UNIVERSIDADE DE SÃO PAULO
FACULDADE DE ODONTOLOGIA DE BAURU

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Performance of computer-assisted technology for manufacturing removable complete dentures and bars used in implant supported overdentures: Systematics reviews

Desempenho da tecnologia assistida por computador na fabricação de próteses totais removíveis e barras utilizadas em sobredentaduras suportadas por implantes: Revisões sistemáticas

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Tese constituída por artigos apresentada à Faculdade de Odontologia de Bauru da Universidade de São Paulo para obtenção do título de Doutora em Ciências no Programa de Ciências Odontológicas Aplicadas, na área de concentração Reabilitação Oral (Linha de pesquisa: Prótese).

Orientador: Prof. Dr. Vinícius Carvalho Porto

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“O dinheiro faz homens ricos, o conhecimento faz homens sábios e a humildade faz grandes homens.”

Mahatma Gandhi

ABSTRACT

Performance of computer-assisted technology for manufacturing removable complete dentures and bars used in implant supported overdentures: Systematics reviews

The purpose of this study was to identify, evaluate, compare, and synthesize the results published in the literature related to the clinical performance of removable dentures manufactured by CAD-CAM methods through two systematic reviews. The first review aimed to compare conventional and CAD-CAM complete dentures, and the second review aimed to analyze the performance of overdentures whose bars were fabricated with this technology. A systematic literature search of clinical studies comparing the conventional and CAD-CAM methods to manufactured dentures published until March 16, 2020, was conducted for the first review. Likewise, another comprehensive search of clinical articles evaluating the performance of bars used in overdentures, published until April 2021, was performed. Both studies used the following platforms: Pubmed/Medline, Web of Science, Cochrane Library, SciELO, and Embase databases following PRISMA criteria. In addition, both reviews were recorded in the International Prospective Registry of Systematic Reviews (PROSPERO) (1CDR: 42020202614/ 2ID 42021284190). Of the 1232 titles obtained by the first search, 6 articles were selected, and of the 64 titles obtained of the second search, 9 articles were selected. The outcomes demonstrated superior retention in dentures manufactured by the CAD-CAM system than dentures manufactured by conventional methods. Also, other studies reported that these dentures have a better adaptation to the mucosa, reduce clinical time, represent a lower cost, and offer a better experience and satisfaction to patients. The second review reported 100% of implant and prosthesis survival rates in titanium and zirconia bars manufactured by the CAD-CAM methods. Otherwise, the PEEK bars showed 80% of prosthesis survival rate. In addition, few biological complications were recorded in the CAD-CAM bars, however, between 5 to 19 years of use of prosthesis, were registered peri-implantitis in the CAD-CAM titanium bars (12.4%). Marginal bone loss and plaque and bleeding index were considered acceptable in the group which received overdentures with titanium CAD-CAM bars. The OHIP values of the CAD-CAM group significantly decreased after prosthesis installation, however, the group of implant-supported fixed prostheses showed better values (1.8 + 1.9). Furthermore, the patients and dentists demonstrated an important acceptance of overdentures with bars manufactured by the CAD-CAM system. This study concluded that, although the planning and the fabrication of CAD-CAM dentures are in progress, they presented a better performance and represent a lower

cost when compared to conventional dentures. Similarly, the bars manufactured by the CAD-CAM methods demonstrated excellent performance in daily practice.

Key words: Complete denture, Computer-Aided Design, Overdenture.

RESUMO

A proposta deste trabalho foi identificar, avaliar, comparar e sintetizar os resultados publicados na literatura relacionados ao desempenho clínico de próteses removíveis confeccionadas pela tecnologia CAD-CAM, por meio de duas revisões sistemáticas. A primeira revisão visou comparar as próteses totais convencionais versus as próteses totais CAD-CAM. Já, a segunda revisão, almejou analisar a performance das sobre dentaduras cujas barras tenham sido confeccionadas por esta tecnologia. Uma pesquisa sistemática da literatura de estudos clínicos comparando próteses totais convencionais versus CAD-CAM publicados até 16 de março de 2020 foi conduzida para a primeira revisão. Da mesma forma, foi realizada outra busca abrangente de artigos clínicos que avaliassem a performance de barras utilizadas em sobre dentaduras, publicadas até abril de 2021. Para ambas as pesquisas foram utilizadas as plataformas: Pubmed/Medline, Web of Science, Cochrane Library, SciELO e bancos de dados de Embase seguindo os critérios PRISMA. Além disso, ambas revisões foram registradas no Registro Prospectivo Internacional de Revisões Sistemáticas (PROSPERO) (1 CDR: 42020202614/ 2 CDR 42021284190). Na primeira busca foram obtidos 1232 títulos, sendo 6 os estudos selecionados. Já, na segunda busca foram adquiridos 64 títulos, sendo 9 os artigos selecionados. Os resultados obtidos demonstraram uma retenção superior nas dentaduras fabricadas pelo sistema CAD-CAM quando comparadas com as fabricadas pelo sistema convencional. Outros estudos reportaram que estas dentaduras apresentam uma melhor adaptação à mucosa, reduzem o tempo clínico, representam um menor custo e oferecem uma melhor experiencia e satisfação aos pacientes. Por outro lado, foi constatada uma taxa de sucesso do 100% na sobrevida dos implantes e das próteses que receberam barras confeccionadas pelo sistema CAD-CAM (barras de titânio e zircônia), exceto o grupo que recebeu barras PEEK, evidenciou uma taxa de sobrevida das próteses de 80%. Além disso, foram registradas poucas complicações biológicas nas barras CAD-CAM, no entanto, entre os 5 e os 19 anos de funcionamento, foi possível encontrar registros de peri-implantite (12,4%) nas barras de titânio. A perda óssea marginal e o índice de placa e sangrado foram considerados aceitáveis no grupo que recebeu sobre dentaduras com barras CAD-CAM de titânio. Por outro lado, os valores OHIP do grupo CAD-CAM diminuíram significativamente após instalação da prótese, no entanto o grupo de próteses fixas implanto-suportadas, evidenciou melhores valores (1.8 ± 1.9). Ademais, foi constatado que tanto os pacientes como os dentistas, demonstraram uma importante aceitação das sobre dentaduras com barras confeccionadas pelo sistema CAD

CAM. Pode-se concluir que, embora o planejamento e a fabricação das dentaduras CAD-CAM, estejam em andamento, estas apresentaram um melhor desempenho e representam um menor custo quando comparadas com as dentaduras convencionais. Semelhantemente, foi constatado que as barras confeccionadas pelo sistema CAD-CAM utilizadas em sobre dentaduras apresentam um excelente desempenho na clínica diária.

Palavras Chaves: Prótese Total, Desenho Assistido por Computador, Sobredentadura.

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LISTA DE ABREVIATURAS E SIGLAS

PMMA	Poli Metil Metacrilato
CAD	Desenho assistido por computador
CAM	Manufatura assistida por computador
JPD	Journal of Prosthetic Dentistry
PROSPERO	The International Prospective Register of Systematic Reviews
PICO	Patient, Intervention, Comparison, Outcome
PEEK	Polyether ether ketone
MBL	Marginal bone loss
OHIP	Oral Health Impact Profile
IFP	Implant fixed prostheses
ISOD	Implant supported overdentures
SciELO	Scientific Electronic Library Online
CASP	Critical Appraisal Skills Program (CASP)
MMA	Methyl methacrylate
PTs	Complete dentures
STL	Standard tessellation language
Mil	Milling technique
PAP	Pack and press
RR	Risk ratio
CI	Confidence interval
NR	Not reported
BOP	Bleeding on proving

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1 INTRODUCTION

1 INTRODUCTION

In recent decades, dentistry has presented many technological advances in the development of diagnoses such as treatments. However, complete edentulism is still a common health problem that mainly affects elderly patients over 65 years of age (EMAMI et al., 2013).

Data provided by the National Ministry of Health revealed that seven million elderly people require complete dentures (CDs) mono or bimaxillary. The use of these devices represents the classic therapy of total edentulism, but currently, there are treatment alternatives capable of replacing the "standard" alternative, thus seeking results with the highest standards and the best techniques that can be taken from more efficiently and quickly in the daily clinic (DA COSTA et al., 2013).

In this sense, in the last 15 years, robotics has entered the field of oral rehabilitation through the techniques of computer-aided design and computer-aided manufacturing (CAD-CAM); among which stand out: the fabrication of intra and extra coronary restorations, crowns, fixed partial dentures, maxillofacial prostheses, bars used in overdentures and total or partial removable dentures (STEINMASSL et al., 2017; GOODACRE et al., 2012; BIDRA et al., 2013; TALLARICO et al., 2018; MAEDA et al., 1994).

Currently, the general industry used this process to automate, streamline and control manufacturing processes. The CAD system recognizes the geometry of an object and involves the materialization and fabrication of the virtual image, while CAM software is used for the fabrication of the devices (VAN NOORT et al., 2012).

The manufacturing process of this technology might include: the manufacturing of additives by rapid prototyping (3D printers) or subtractive which consists of CNC-computer numerical control machining (Mills) (VAN NOORT et al., 2012). The additive manufacturing technique is given through 3D printers and its use in dentistry is more recent. In this process, resins are light-cured layer by layer until the entire piece is built (VAN NOORT et al., 2012; REVILLA-LEÓN; OZCAN, 2019). The difference with the subtractive technique is that the waste of material is minimal. Regarding costs, they are more economical than milling machines, but this is limited to the use of resins; ceramic, and metal printers that still represent a very high-cost today (VAN NOORT et al., 2012; REVILLA-LEÓN; OZCAN, 2019; BILGIN et al.,

2016). Otherwise, the subtractive technique is performed using CNC milling machines, in which part of a disk or block will have material removed by milling cutters (drill bits) until it reaches the projected shape. This technology has more time in dentistry and reaches a wide range of materials, such as waxes, resins, and ceramics (BILGIN et al., 2016).

In the area of removable dentures, the use of this technology has shown exponential growth in the dental market and the number of commercially available CAD/CAM systems increases every year (BILGIN et al., 2016).

Among the advantages obtained through this manufacturing method, we have a better adaptation of the dentures and a significant decrease in the number of patients that return to the clinic, this latter topic significantly attracts the attention of dentists and patients. In addition, this technology has provided better predictability of the desired results, allowing for high accuracy of the fitting of prosthesis (BILGIN et al., 2016; YOON et al., 2020; ALRUMAIH et al., 2018; DRAGO; BORGERT, 2019).

With the help of these advances, different materials were produced for the use of CAD-CAM systems such as polymethylmethacrylate blocks and liquid resins based on epoxy acrylate, which replaces the heat-activated polymethylmethacrylate resin (PMMA), which is the principal material used for the manufactured of conventional complete dentures (KUANG et al., 2018; AL-DWAIRI et al., 2019).

