta-analysis forest plot showing comparison of accuracy of RPD rest seats produced with indirect additive manufacturing.



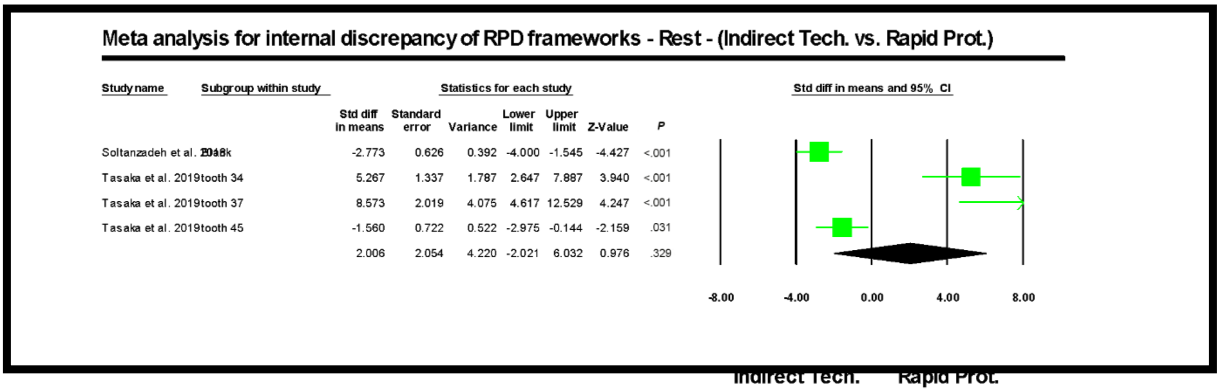
RPD, removable partial denture; CI, confidence interval.

Figure 6. Meta-analysis forest plot showing comparison of accuracy of RPD rest seats produced with indirect additive manufacturing.



RPD, removable partial denture; CI, confidence interval.

Figure 7. Meta-analysis forest plot showing the comparison of the accuracy of RPD rests produced with direct additive manufacturing.



RPD, removable partial denture; CI, confidence interval.

Supplementary Table. Manual search was performed in the following journals:

The Journal of Prosthetic Dentistry
The Journal of Engineering in Medicine
Journal of Prosthodontics
The International Journal of Prosthodontics
The Journal of Advanced Prosthodontics
Journal of Prosthodontic Research
Journal of Oral Rehabilitation
Medical & Biological Engineering & Computing

3 DISCUSSION

3 DISCUSSION

This systematic review evaluated studies that measured the adaptation or adjustment of RPD's structures by CAD-CAM methods, concluding that digital techniques for making RPD infrastructures seem to be a viable alternative. The results found in this systematic review accept the null hypothesis: the internal discrepancy in the cobalt-chromium infrastructures made by the mixed technique, when compared to the conventional technique, presented clinically acceptable values.

According to previous studies, the introduction of CAD-CAM, reduced and standardized the laboratory steps, which led to improvements in the quality of RPDs, including better adjustment accuracy. Traditional waxing and casting procedures depend on the processes performed in the laboratory, the professional's experience and the characteristics of the chosen alloy. These aspects can result in several errors that have a negative impact on the adaptation of the RPD structures. However, these results are conflicting in some studies.

Among the different CAD-CAM methods evaluated, the direct subtractive technique seems to produce a better fit. YE et al. (2018) and NEGM et al. (2019) found, respectively, averages of precision of 42.8 μm and 110.0 μm. ARNALD et al. (2018) obtained a precision adjustment of 43 μm (horizontal) and 38 μm (vertical) in the occlusal supports. These results can be explained by a better surface finish when using this technique, which can facilitate polishing, reducing its influence on the final adjustment of the structure.

While, according to ARNALD et al. (2018), the additive technique (selective laser fusion) produced larger discrepancies, with average values of 365 μm (horizontal) and 363 μm (vertical). Likewise, SOLTAZANDEH et al. (2018) reported less adaptation from structures produced with rapid prototyping (150 μm), also highlighting a greater mismatch of the anterior palatal bar (330 μm). It was suggested that these results could have been a consequence of errors introduced during the scanning procedures or during the processing of STL files performed by the software used. Despite this, the authors stated that these values were within the clinically accepted parameters (EGGBEER et al., 2005; SOLTAZANDEH et al., 2018).

When direct and indirect workflows were taken into account, ARNALD et al. (2018) did not notice a statistical difference between directly and indirectly milled frames. However, the authors found greater vertical mismatch ($p < 0.05$) in the direct rapid prototyping group compared to the indirect group. SOLTAZANDEH et al. (2018) obtained, using the additive technique, superior adjustment when applying the indirect workflow in combination with conventional casting. In contrast, TASAKA et al. (2019) found that direct rapid prototyping using additive manufacturing provided a smaller mismatch, suggesting that this technique had better re productivity. Many factors may have influenced these contrasting results, such as different measurement methods applied, areas, arcs and techniques evaluated. In addition, it is worth mentioning the influence of the software used and the level of knowledge of the professional. Thus, future studies on this subject are needed.