PMMA has some limitations, the most important is the release of residual methyl methacrylate (MMA) monomer that affects the dimensional stability, mechanics, and biocompatibility of the device, in addition, the monomer leaching gives rise to allergic reactions with symptoms related to burning sensations, stomatitis, edema and ulceration of the oral mucosa (ZISSIS et al., 2000; HARRISON; HUGGET, 1992; GAD et al., 2019).

In contrast, the polymethylmethacrylate blocks used in CAD-CAM systems are produced by industrial standardization under conditions of high temperature and pressure (RZAYEV; PENELLE, 2004). The addition of inorganic agents restricts dimensional polymerization shrinkage and reinforces the mechanical properties of these resins, including hardness and resistance (STEINMASSL et al., 2017; MURAKAMI et al., 2013). Such properties also reduce surface deterioration and adhesion of the microbial plaque to the prosthesis (STEINMASSL et al., 2017). Regarding the materials used in 3D printers, we have the light-cured resin whose composition consists of the following materials: Acrylates, methyl

acrylates, methacrylates oligomers, and monomers, photoinitiators, colorants, and absorbers (ENVISIONTEC, 2021). This material is cured in the presence of ultraviolet radiation and offers a wide choice of color, mechanical properties, and includes the support material for complex geometries. Also, this technique represents an economical option because compared to subtractive methods, it does not involve the wear of rotary tools or waste of raw materials and enables the simultaneous manufacture of multiple products (BERMAN, 2012; ABDUO; LYONS; BENNAMOUN, 2014). However, to achieve good results with this method, some parameters such as the printing layer thickness, laser intensity, laser speed, printing angle, and printing orientations need to be considered (PUEBLA et al., 2012; BHATTACHARJEE et al., 2016; URRIOS et al., 2016). Thus, both materials have allowed the development of industrial acrylics with physical and chemical qualities superior to conventional heat-cured acrylics because there manufactured under specific controlled conditions (STEINMASSL et al., 2017; SRINIVASAN et al., 2018).

Although jaw rehabilitation with conventional or digital complete dentures restores the required tissues, esthetics, phonetics, and oral function, patient satisfaction remains slightly compromised (VAN DER BILT et al., 2010). However, when compared to the dentate or partially dentate individuals, the chewing efficiency and bite force of these users remain impaired. (TALLGREN, 1972; ALBREKTSSON; BLOMBERG; BRANEMARK, 1987; ASSUNÇÃO et al., 2010).

The advent of the treatments for overdentures over implants demonstrated efficiency in mastication and, consequently, an improvement in the quality of life related to oral health, the maximum bite force, and the thickness of the masseter muscle (MÜLLER et al., 2012; SCHIMMEL et al., 2010). In addition, it should be noted that this treatment alternative provides structural benefits in edentulous arches, slowing down bone loss in the peri-implant area (BEHNEKE et al., 1996; NAERT et al., 1998). The standard therapy for the rehabilitation of these cases involves the placement of interforaminal implants, however, this anterior support allows the posterior part of the denture to sink when the occlusal load is applied during mastication (ELYSAD; SHOUKOUKI, 2010; JACOBS et al., 1992; MOSNEGUTU et al., 2015). Consequently, this leads to increased posterior bone resorption, therefore ideally having posterior support such as placing an implant in the premolar and molar area. However, this would imply a more invasive surgery, higher costs, and risks, as well as increased treatment to healing time (SCHIMMEL et al., 2017). Furthermore, immobilization of large sections of the mandible may interfere with mandibular flexion resulting in implant loss. Additionally, the

distal implants are more difficult to clean, especially in elderly patients with reduced vision and manual dexterity (MIYAMOTO et al., 2003). To avoid these risks, bars with distal extensions seem to be an attractive alternative for solving this problem, but according to Waddell et al. (2006), the conventionally welded fractured regularly due to their inability to support the occlusal load (WADDELL et al., 2006; BEHNEKE, 1996). In front of that, the CAD-CAM system provides us with an alternative for manufacturing milled bars from a single block of metal, thus avoiding the need for welding and other fusion processes, but the little evidence about the use of this type of technology makes it difficult to use in the daily clinic (KATSOULIS et al., 2011; UEDA et al., 2011). Therefore, this work aims to develop two systematic reviews that evaluate the use of the CAD-CAM system in the manufacture of dentures, comparing them with those manufactured by the conventional system. Also, this work aimed to analyze the use of this technology in the manufacture of bars fabricated for implant-supported dentures.

The null hypothesis contemplated in the first systematic review was that the CAD-CAM and conventional base retention did not present significant differences. The second null hypothesis considered in this study was that the cost, clinical time, adaptation, patient satisfaction, and unscheduled postinsertion visits are similar in both types of dentures. Otherwise, the null hypothesis of the second systematic review was that the use of CAD-CAM bars does not improve the clinical performance of overdentures.

2 ARTICLES

2 ARTICLES

2.1 ARTICLE 1

Chappuis-Chocano AP, Venante HS, Da Costa RMB, Pordeus MD, Santiagio Jr JF, Porto VC. Evaluation of the clinical performance of dentures manufactured by computer-aided technology and conventional techniques: A systematic review. J Prosthet Dent [internet]. 2021 [cited Jul 28]; S0022-3913(21)00346-2. Available from: http://dx.doi.org/10.1016/j.prosdent.2021.06.029

Evaluation of the clinical performance of dentures manufactured by computer-aided technology and conventional techniques: A systematic review

ABSTRACT

Statement of problem. The introduction of computer-aided design and computer-aided manufacturing (CAD-CAM) technology for complete denture fabrication may have improved clinical outcomes compared with conventional techniques. However, systematic reviews comparing these techniques are lacking.

Purpose. The purpose of this systematic review was to identify, compare, and synthesize the outcomes of published clinical studies related to CD complete denture fabrication, with respect to the differences between CAD-CAM technology and conventional techniques.

Material and methods. A comprehensive search of studies published up to March 16, 2020 was conducted using the PubMed/MEDLINE, Web of Science, Cochrane Library, SciELO, and Embase databases according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement criteria and was registered in the International

Prospective Register of Systematic Reviews (PROSPERO ID 42020202614). The population, intervention, comparison, and outcome (PICO) was: Do CAD-CAM complete dentures have a similar functional performance to those fabricated by conventional techniques? The quality of publications was appraised by using the Critical Appraisal Skills Program (CASP) checklists.

Results. Of the 1232 titles, 6 articles were selected. The studies reported better retention of digitally manufactured complete dentures without denture adhesives compared with conventional complete dentures with or without denture adhesives. Other studies reported that dentures manufactured with digital systems were better adapted to tissue surfaces, required less clinical time, were lower in cost, and provided better experience and satisfaction to patients.

Conclusions. The assessment of CAD-CAM planning and manufacturing through clinical studies is ongoing. However, preliminary results indicate better clinical performance and lower overall costs of digital complete dentures compared with conventional dentures.

CLINICAL IMPLICATIONS

The clinical performance of CAD-CAM complete dentures is comparable with that of conventional complete dentures; moreover, there is evidence that CAD-CAM complete dentures present better surface adaptation, provided more retention, and demanded less clinical time and cost.

INTRODUCTION

Computer-aided design and computer-aided manufacturing (CAD-CAM) technology has revolutionized clinical and dental laboratory procedures, with improved clinical outcomes.[1] It has multiple applications, including in prosthetic dentistry, enabling the manufacturing of

digital casts through scans, planning with specific software programs, building of prototypes, and manufacturing of parts from various materials in an automated and expedited way.[2]

CAD-CAM complete dentures (CDs) can significantly reduce clinical time and allow the storage of digital casts and designs in a digital library. The digital record can be stored in a database as a standard tessellation language (STL) file. The fabrication of the designed CD can be additive (rapid prototyping) or subtractive (milling of prefabricated blocks).[3]

The subtractive method is currently more commonly used, milling the denture base from prefabricated blocks of polymethylmethacrylate (PMMA) resin that had been polymerized by injection under high temperature and pressure. The blocks exhibit improved mechanical and physical properties compared with conventionally processed PMMA materials.[4] Traditional materials experience greater dimensional changes, more internal bubbles, less resistance to fracture, fewer residual monomers, and greater surface roughness, all of which can compromise oral hygiene. A porous denture base may lead to the development of denture stomatitis, one of the most recurrent pathologies among CD users.[4,5]

Therefore, CDs designed and manufactured with CAD-CAM may be advantageous over conventional dentures. Clinical studies have been conducted to evaluate this hypothesis,[3,4] but systematic reviews are lacking. The purpose of this systematic review was to identify, compare, and summarize the outcomes of clinical studies related to CD manufacturing, with respect to the differences between CAD-CAM technology and conventional techniques. The null hypotheses were that no differences would be found in denture base retention in denture manufacturing using CAD-CAM and that using traditional techniques; and that these techniques would be similar in terms of cost, clinical time, adaptation, patient satisfaction, and unscheduled postinsertion visits.

MATERIAL AND METHODS

This systematic review was conducted according to the criteria established by the Cochrane Collaboration (Cochrane Handbook for Systematic Reviews of Interventions, Handbook 6.2),[6] and followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations to develop and elaborate on a systematic review.[7-9] This systematic review, which was limited to clinical studies, was registered in the International Prospective Register of Systematic Reviews (PROSPERO) database (CRD42020202614) to evaluate the proposed methodological design.

Analyses were based on the population, intervention, comparison, and outcome (PICO) index: those undergoing prosthetic treatment involving CDs (population), those receiving digitally manufactured CDs (intervention), those receiving CDs using digital and conventional methods (comparison), and studies evaluating retention, tissue surface adaptation, time and costs, and unscheduled visits (outcome). Studies were selected according to the search strategy with respect to 4 inclusion criteria: English language; studies involving scanning (intraoral or laboratory), planning and printing or milling of CDs with the CAD-CAM technology; clinical studies; and studies that used conventional dentures as a comparison. Clinical reports, proofs of concept, and systematic reviews were excluded.

The databases used included Medline/PubMed, Cochrane Library, SciELO, Web of Science, and Embase. Searches were conducted for articles published from 1991 to March 16, 2020. The following MeSH/PubMed-based Boolean operators were used: “Removable complete Denture,” “Complete denture,” “Removable denture,” “CAD-CAM,” “Digital,” “OR,” and “AND.” A related search of PubMed is presented in Supplementary Table 1. A manual search of specific journals and related studies on dental dentures and digital technology was also conducted.

Two previously calibrated reviewers (H.S.V., A.P.C.C.) conducted the article selection and data collection; articles related to the theme were sought, submitted, and approved by using the kappa test (κ=1.0). The study included 3 other researchers (M.P., R.M.B.C., J.F.S.Jr), who evaluated the selected articles, data collection analysis, and risk of bias. Further clarifications on doubts and technical support were provided by an additional reviewer (V.C.P.). The clinical studies included were evaluated for their methodology and classified according to the type of research (randomized controlled trials, cohort studies, cross-sectional studies, or case control studies).[10] All data in the tables (qualitative data and risk of bias) were extracted by 2 investigators (H.S.V., A.P.C.C.) and checked by another investigator (J.F.S.Jr). For bias risk analysis, comparisons were evaluated by using methodology structure and classified according to the type of study conducted and the clinical outcomes.[11] The quality of publications was appraised by using the Critical Appraisal Skills Program (CASP) checklists for randomized controlled trials; results were analyzed and discussed by using a narrative synthesis approach (Table 1).

RESULTS

The initial search resulted in 1232 titles, of which 12 were selected based on the title and abstract. On reading, 6 studies were excluded as they did not meet the inclusion criteria; the remaining 6, all clinical studies,[12-17] were selected (Fig. 1). Two assessed retention,[12,13] 2 evaluated the time and cost,[14,15] 1 reported the tissue surface adaptation,[16] 1 presented the experience and satisfaction of patients,[14] and the other counted the unscheduled and postinsertion adjustment visits of digital and conventional CDs.[17] Several CD manufacturing techniques were reported, including pack and press and injection molding as traditional processes; milling, and digital light processing as digital processes (Table 2). The main results were divided based on the objectives, summarizing each selected study.

Two articles[12,13] evaluated the retention between conventional and digital dentures. Both studies included the same participants (n=20) who received conventional and digital CDs in the maxilla. In the initial study, Al-Helal et al[13] reported that complete digital dentures made using the milling technique provided greater retention (74.14 N) than conventional CDs (54.23 N)(*P*<.001). Subsequently, the research group also evaluated the effect of using adhesives (Fixodent; Procter & Gamble Co). Similarly, Al-Rumaih et al[12] reported that digital CDs (74.14 N) had a greater retention than conventional CDs (54.23 N) (*P*<.001). When adhesives were used, no significant differences were found in the retention means with digital CDs (58.79 N) compared with the conventional CDs (52.81 N) (*P*=.088). Additionally, there was no significant increase in the retention of conventional CDs with the use of the adhesive (*P*=.570).

Two articles[14,15] assessed the time required to manufacture digital and conventional dentures; both studies used the Avadent block to manufacture digital CDs. Kattadiyil et al[14] reported that the conventional manufacturing of CDs required significantly (*P*=.003) more clinical time compared with digital CDs, with the time difference between the techniques averaging 205 minutes. Similarly, Srinivasan et al[15] reported statistically significant differences between the techniques (*P*=.02, *P*=.002), with mean differences of 108 minutes for a single arch CD and 233 minutes for opposing CDs, with less time for digitally made CDs. In addition, Srinivasan et al[15] evaluated differences in material costs, concluding that there were significant differences (*P*=.0002) between techniques. Conventional CDs had the lowest average values (18.46 ±1.91 CHF), and the laboratory costs were statistically significant (*P*=.008) between the techniques, with digital CDs having the lower average cost (1022.70 ±74.09 CHF).[15]

One article[16] was selected to compare the surface adaptation between different digital techniques (digital light processing and milling) and the conventional technique (pack and

press) in 9 edentulous participants with 12 completely edentulous arches (7 maxillary and 5 mandibular). This study did not report statistical differences in the absolute tissue surface adaptation among the 3 denture base fabrication techniques ($P>.05$). However, in terms of relative tissue surface adaptation, the maxillary dentures manufactured with the digital light processing (DLP) technique had better adaptation to tissues in the maxillary arch areas of tension (residual ridge and midpalatal suture) compared with the conventional method ($P=.001$, $P=.005$). The maxillary denture manufactured with the milling technique had small gaps between the supporting tissue and denture base. In terms of the mandibular denture, both digital techniques demonstrated a more intimate adaptation in the lingual inclination area compared with the conventional denture.[16]

One article[14] assessed the experience and satisfaction of 16 participants rehabilitated with CDs manufactured with conventional and digital techniques; this assessment was conducted by using a questionnaire and a 5-point Likert rating scale (0–4). The study found a statistically significant difference ($P=.001$) between the scores of conventional CDs and digital CDs, with the participants preferring the digital CDs.

One of the digital CDs had an open anterior occlusal relationship, and it was necessary to remake the mandibular CD. In terms of the CDs manufactured with the conventional technique, 1 required relining as the retention, stability, and occlusion were compromised.[14]

One article[17] was selected to evaluate the number of unscheduled postinsertion adjustment visits of patients with CDs. This study involved 106 nonsmoking participants, predominately women. The first 33 received CDs manufactured with the conventional technique (injection molding), and 73 received digital dentures (milling). No statistically significant differences ($P>.05$) were found between the number of unscheduled postinsertion adjustments for participants provided with digital and conventional CDs.[17]

DISCUSSION

The first null hypothesis of this systematic review was rejected. The qualitative synthesis results demonstrate that CDs manufactured with CAD-CAM technology provide better retention than the conventionally manufactured CDs. The second null hypothesis was partially rejected, as no significant differences were found between CAD-CAM and conventional techniques in terms of unscheduled postinsertion adjustment visits. However, significant differences were found for other variables, including experience, satisfaction, time, and cost.

In terms of retention, both studies reported better retention in CAD-CAM CDs when compared with conventional CDs, possibly related to a better fit obtained with the prepolymerized CAD-CAM CDs.[12,13,18–21] Contrary to the findings in previous studies,[22–25] Al-Rumaih et al[12] reported that denture adhesives significantly reduced the retention of CAD-CAM CD. This reduction may be attributed to the better adaptation and intimate contact of the milled CDs on the maxillary tissues, which does not allow an adequate settlement of the adhesive. However, these studies did not assess the adaptation of the CDs; the performance of denture adhesives on CAD-CAM dentures should be further investigated.

An intimate adaptation of the intaglio surfaces of dentures is important for successful treatments, directly influencing the retention and stability of CDs.[20,26] Yoon et al[16] reported a significant difference between CDs manufactured by milling and DLP techniques, which provided better adaptation to tissues of the maxillary ridge and hard palate. Additionally, DLP-manufactured dentures may contribute to better adaptation in stress-bearing areas than conventional and CAD-CAM milled dentures.[16] Also, CDs manufactured with the conventional technique tended to press the center of the palate in contrast with the CDs manufactured by using the DLP and milling techniques.[16] This finding was consistent with the finding of Hwang et al,[27] who reported trueness and surface adaptation improvement in CDs manufactured with the DLP, displaying a misfit within 100 μm. Previous studies have also

indicated the better adaptation of CAD-CAM-milled CDs.[20,28] These may be related to the more precise standardization of procedures with CAD-CAM techniques and reduced polymerization shrinkage, a significant factor with the conventional technique.[20]

The reduction of chairside time is considered one of the significant advantages of the CAD-CAM technique, whereby treatment was concluded in 2 to 3 visits depending on the system and protocol used.[19–21] Kattadiyil et al[14] indicated that CAD-CAM CDs required a mean of 205 minutes less chairside time than conventional dentures. Srinivisan et al[15] also reported that providing milled CDs required significantly less chairside time, with differences of 108.3 minutes for maxillary CDs and 233 minutes for maxillary and mandibular CDs. Other studies also reported the practicality of the CAD-CAM workflow for CDs.[18-20,29,30] Thus, the versatility of this technique, with the potential to obtain definitive impressions, interocclusal relationship records, and tooth selection at the first appointment, is the primary factor in these results. By contrast, the conventional technique requires 5 to 6 visits, which may introduce difficulties, particularly for less experienced clinicians.[14,15]

Treatment cost is another critical parameter to be assessed, as it influences treatment applicability and acceptability by clinicians and patients alike. Srinivisan et al[15] evaluated the costs associated with treatments for conventional and CAD-CAM-milled CDs by dividing them into clinical fees, clinical materials, and laboratory costs and by stipulating an hourly labor cost. They reported that, except for clinical materials, treatment with CAD-CAM CDs was markedly lower in cost compared with other parameters and that a lower price in general was a treatment option. This study was conducted in Switzerland, and the authors stated that it was difficult to extrapolate these results to other countries because of the particularities of and variations in costs, which was a study limitation.

In terms of the patient experience and level of satisfaction with conventional and CAD-CAM CDs, Kattadiyil et al[14] indicated significantly higher preferences for CAD-CAM

CDs in terms of comfort, mastication, prosthesis selection, and technique efficiency. However, some problems have been reported; one of the CAD-CAM CDs presented with an open anterior occlusal relation requiring replacement. For CDs manufactured with the conventional technique, one required relining as the retention, stability, and occlusion were compromised.[14] These findings may be related to complications encountered during the treatments in both techniques, which may have influenced patient perceptions. Moreover, the lower number of clinical visits and steps required by the CAD-CAM workflow may also have influenced patient perceptions on treatment.[14]

In terms of unscheduled postinsertion adjustment visits required for conventional and milled CAD-CAM CDs, the number of unscheduled visits was found not to be related to the technique, rather, to patients with single CDs and to those who attended scheduled visits following CD insertion.[17] The study suggests that this may be related to the adequate standardization of treatment protocols or the location of the clinical practice, which may be distant and difficult for patients to access. Only 20% of patients attended scheduled visits, thus corroborating this hypothesis. The average number of unscheduled visits recorded was 1.7 for CAD-CAM and 1.8 for conventional CDs. Conversely, Bidra et al,[31] reported an average of 3.3 adjustments following insertion. However, this study applied a 2-visit protocol, which included conventional CDs and implant-supported overdentures, and had a small sample size; these factors may have produced different outcomes. Standardized protocols to assess postinsertion visits should be applied in further studies.

Limitations of this systematic review included the small number of clinical studies published on this subject that fit the inclusion criteria and the potential for non-English published papers. Randomization of participants and sample size calculations were lacking, as was difficulty in establishing a blinding method to evaluate patients and research personnel.[14,17] However, there was concern for eliminating certain clinical conditions that may

affect treatment outcomes, such as palatal tori, alveolar ridges presenting severe undercuts, and reduced salivary flow.[18,19,21] Finally, there was a trend toward the classification of maxillary arches and/or palatal throats to include participants.[12–16] Additionally, the small sample sizes and differences among methodologies prevented meta-analysis. Thus, future studies should standardize treatment protocols to obtain comparable clinical outcomes.