It is worth mentioning that WILLIAM (2006), using the Selective Laser Melting (SLM) technique, manufactured PPR structures and considered that they are possible to be used, however there is a need for some adjustments, in addition to emphasizing that this process requires a high cost. Despite the internal discrepancies and the need for corrections, the authors reported that the infrastructures made in

CoCr with the aid of a digital system through these two techniques are acceptable for the rehabilitation treatment.

However, YE et al. (2017) showed values between 165 - 180 µm, in the SLM technique. In view of these results, the SLM technique can perform a technique with greater precision when compared to an indirect technique (planning in the software + 3d printing in resin + conventional casting). According to these results, BAJUNAID et al. (2019), in vitro study, compared these two techniques, finding that there was no statistically significant difference, however, emphasizing that the SLM technique presents less discrepancy than the indirect technique. Clinical reports also confirm these findings (BIBB, EGGBEER and WILLIANS; 2006; WILLIAM 2006). BIBB, EGGBEER and WILLIANS (2006), used the indirect technique for the fabrication of the infrastructures, emphasizing that the frame needs adjustments and the fabrication requires a long period of time.

Considering the CAD-CAM technique and the material used, WU, LI and ZHANG (2017) reported the manufacture of titanium frames with the aid of the SLM technique. The authors highlighted that this technique offers better precision when compared to the conventional one. This is due to the ability of the CAD software to automatically remove unwanted retention areas, check the retention of the columns and select RPD components from the virtual library and bring them over the 3D dental model, making a prototype by the software, thus minimizing the time and eliminating variability between operators.

When in vitro studies are considered, the articles included different infrastructure manufacturing procedures. The conventional casting technique was included as a control group in four studies (ARNALD et al., 2018; SOLTAZANDEH et al., 2018; YE et al., 2018; BAJUNAID et al., 2019). For the manufacture of CAD-CAM frames, additive and subtractive techniques were applied. In addition, some studies have taken into account the influence of direct and indirect workflows (ARNALD et al., 2018; SOLTAZANDEH et al., 2018; TASAKA et al., 2019; NEGM et al., 2019).

YE et al. (2018) observed a better adjustment of directly milled PEEK structures ($p < 0.05$). Similarly, ARNALD et al. (2018) also observed a superior adaptation of clasps made digitally using direct and indirect milling ($p < 0.05$) and suggested that the contraction of the Co-Cr alloy, combined with the necessary polishing procedures, may have induced these results. Although it is known that high-fusion alloys, such as Co-Cr, have greater solidification retraction and that polishing procedures can produce a loss of metal of 127μm (BRUDVIK and REIMERS, 1992), this does not fully explain the best results of the indirect milling over conventional,.

On the other hand, SOLTAZANDEH et al. (2018) obtained better precision adjustment of structures produced with conventional casting compared to groups of rapid prototyping. BAJUNAID et al. (2019) found no statistical difference between the general averages of the conventional casting and selective laser fusion groups ($p > 0.05$). The disparity between these results is probably due to differences in the applied methodologies: sample size, evaluated techniques and, mainly, the adaptation measurement methods used in each study.

The results of the meta-analysis, for the in vitro studies, showed a discrepancy between the studies. The discrepancy of direct rapid prototyping was smaller when compared to the indirect technique. However, this comparison did not reach statistical significance ($p = 0.329$). Thus, as these values are reduced and confined in a digital simulation, it is possible that these results do not reach clinical relevance. Therefore, further studies are needed. Considering the meta-analysis performed for clinical studies involving 25 patients, an average mismatch of 184.91 μm was identified for occlusal supports. These values, considering the process of adaptation and polishing, can be reduced and controlled, emphasizing the importance of new clinical studies to present the comparison with the conventional technique.

Another important aspect refers to different CAD-CAM techniques and materials used to manufacture RPD frames in clinical case reports. HARB et al (2019); ICHIKAWA et al (2019); NISHIYAMA et al (2019) made PEEK clasps using a subtractive technique, showing that patients were more satisfied with aesthetics, concluding that this material can be considered a good alternative to overcome this limitation of conventional metal frames. According to ZOIDIS et al (2016), the PEEK infrastructures, due to the white color, represent an excellent aesthetic alternative and, in addition, this material is highly resistant, producing well-adapted frames with good stability of the occlusal supports. Another positive factor according to HARB et al (2019), ICHIKAWA et al (2019) and NISHIYAMA et al (2019) is the shorter clinical time for the manufacture of RPDs, with fewer consultations, that represents a great advantage, since patients commonly look forward to the end of treatment.

However, some negative points were also reported that deserve to be highlighted. According to ICHIKAWA et al. (2019), a clasp made of PEEK may present an increase in plaque retention, due to the greater porosity and roughness of the material, characteristic of polymers (HAHNEL et al., 2015). It is mentioning that the polishing procedure, in order to overcome this limitation, would be unfeasible. Wear, even if minimal, could compromise the retentive capacity and / or hinder the precise seating of the RPDs.

The use of the intraoral scanner was also considered. WU, LI and ZHANG (2017) highlighted some advantages of this technique. The scanner allows the reconstruction of oral structures with high precision in less time, since there is no manipulation of the material or construction of the plaster model. In addition, it allows the archiving of digital models without distortion of the impression, with less probability of operator failure and there is no need for physical spaces to store models. In their study, the authors rehabilitated a patient with limited mouth opening and stated that the use of the scanner is a good alternative for patients with this condition, offering greater comfort.

One of the limitations of this systematic review was the scarce publications in the literature that address the use of manufacturing CAD-CAM structures in RPDs. In addition, there was a remarkable heterogeneity between materials and techniques. It is also worth noting that the majority of identified studies do not have a control group to compare the internal discrepancy of the structures processed by the CAD-CAM system and the conventional technique. Finally, it is mentioning that only 25 patients were included in the analysis of clinical studies. Therefore, randomized studies with a larger number of patients and longitudinal analyzes are needed to determine whether there are advantages in structures manufactured with digital systems over those performed by the conventional technique. In this systematic review it was possible to show the feasibility of using CAD-CAM technology to manufacture RPDs.

Although the CAD-CAM technology has a vast literature on fixed partial denture and implants prostheses, in the case of RPDs there is a lack of clinical articles and homogeneity of methodologies between the studies, making it difficult to analyze data that compare conventional and digital methods. In addition to the few articles with quantitative data, these varied in terms of "n" and the methodology used to verify fit and manufacture master models. As an example, YE et al. 2018 and BAJUNAID et al. (2019), in the fit analysis, used fluid silicone impression. However, SOLTAZANDEH et al. (2018), ARNALD et al. (2018) and NEGM et al. (2019)

performed a digital overlay analysis that appears to be a future trend in standardization to verify adaptation, avoiding distortions of molding materials, for example. Regarding the new materials studied, PEEK was introduced in several areas of dentistry, such as implants. NAJEEB et al. (2016) cited PEEK as promising material in dentistry and some authors (ARNOLD et al. 2018, YE et al. 2018 HARB et al. 2019 ICHIKAWA et al. 2019) also studied this material within the RPD area, but it was not a standard for the infrastructure has been established in relation to its proper design: clasp planning, depth of niches, size of supports, thickness of the infrastructure or biomechanics. Thus, additional studies with this material are necessary in the RPDs for correct planning of the frame.

This systematic review has some limitations, such as the low number of clinical studies included. We chose to include in vitro studies in the analysis to complement the results. Despite this, it was possible to conclude that the clinical application of the infrastructures made by CAD-CAM is feasible based on the reported literature. However, it must be taken into account that procedures, such as standardization of the steps of applied techniques and adequate digital planning, are imperative to obtain a satisfactory clinical result. More clinical studies are needed, establishing longer follow-up periods, in order to obtain a better understanding of the results of this manufacturing technique. Finally, it should be noted that satisfactory aesthetic results associated with reduced manufacturing time and costs are already achievable.

Although WILLIANS et al. (2004) demonstrated, fifteen years ago, through digital planning and electronic design, that the production of RPD infrastructures was a possibility, few articles have been published so far, demonstrating the need for significant long-term clinical studies to eliminate or minimize confusing variables.

With CAD CAM technology advancing in all areas of dentistry, implementing new software and familiarizing professionals with more elaborate techniques, it is expected that precision and adaptation to procedures, the introduction of new materials and the reduction of treatment time will be future implementation trends.

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ANNEX

ANNEX

De: "The Journal of Prosthetic Dentistry" <em@editorialmanager.com>
Data: 18 de maio de 2020 08:34:31 BRT
Para: "Helena Sandrini Venante" <helenavenante@usp.br>
Assunto: Editor Decision - Final Questions
Responder A: "The Journal of Prosthetic Dentistry" <jpd@augusta.edu>

May 18, 2020

Re: Manuscript # JPD-D-19-01110R4

Dear Venante:

I am happy to report that the manuscript #JPD-D-19-01110R4, entitled "Computer-aided technology for the fabrication of removable partial denture frameworks: A systematic review and meta-analysis," has been accepted for publication pending your responses to the following final requests:

Please download and review the edited manuscript to ensure that your meaning has not been inadvertently altered. Please address the comments.