The association between the adaptation and retention of dentures and the role of denture adhesives in CAD-CAM CDs should be assessed in further studies. Clinical studies addressing longer follow-up periods are necessary to compare differences among techniques. However, cost and clinical time outcomes that demand CD manufacturing with both techniques are already achievable.

CONCLUSIONS

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

1. Rehabilitation with digitally manufactured dentures offers higher retention than CDs manufactured by conventional techniques.
2. The clinical time and overall cost of digital dentures were lower than for conventional CDs.
3. The CAD-CAM CDs demonstrated better adaptation than conventional CDs, improving patient experience and satisfaction.
4. No differences were found between digital and conventional CDs in terms of the number of unscheduled postinsertion visits.

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TABLES

Table 1. Quality appraisal using CASP checklist for randomized controlled trials. CI, Confidence interval; Significance, $P<.05$

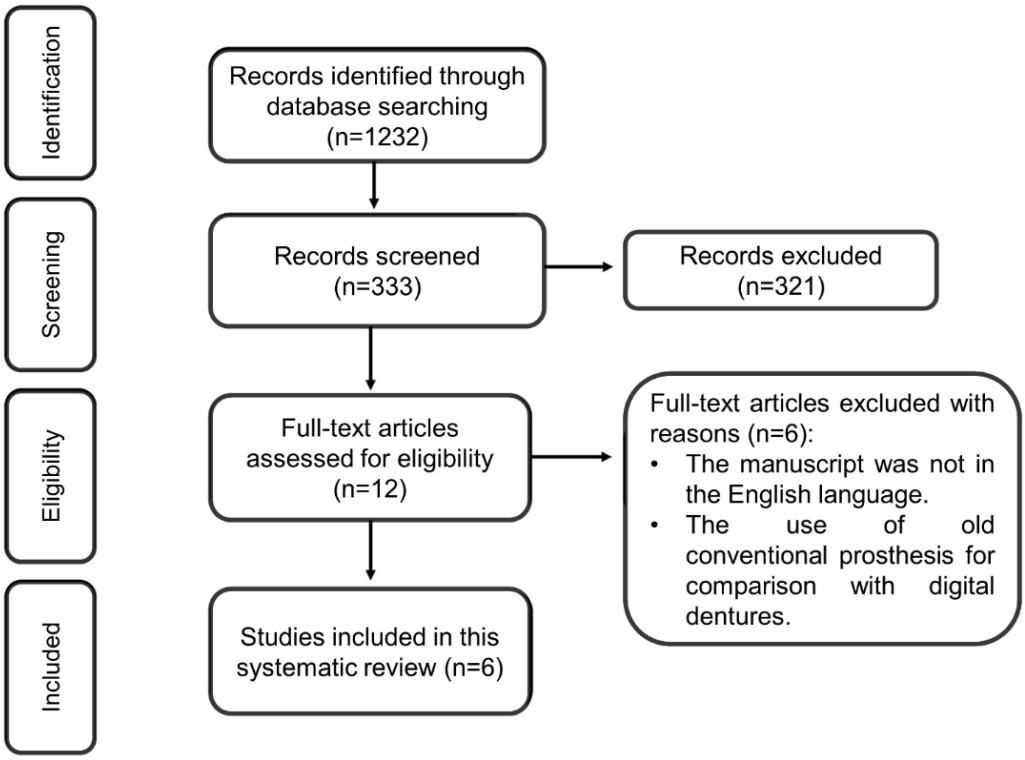
CASP randomized control study checklist						
	Drago and Borget 2019	Al-Rumaih et al 2017	Al-Helal et al 2016	Kattadiyil et al 2015	Yoon et al 2020	Srinivasan et al 2018
Did the trial address a clearly focused issue?	Yes	Yes	Yes	Yes	Yes	Yes
Was the assignment of patients to treatments randomized?	Yes	Yes	Yes	Yes	Yes	Yes
Were all patients who entered the trial properly accounted for at its conclusion?	Yes	Yes	Yes	Yes	Yes	Yes
Were patients, health workers, and study personnel blind to treatment?	No	Yes	Yes	Inconclusive	Yes	No
Were groups similar at the start of the trial?	Yes	Yes	Yes	Yes	Yes	Yes
Aside from experimental intervention, were groups treated equally?	Yes	Yes	Yes	Yes	Yes	Yes
How large was the treatment effect?	Not significant ($P=.55$)	Not significant ($P>.05$)	Significant ($P<.001$)	Significant ($P=.0007$), ($P=.001$), ($P<.01$), ($P<.05$)	Not significant ($P<.05$)	Significant ($P<.02$)
How precise was the estimate of the effects of treatment?	Cannot tell (no CI limits)	Cannot tell (no CI limits)	Cannot tell (no CI limits)	Cannot tell (no CI limits)	Cannot tell (no CI limits)	Cannot tell (no CI limits)
Are the results applicable in your context? (Or to the local population)	Yes	Yes	Yes	Yes	Yes	Yes
Were all clinically important outcomes considered?	Yes	Yes	Yes	Yes	Yes	Yes
Are the benefits worth the harms and costs?	No	Yes	Yes	Yes	No	Yes

Table 2. Clinical studies of dentures processed by CAD-CAM systems and conventional techniques. Digital light processing (DLP); Milling technique (MIL); Pack and press (PAP) conventional technique

Author	Year	Number of patients	Level of evidence	Fabrication technique/Patients	Framework material	Arch	Methodology	Results
Al-Rumaih et al	2017	20	III-2	Milled/20 Conventional (pack and press)/20	Avadent PMMA block Lucitone 199	Maxilla	Motorized test stand (ESM301L, Mark-10 Corp) + advanced digital force gauge (Series 5; Mark-10 Corp).	Milled denture presented significantly higher retention than heat-activated resin bases without use of denture adhesives. Denture adhesives significantly affected retention of milled dentures.
Al-Helal et al	2016	20	III-2	Milled/20 Conventional (pack-press)/20	Avadent PMMA block Lucitone 199	Maxilla	Motorized test stand (ESM301L, Mark-10 Corp) + advanced digital force gauge (Series 5; Mark-10 Corp).	Milled complete dentures presented higher retention than conventional heat-polymerized dentures.
Drago and Borgert	2019	106	III-2	Milled/73 Conventional (Injection molding)/33	Avadent PMMA block SR Ivocap Injection System (Ivoclar Vivadent AG)	Maxilla and Mandible	Computerized search of the electronic medical records using the American Dental Association codes (5110, maxillary complete denture; 5120, mandibular complete denture).	No significant differences in number of unscheduled postinsertion visits in patients that received conventional or milled dentures.
Srinivasan et al	2018	12	III-2	Milled/12 Conventional/12	Avadent PMMA block Candulor Aesthetic red	Maxilla (6) Both archs (12)	Cost minimization analysis: Estimated hourly labor cost= (clinical cost- mean clinical materials cost) /mean chairside time (in h)	Clinical chairside time, laboratory and overall cost of CAD-CAM denture protocol significantly lower than conventional protocol, despite materials costs for this protocol being higher.
Yoon et al	2020	9	III-2	Milled/9 DLP/9 ventional (pack and press)/9	Vipi block gum Next Dent base SR Triplex Hot, Ivoclar Vivadent)	Maxilla (7) Mandible (5)	Evaluation of adaptation indicator (Fit checker II) + Stereomicroscope (SZX16) at ×50 magnification + image analysis software program (ToupView, Touptek)	DLP denture bases demonstrated superior adaptation to tissue surfaces than MIL or PAP denture bases. The MIL denture bases showed acceptable level of adaptation to tissue surfaces and when compared with PAP bases, had better adaptation on lingual slope.
Kattadiyil et al	2015	15	III-2	Milled/15 Conventional (Lost wax technique)/15	Avadent PMMA block Lucitone 199	Maxilla and mandible	5-point Likert rating scale (0 to 4)	Milled technique more efficient than conventional technique in predoctoral program.

FIGURES

Figure 1. Data on article selection according to PRISMA diagram. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.



SUPPLEMENTARY TABLE

Supplementary Table 1: Related search within PubMed

“cad cam” and “complete denture”	(“computer-aided design”[MeSH Terms] OR (“computer-aided”[All Fields] AND “design”[All Fields]) OR “computer-aided design”[All Fields] OR (“cad”[All Fields] AND “cam”[All Fields]) OR “cad cam”[All Fields]) AND (“denture, complete”[MeSH Terms] OR (“denture”[All Fields] AND “complete”[All Fields]) OR “complete denture”[All Fields] OR (“complete”[All Fields] AND “denture”[All Fields]))
“cad cam” and “complete dental prosthesis”	(“computer-aided design”[MeSH Terms] OR (“computer-aided”[All Fields] AND “design”[All Fields]) OR “computer-aided design”[All Fields] OR (“cad”[All Fields] AND “cam”[All Fields]) OR “cad cam”[All Fields]) AND complete[All Fields] AND (“dental prosthesis”[MeSH Terms] OR (“dental”[All Fields] AND “prosthesis”[All Fields]) OR “dental prosthesis”[All Fields])
“cad cam” and “complete prosthesis”	(“computer-aided design”[MeSH Terms] OR (“computer-aided”[All Fields] AND “design”[All Fields]) OR “computer-aided design”[All Fields] OR (“cad”[All Fields] AND “cam”[All Fields]) OR “cad cam”[All Fields]) AND complete[All Fields] AND (“prostheses and implants”[MeSH Terms] OR (“prostheses”[All Fields] AND “implants”[All Fields]) OR “prostheses and implants”[All Fields] OR “prosthesis”[All Fields])

2.2 ARTICLE 2

The second article of this work was written according to the Clinical Oral Investigation Journal instructions and guidelines for article submission.

A systematic review and meta-analysis of the clinical performance of computer-aided design–computer-aided manufacturing bars used in implant-supported dentures

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ABSTRACT

Objectives: To evaluate the performance of computer-aided design–computer-aided manufacturing (CAD-CAM) bars used in implant-supported overdentures.

Materials and Methods: A comprehensive search of studies published up to April 2021 was performed in the PubMed/MEDLINE, Web of Science, Cochrane Library, and SciELO databases according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses criteria and registered in the International Prospective Register of Systematic Reviews (PROSPERO: CDR 42021284190). The population, intervention, comparison, and outcome question was "How is the clinical performance of the overdenture bars fabricated by the CAD-CAM system?" The meta-analysis included clinical studies based on the effect size and test of null (2-Tail) with 95% confidence interval.

Results: Nine out of 64 studies were selected. The outcomes revealed 100% implant and prosthesis survival rates; however, polyether-ether-ketone bars showed 80% prothesis survival. The marginal bone loss and plaque and bleeding index were considered acceptable; however, few biological complications were registered in the CAD-CAM group. The Oral Health Impact Profile scores significantly decreased after prosthesis delivery; however, the fixed implant prosthesis demonstrated better data (1.8 ± 1.9). Therefore, patients and prosthodontists demonstrated important clinical acceptance with CAD-CAM bars.

Conclusions: The CAD-CAM-milled titanium bars exhibited excellent performance in daily clinical practice. Moreover, patient and prosthodontist satisfaction was very high when this method was used.

Clinical Relevance: CAD-CAM bars have shown great potential for use in clinical practice.

Keywords: Computer-aided Design, Dental implants, Overdenture, Prosthodontics, Workflow

INTRODUCTION

Edentulism is a physical disability associated with partial or total tooth loss. This condition decreases masticatory capacity and compromises speech as well as facial and oral esthetics, in addition to producing unfavorable psychological changes in patients, worsening their oral and general health [1].

For decades, the total removable prosthesis has been the conventional solution for treating this condition; however, this device has a limited improvement in masticatory function, leaving patients dissatisfied with the results obtained, especially in relation to the mandibular prosthesis. Moreover, this condition causes the basal edges to be constantly reabsorb, compromising the retention and stability of these devices [2, 3]

With the advancement of science and technology, these problems can be circumvented by means of implant-supported fixed prostheses; however, this type of prosthesis represents a high cost and specific indication due to maxillary discrepancies [2]. Another alternative that has demonstrated success in the rehabilitation of edentulous patients and presents high survival rates is the use of implant overdentures, which provide greater stability and masticatory function, in addition to significant patient satisfaction when compared to conventional complete denture [4-6].

Computer-aided design–computer-aided manufacturing (CAD-CAM) technology has been successfully applied in many fields of dentistry, with promising applications for overdenture frameworks. This technology provides the construction of a 3D digital framework with accurate designs using software programs with geometric analysis tools [7]. The definitive framework can be manufactured using either subtractive or additive CAD-CAM techniques with different materials, including titanium, cobalt chromium, zirconia, and polyether-ether-ketone (PEEK) in the case of removable dentures [8-10].

Therefore, the purpose of this systematic review and meta-analysis was to evaluate the clinical performance of bars used in overdentures fabricated using CAD-CAM systems. The null hypothesis was that the use of CAD-CAM bars did not improve the clinical performance of overdentures.

MATERIALS AND METHODS

Standardized Criteria and study type

This study was conducted using the criteria established by the Cochrane Collaboration (Cochrane Handbook for Systematic Reviews of Interventions-handbook 6.2) [11] and followed the preferred reporting items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations for the elaboration of systematic reviews [12-14].

Protocol and Registration

This systematic review was registered in the PROSPERO database (CDR 42021284190) to evaluate the proposed methodological design.

Eligibility Criteria

The analyses were based on the population, intervention, comparison, and outcome index: patients with edentulism undergoing prosthetic treatment involving digital systems (population), patients who received implant overdentures (intervention), patients who received overdentures using digital and conventional methods (comparison), and quantitative survival rates, marginal bone loss, complications (biological and prosthodontics), Oral Health Impact Profile (OHIP), plaque and bleeding index, and patient and professional satisfaction data for this type of prosthesis (outcome).

Inclusion criteria

Studies were selected according to the following inclusion criteria: English language, clinical studies, bars used in overdentures and bars manufactured using CAD-CAM technology, and bars manufactured by printing or milling techniques.

Exclusion criteria

In vitro studies, clinical reports, proofs of concepts, and systematic reviews were excluded.

Study search strategy

Multiple databases, including MEDLINE, PubMed, Cochrane Library, SciELO, and Web of Science, were searched for articles published between 2004 and April 2021. The following MeSH/PubMed-based Boolean operators were used: “Overdentures,” “CAD-CAM,” “BAR,” and “Digital.” A related search within PubMed is presented in Supplementary Table 1. A manual search of specific journals and related studies in the field of implant overdentures and digital technology was also conducted.

Data collection process

Articles selection and data collection were conducted by two previously calibrated reviewers (M.D.P. and A.P.C.C.). Articles related to the theme were sought and approved using the Kappa test (k=1.0). In case of disagreement, consensus meetings were held to evaluate the titles and abstracts selected. Then, a definitive consensus meeting including four other researchers (J.F.S.Jr, H.S.V., R.M.B.C, and T.O.O.M) was held to evaluate the selected articles, data collection, and risk of bias. Further clarification on doubts and technical support was offered by an additional researcher (V.C.P). All data in the tables (qualitative data and risk of bias) were extracted by one researcher (A.P.C.C) and checked by another (J.F.S.Jr).

Summary measures

The quantitative data were grouped for some variables: number of complications in overdenture bars and biological complications divided according to the CAD-CAM and control groups. The numbers of overdentures and dentures were considered for data analysis (dichotomous data), which was used as the risk ratio (RR) [12-13], and comparisons were made between the types of overdentures. Statistical significance was set at $p < 0.05$. The prevalence of mechanical/technical bar-level complications and biological complications was also analyzed in the CAD-CAM group. Regarding the analysis of marginal bone loss in the CAD-CAM group, the mean rate of bone loss, standard deviation, and total implants installed were considered. This information was evaluated for the event rate considering the 95% confidence interval (CI). The contribution weight of each study was assessed. Comprehensive Meta-Analysis software (Software version 3.0; Biostat, Englewood, NJ, USA) was used to build the forest plots [15].

Risk of bias in the studies

Regarding the risk of bias, heterogeneity was assessed using the Q method, and the I2 value was analyzed [13, 16, 17]. This study adopted analysis randomization for all meta-analyses to reduce the potential for heterogeneity [18].

RESULT

Descriptive analysis

The search performed in the databases yielded 64 references, and after duplicate references were removed, 52 articles remained. Subsequently, 11 articles were selected for full-text reading after a detailed review of the titles and abstracts. Finally, two articles were excluded as they did not meet the inclusion criteria; the remaining nine studies were selected (Fig.1).

Implant survival rates

Of the nine selected articles, eight evaluated implant survival rates after prosthesis delivery. Three studies analyzed the CAD-CAM milled titanium bars after one year of function, showing 100% survival rate in all groups [8, 19, 20]. Similarly, Mangano et al. demonstrated that, after one year, PEEK bars showed 100% implant survival rates [10]. After two years, Toia et al. and Katsoulis, Brunner, and Mericske-Stern demonstrated 100% of implant survival rates in the CAD-CAM milled titanium bar groups [21, 22]. Katsoulis et al. reported 100% of implant survival rates in the same group [23]. Rinke et al. demonstrated 97% implant survival rates between 5 and 19 years of prosthesis delivery; however, the authors did not indicate which group presented the failures [24]. The outcomes are summarized in Table 1.

Prosthesis survival rates

Prothesis survival rates were also analyzed in six studies. Pozzi et al., demonstrated that after one year, the overdentures rehabilitated with CAD-CAM milled titanium bars presented 100% survival [19]. Similarly, after two years, Katsoulis, Brunner, Mericske-Stern, and Toia et al. reported the same data [21, 22]. However, between three and four years of prothesis delivery, Katsoulis et al. demonstrated that the CAD-CAM milled titanium bars presented nine fractures, all located at the extensions (n = 192); however, when compared with soldered gold bars, these bars presented significantly better values ($p < .001$) [23]. Furthermore, between 5 and 19 years, Rinke et al. documented that the CAD-CAM milled titanium bars presented lower complications than the prefabricated round bars group; however, all groups showed a survival rate of 100% [24]. In another study, Mangano et al. reported 80% survival of overdentures with bars manufactured by PEEK, because three bars did not present sufficient passive fit and two overdentures had problems with tooth fractures [10]. The data are presented in Table 1.

Meta-analysis

It was possible to perform two meta-analyses on this topic. The first evaluated the complications of overdentures manufactured by CAD-CAM and conventional methods. In two studies, a total of 113 overdentures with bar-shaped retention obtained by the CAD-CAM method were made and nine complications were identified, and 128 overdentures were obtained using the conventional method, which presented 13 complications [21, 23]. The meta-analysis did not indicate a significant difference in this comparison (RR, 0.638; 95%CI, 0.108–3.755; P = 0.619; Figure 4). The heterogeneity was Q-value: 1.804, p = 0.179, $I^2 = 44.561$. See Figure 2.

The event rate for overdenture complications in the CAD-CAM group was also evaluated. In six studies involving a total of 215 overdenture prostheses obtained by the CAD-CAM method, 22 complications at the bar level were identified. The event rate data ranged from 5.5% to 22.1%. The overall pooled event rate was 11,4% (random; 95% CI: 5,5%–22,1%; figure 3) [10, 19, 21-24]. The heterogeneity for the failure rate was considered as Q-value: 11,505, p = 0,042, $I^2 = 56,539$. See Figure 3.

Biological complications

Regarding biological complications, three studies revealed some problems. After two years, Toia et al. reported that one implant, rehabilitated with a CAD-CAM milled bar, presented with peri-implant mucositis [22]. Katsoulis et al. reported that between 3 and 4 years, 66% of patients rehabilitated with soldered gold bars presented soft tissue hyperplasia, in contrast to patients rehabilitated with CAD-CAM milled titanium bars who presented only one patient with this condition [23]. Rinke et al. observed peri-implantitis in 20 implants between 5 and 19 years; however, the authors did not report which group presented this condition (CAD-CAM milled titanium bars or

prefabricated round bars) [24]. In the other form, Pozzi et al. demonstrated that after one year, the CAD-CAM milled titanium bars did not present biological complications [19]. The outcomes are presented in Table 2.

Meta-analysis

Two meta-analyses on this topic were developed. The first study evaluated the biological complications of bars manufactured using CAD-CAM and conventional methods. Therefore, in two studies involving a total of 130 overdentures with bar-shaped retention and obtained using the CAD-CAM method, 13 biological complications were identified. Conversely, 119 overdentures obtained by the conventional method presented nine biological complications [23, 24]. The meta-analysis did not indicate a significant difference in this comparison (RR: 0.771; 95% CI: 0.308–1.933; P = 0.580; Figure 4). The heterogeneity was Q-value: 0.987, p = 0.320, I2 = 0.0. See Figure 4.

Furthermore, the rate of biological complications in the CAD-CAM group was assessed using a meta-analysis. In five studies involving a total of 203 overdenture prostheses obtained using the CAD-CAM method, 16 biological complications were identified. The event rate data ranged from 1.8% to 26.8%. The overall pooled event rate was 7.6% (random; 95% CI: 1.8%–26.8%; figure 5) [10, 19, 22-24]. The heterogeneity for failure rate was considered as Q-value: 22.056, p = 0.000, I^2 = 81.864. See Figure 5.

Marginal bone loss analysis

Peri-implant marginal bone loss was also evaluated in this study. According to Pozzi et al., the CAD-CAM milled titanium bars group presented significant differences between the periods evaluated (baseline values: 0.35 $\pm$ 0.34, one-year values 0.64 $\pm$ 0.21) (p = 0.003) [19]. In the other form, Srinivassan et al. compared the performance of this bar and the retentive anchors + gold matrices and found no statistically significant differences among the groups (p = 0.337) [8]. Similarly, Toia et al. demonstrated no statistically significant differences between the periods evaluated (baseline and two years after prosthesis delivery) in CAD-CAM milled titanium bars (p > 0.05) [22]. All data are listed in Table 3.

Second, a meta-analysis evaluating peri-implant marginal bone loss in the CAD-CAM group was developed. Three studies involving a total of 295 implants, which received overdentures obtained by the CAD-CAM method, were followed up from 12 to 24 months. The mean marginal bone loss rate data ranged from 0.4–1.6. The overall pooled mean rate was 1.09 mm (random; 95% CI: 0.4 to 1.6; figure 6) [8, 19, 22]. The heterogeneity for mean marginal bone loss was considered as Q-value: 490.887, p = 0.000, I^2 = 99,593. See Figure 6.

Plaque and bleeding index

Plaque and bleeding indices were also evaluated in this systematic review. After one year, Cordaro et al. demonstrated statistically significant differences between the plaque found in the CAD-CAM milled titanium bar group and the Locator® group, with the latter having the lowest values (21%). Similarly, when evaluating the bleeding index, statistically significant differences were found among groups ($p < 0.001$), and the locator® group had the lowest values (21.7%) [20]. Similarly, Pozzi et al., reported that after 1 year of follow-up, the CAD-CAM milled titanium bar group presented bleeding in two participants (11.1%) around three implants (4.1%). Three participants (16.6%), accounting for five implants (6.9%), showed a slight amount of plaque around the implant-abutment interfaces [19]. Similarly, Srinivasan et al. compared the plaque and bleeding index of CAD-CAM milled titanium bars and retentive anchors + gold matrices and revealed no statistical differences among the groups at baseline. However, when evaluating the presence of plaque after each period (2 weeks, 6 months, and one year), the CAD-CAM milled titanium bars presented statistically significant differences in all periods ($p = 0.027$). However, the retentive anchors + gold matrices group did not show significant differences ($p = 0.808$) [8]. When evaluating the bleeding index, the CAD-CAM milled titanium bar groups significantly decreased the mean values ($p = 0.019$) after the evaluation period (2 weeks, 6 months, and one year). In the other form, the retentive anchors + gold matrices did not exhibit a significant decrease ($p = 0.777$) [8]. In the other form, Toia et al. demonstrated that the CAD-CAM milled titanium bar group presented plaques in 34 sites out of 740 (4.6%) at baseline and 55 sites out of 740 (7.4%) after two years, but no statistically significant differences were found among the time points ($p > 0.05$) [22]. The presence of bleeding was observed at 114 sites of 740 (14.41%) at baseline, and at 165 sites out of 740 (22.3%) after two years; however, no statistically significant differences were found among the periods [22]. All the data are presented in Supplementary table 2.

OHIP outcomes

This study evaluated the impact of oral disorders in patients who received implant overdentures made of CAD-CAM bars, using the Oral Health Impact Profile Questionnaire (OHIP). Pozzi et al. used the OHIP-21 questionnaire and revealed a significant decrease in the OHIP scores after two weeks of prosthesis delivery ($p < 0.001$), and these data continued to decrease up to one year after prosthesis use [19]. Further, these data revealed significant differences when compared to the values at two weeks ($p = 0.016$) [19]. Similarly, Srinivasan et al. analyzed the impact of oral health using the OHIP-EDENT questionnaire in patients who received retentive anchors + gold matrices and CAD-CAM milled titanium bars. These data demonstrated that after one year, the retentive anchors + gold matrices group showed a significant improvement ($p = 0.003$); however, the CAD-CAM

milled titanium bar group showed a significant improvement from two weeks ($p = 0.002$) until one year ($p < 0.001$) [8]. Toia et al. used the OHIP-14 questionnaire to evaluate the impact of oral health in patients who received CAD-CAM milled titanium bars and found that after 1 month, 3 months, and 2 years, there was a statistically significant decrease in relation to the pretreatment values ($p < 0.0001$); however, these scores were not significantly different among them ($p > 0.05$) [22]. Similarly, Katsoulis, Brunner, and Mericske-Stern used the OHIP-14 questionnaire, and these outcomes revealed a better quality of life and satisfaction with the use of the CAD-CAM milled titanium bars; however, the patients who received implant fixed prosthesis demonstrated a significant improvement when compared to the patients with bars ($p < 0.05$) [21]. The outcomes are shown in Supplementary table 3.

Patient satisfaction

Patient satisfaction was evaluated in three studies. Srinivasan et al. demonstrated that after two weeks, the patients who received CAD-CAM milled titanium bars demonstrated significant satisfaction when compared to baseline ($p < 0.001$). This significant increase persisted for up to one year ($p < 0.001$) [8]. Otherwise, the retentive anchors + gold matrices (control group) only showed a significant increase after one year of prothesis use ($p = 0.003$) [8]. Similarly, Cordaro et al. evaluated patient satisfaction in users who received CAD-CAM milled titanium bars and the Locator® attachment system and demonstrated a significant difficulty in cleaning the bars group ($p = 0.018$) [20]. However, no differences were found in terms of general satisfaction, ability to chew, ability to speak, stability, comfort, appearance, pain around the implants, and pain on the gingiva. In relation to the number of visits, the locator® group showed a median of 5.18 visits and the CAD-CAM milled titanium bars group showed a median of 5.6 visits [20]. In the other form, Altonbary and Emera evaluated the CAD-CAM zirconia bars and cobalt-chromium metal bars after 3 months of prosthesis delivery, and found significant differences regarding appearance, time, hygiene, and overall experience, with zirconia bars having better values. However, regarding speech, capacity, restorative procedures, complications, discomfort in surgery, information prior to treatment, and satisfaction with the doctor, few differences were found [9]. All data are listed in Supplementary table 4.

Professional satisfaction

In the same manner, professional satisfaction was evaluated in two articles. Cordaro et al. documented that the clinicians demonstrated more preferences with locator® attachments because the patients who received it presented better soft tissue conditions ($p < 0.001$), and hygiene maintenance was easier than in the CAD-CAM milled titanium bar group [20]. Then, in relation to the retention of the prothesis, the locator attachments appeared to be superior to the CAD-CAM milled titanium bars. Similarly, Toia et al. evaluated CAD-CAM milled titanium

bars and demonstrated that prosthodontists were very satisfied with the delivery and versatility of these bars [22]. All outcomes are listed in Supplementary table 4.

DISCUSSION

The results observed in this systematic review and meta-analysis supported the null hypothesis of this study: the CAD-CAM milled bars used in overdentures presented an excellent performance for use in daily clinical practice. To corroborate this hypothesis, this study evaluated the implant and prosthesis survival rates, biological complications, marginal bone loss, plaque and bleeding index, OHIP scores, and patient and professional satisfaction.

Regarding implant survival, most of the studies selected reported implant survival rates of 100%; however, Rinke et al. reported a percentage of 97% between 5 and 19 years of prothesis delivery, but the authors did not report what group presented the failure (CAD-CAM bars or prefabricated round bars) [24]. In agreement with these outcomes, Tallarico et al. evaluated the implant survival rates in different bar designs and attachment systems, including the CAD-CAM milled bars, reporting 95.9% implant survival rates after 19 years of follow-up [2]. Moreover, other studies confirmed these findings [5, 25-28]. In view of these percentages, this systematic review considered that the implant survival rates of the CAD-CAM milled bars are excellent for use in daily clinical practice.

Otherwise, the prosthesis survival rate was also evaluated. Most of the studies reported an optimal performance until 19 years after prothesis delivery; however, two articles documented some problems [10, 23]. Katsoulis et al. demonstrated that between three and four years, nine fractures were observed in the distal extensions of the control (gold bars) and experimental (CAD-CAM milled titanium bars) groups, indicating that the CAD-CAM bars had lower fractures. It is possible that the use of welding on conventional bars increases the risk of fractures. Otherwise, the bars made by the CAD-CAM system were fabricated from a single titanium block and did not require any type of welding sale. Therefore, this study assumes that, although CAD-CAM bars do not prevent the occurrence of fractures in distal complications, they can reduce their risk [23, 29].

Mangano et al. reported an 80% survival rate in overdentures with PEEK bars. Three bars did not present sufficient passive fit, and two overdentures had problems with tooth fractures [10]. Furthermore, it is important to note that these authors used an intraoral scanner to capture the position of the implant, and also reported that in cases of inadequate adaptation, the distal implants were somewhat tilted and unparallel to each other. After new intraoral scans, new PEEK bars were manufactured, and in these cases, all bars showed an excellent passive fit [10]. Perhaps the scanning strategy or the operator's experience could be the main reasons for these outcomes [29].

Additionally, the meta-analysis showed no statistical differences between the survival rates of CAD-CAM and conventional overdentures. Otherwise, this analysis reported a prevalence of 11.4% in bars manufactured using the CAD-CAM system. Consequently, this study concluded that the CAD-CAM milled bars presented excellent implant and prosthetic survival rates.

Three articles included in the sample reported minor biological complications. Furthermore, a meta-analysis of this item was performed, which showed an overall event rate of 7.6%. Katsoulis et al. demonstrated that patients rehabilitated with soldered gold bars presented significantly more soft tissue hyperplasia than those in the CAD-CAM milled titanium bar group [23]. Furthermore, Rinke et al. documented that 20 patients presented with peri-implantitis between 5 and 19 years of prothesis delivery. However, this work did not report what groups presented these problems (CAD-CAM milled bars or prefabricated round bars). These outcomes are in line with those of other studies that have reported low biological complications [2, 30]. The main causes of mucosal hyperplasia in the patients who received gold bars can be attributed to the design of the bars and a negative pressure on the gums. Additionally, the poor accessibility of some of the bars is another factor that could affect the hygiene procedures and consequently promote mucosal hyperplasia [24].

Regarding peri-implant marginal bone loss, all studies reported satisfactory outcomes with the use of CAD-CAM milled titanium bars. However, one article reported a significant decrease in marginal bone loss in this type of bar [19]. However, it is important to note that this study splinted the implant with a rigid connecting bar, which may have contributed to these differences [25, 31]. Although these outcomes indicated a significant reduction in marginal bone loss, this study considered the treatment with CAD-CAM milled titanium bars as satisfactory. Moreover, according to the meta-analysis, the overall pooled mean rate was 1.09 mm ($p = 0.00$); however, these values were considered optimal in all evaluated studies [10, 19, 22].

Plaque and bleeding indices were also investigated in this review. Three of the four articles selected for this item reported satisfactory results with the use of CAD-CAM milled titanium bars [10, 19, 22]. It is possible that the improvement in the retention and stability of overdentures and the removal of this device to improve hygiene maintenance, especially in elderly patients whose motor coordination can be affected by age, influenced these outcomes [32]. Nevertheless, Cordaro et al. compared the plaque and bleeding index between the CAD-CAM milled titanium bars and locator® attachments, with the latter having the lowest value ($p < 0.001$) [20]. In agreement with these outcomes, other articles emphasized that hygienic maintenance is more difficult around implants supported by bars [33, 34]. However, this does not prevent the use of this type of bar in overdenture rehabilitation.

The impact of oral disorders was assessed in this study. All studies selected for this item confirmed that after prothesis delivery, OHIP scores decreased significantly in all patients. However, the patients who received the CAD-CAM milled titanium bars presented significantly lower OHIP scores from two weeks after prothesis use [10, 19, 21, 22]. It is also important to note that Katsoulis et al. demonstrated significantly lower OHIP scores in the implant-fixed prosthesis ($p < 0.05$). It is possible that the improvement in esthetic, phonetic, and chewing efficiency influenced the OHIP outcomes between these groups. In contrast to implant-fixed prostheses, overdentures are supported by implants and mucosa, and this fact may produce greater discomfort when compared to fixed implant-supported prostheses [35, 36].

Regarding patient satisfaction, all selected studies reported that the users rehabilitated with CAD-CAM milled bars reported a significant improvement in general satisfaction [9, 10]. However, Cordaro et al. noticed that the users rehabilitated with CAD-CAM milled titanium bars presented some complications with the cleaning of bars, producing an uncomfortable feeling in some users [20]. Conversely, the patients rehabilitated with locator® attachments did not report this kind of problem and stood out with better values ($p = 0.018$) [20].

Additionally, Altonbary and Emera reported that regarding appearance, time, hygiene, and overall experience, the users rehabilitated with zirconia bars demonstrated a higher satisfaction than those rehabilitated with metal bars. To justify these outcomes, the authors reported that the color of the material is more realistic and, consequently, is more acceptable for patients. Furthermore, the fabrication of zirconia bars is more advantageous because it saves more time and produces smoother bars that facilitate hygienic maintenance [9].

Finally, professional satisfaction was assessed in this study. According to Toia et al. and Cordaro et al., the professionals were very satisfied with the performance of the CAD-CAM milled bars [20, 22]. However, Cordaro et al. documented that the professionals preferred to work with locator® attachments because these components provided better soft tissue conditions and appeared to be superior to CAD-CAM milled bars in hygiene maintenance [20].

Further long-term follow-up studies should be conducted to obtain more outcomes of the performance of CAD-CAM milled bars compare with bars manufactured by conventional protocols.

CONCLUSION

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

1. The CAD-CAM methods presented a better performance in daily clinical practice due to the high rates of implant survival and the few biological and mechanical complications that were found in the users.

2. The marginal bone loss of CAD-CAM-milled titanium bars was less than that of the retentive anchors (conventional attachments).
3. The plaque and bleeding index of CAD-CAM milled titanium bars were considered acceptable; however, the locator® attachments showed significantly lower values.
4. There was a significant improvement in the quality of life of patients rehabilitated with overdentures with or without bars manufactured by the CAD-CAM system. However, the rehabilitation of the implant-fixed prostheses showed better values.
5. The participants and prosthodontists demonstrated a significant acceptance with the bars manufactured by the CAD-CAM methods; however, the patients reported more preferences with the zirconia bars.
6. None of the clinical studies selected for this systematic review reported the use of CAD-CAM bars manufactured using additive methods.

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FIGURES

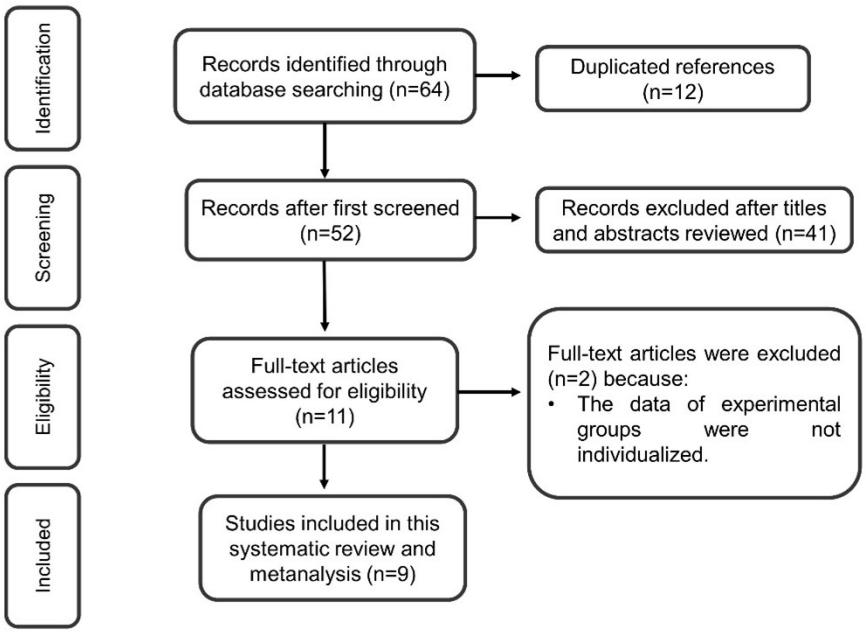

Figure 1. Data of article selection according to the PRISMA diagram. PRISMA, Preferred Reporting Items for Systematic Reviews and Metanalysis.

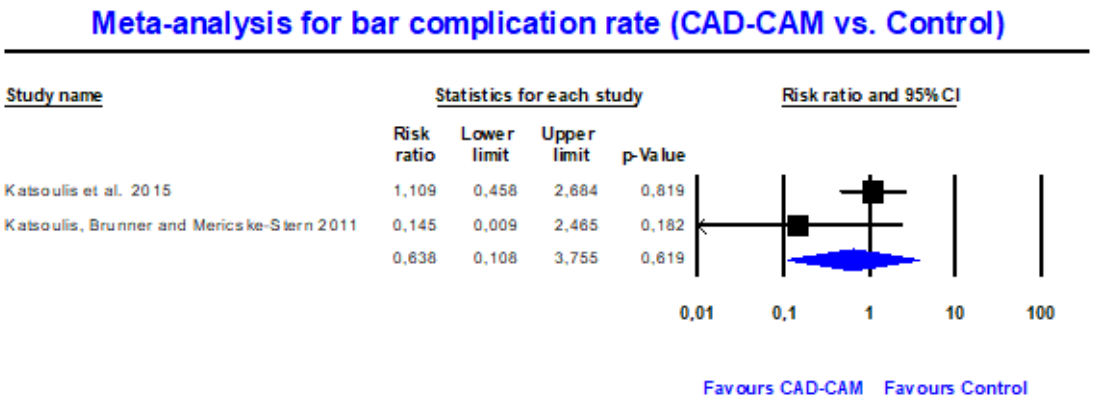

Figure 2. Forest plot for Overdenture-based bar CAD-CAM vs. Control.

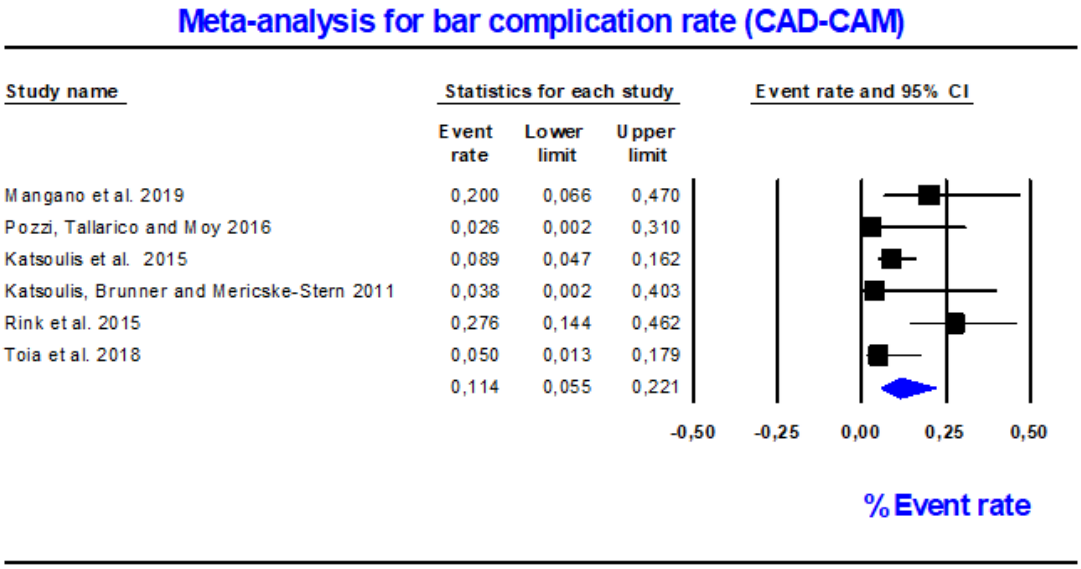

Figure 3. Forest plot for bar complication rate (CAD-CAM).

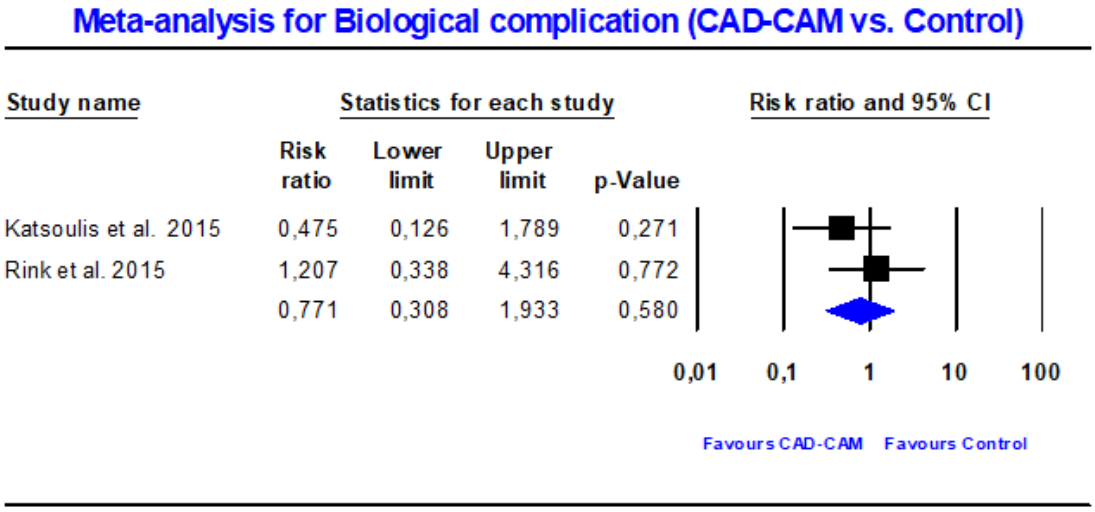

Figure 4. Forest plot for Overdenture-based bar CAD-CAM vs. Control (Biological Complications)

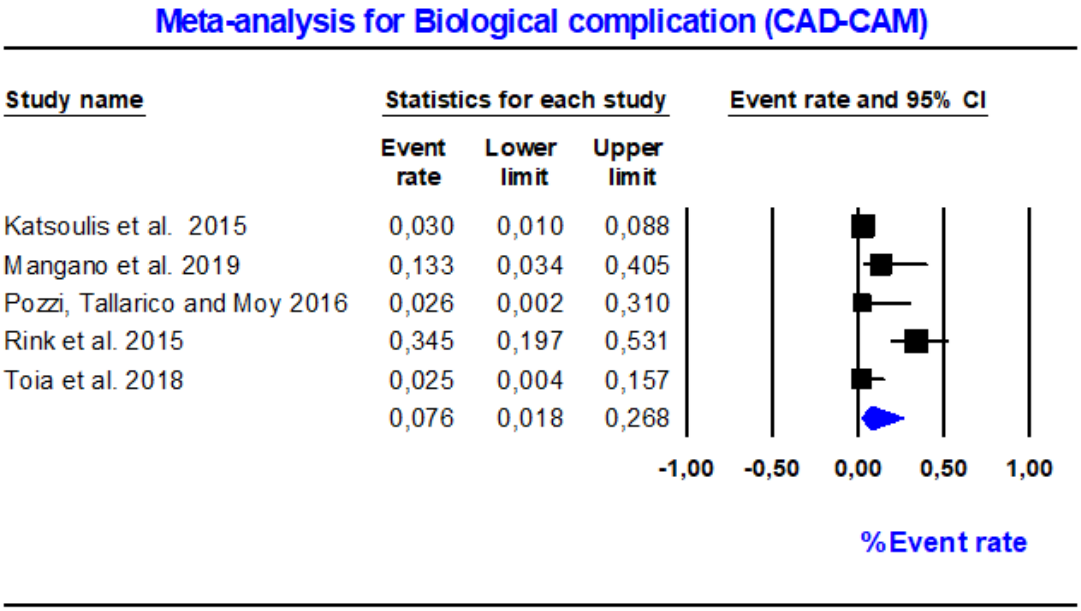

Figure 5. Forest plot for Overdenture-based bar CAD-CAM vs. Control (Biological Complications)

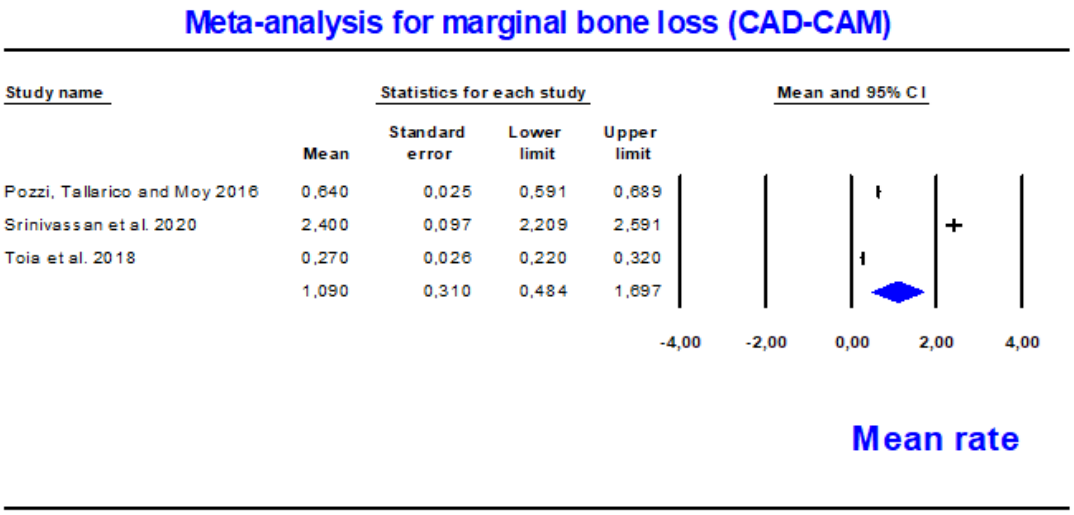

Figure 6. Forest plot for bar complication rate (CAD-CAM)

Table 1. Summary of implants and prosthetic survival rates.

Author	Type of study	Period of evaluation	Groups	Number of implants	Implant Survival Rate	Number of overdentures	Number of fractured matrices/fracture rates of matrices	Results
Katsoulis et al. 2015 [23]	Prospective	3-4 years	CAD-CAM milled titanium bar	231	100%	101	1/1.0%	Activation of matrices was required 2.4x less often in Ti-bar. No difference was observed for denture repair (fracture of base or teeth)
			Soldered gold bars	246		112	15/13.0%	
Katsoulis, Brunner and Mericske-Stern 2011 [21]	Prospective	2 years	CAD-CAM milled titanium bar	51	100%	16	0	The prosthetic maintenance that includes sore spots and the need for occlusal adjustment was similar for all three groups.
			Conventional gold bars	68	100%	12	2	
			Implant fixed protheses	74	100%	13	0	
Rinke et al. 2015 [24]	Retrospective	5-19 years	Prefabricated round bars	NP	97%	7	NR	The prefabricated group demonstrated more denture complications (n=22) than CAD-CAM milled bar groups located anteriorly (n=11) or bilaterally (n=7).
			One-piece anterior milled bars	NP		20	NR	
			Two bilaterally placed milled bars	NP		9	NR	
Toia et al. 2019 [22]	Prospective	2 years	CAD-CAM milled titanium bar	185	100%	40	0	In one patient, two prosthetic screws lost their tightness in the mesostructured. One patient reported a technical complication consisting of a chipping of the resin central lower left incisor.
Pozzi et al. 2016 [19]	Prospective	1 year	CAD-CAM milled titanium bar	72	100%	18	0	No technical complication occurring during the follow-up, resulting in a prosthetic success rate.

Mangano et al. 2019 [10]	Prospective	1 year	PEEK	60	100%	15	2	Three out of 15 PPEK bars did not present a sufficient passive fit or adaptation. Otherwise, two overdentures need to be repaired by tooth fractures
Cordaro et al. 2012 [20]	Retrospective	13 months	Locator®	76	100%	NR	NR	No complications were found in the studied implants, demonstrating a 100% of survival in the treatment with CAD-CAM bars.
		18 months	CAD-CAM milled titanium bar	80	100%	NR	NR	
Srinivasan et al. 2020 [8]	Prospective	1 year	CAD-CAM milled titanium bar with distal extension + gold clip	38	100%	NR	NR	No complications were found in the implants rehabilitated in both groups.
			Retentive anchors + gold matrices	38	100%	NR	NR	

CAD-CAM, Computer aided design-Computer aided manufacturing; PEEK, Polyether-ether-ketone; NR, No reported.

Table 2. Summary of biological complications.

Author	Period of evaluation	Number of prothesis/implants	Groups	Results
Katsoulis et al. 2015 [23]	3-4 years	101/231	CAD-CAM milled titanium bars	The soft tissue hyperplasia was a common finding with gold bars and was present in 66% of patients, however the group of CAD-CAM milled bars exhibited only one patient with hyperplasia.
		112/246	Soldered gold bars	
Pozzi et al. 2016 [19]	1 year	18/72	CAD-CAM milled titanium bar	No biologic complications occurred during the follow-up, resulting in the success of implants and prosthesis success.
Rinke et al. 2015 [24]	5-19 years	7/NR	Prefabricated round bars	It was observed peri-implantitis in 20 implants (12.4%), in 12 implant overdentures. Six of the 10 smokers and 4 of the 17 non-smokers.
		20/NR	One-piece anterior milled bars	
		9/NR	Two bilaterally placed milled bars	
Toia et al. 2019 [22]	2 years	40/185	CAD-CAM milled titanium bars	Only one implant of 185 presented a peri-implant mucositis.
Mangano et al. 2019 [10]	1 year	15/60	Polyether-ether-ketone (PEEK)	Two fixtures with peri-implantitis were founded in one patient.

CAD-CAM, Computer aided design-Computer aided manufacturing; PEEK, Polyether-ether-ketone; NR, No report

Table 3. Data of peri-implant marginal bone level.

Author	Period of evaluation	Groups	Number of implants	Mean + SD	P-value
Srinivassan et al. 2020 [8]	1 year	CAD-CAM milled titanium bar + gold clip	38	2.4 ± 0.6	0.337
		Retentive anchors + gold matrices	38	2.7 ± 0.6	
Pozzi et al. 2016 [19]	Baseline 1 year	CAD-CAM milled titanium bar	72	0.35 ± 0.34 0.64 ± 0.21	0.003
Toia et al. 2019 [22]	Baseline 2 years	CAD-CAM milled titanium bars	185	0.30 ± 0.40 0.27 ± 0.35	P>0.05

CAD-CAM, Computer aided design-Computer aided manufacturing

SUPPLEMENTARY INFORMATION (SI)

“cad cam bar” and “overdentures”	**("computer-aided design"[MeSH Terms] OR ("computer-aided"[All Fields] AND "design"[All Fields]) OR "computer-aided design"[All Fields] OR ("cad"[All Fields] AND "cam"[All Fields]) OR "cad cam"[All Fields]) AND bar[All Fields] AND ("denture, overlay"[MeSH Terms] OR ("denture"[All Fields] AND "overlay"[All Fields]) OR "overlay denture"[All Fields] OR "overdentures"[All Fields])**
“digital bar” and “overdentures”	**digital[All Fields] AND bar[All Fields] AND ("denture, overlay"[MeSH Terms] OR ("denture"[All Fields] AND "overlay"[All Fields]) OR "overlay denture"[All Fields] OR "overdentures"[All Fields])**

Supplementary table 1. Related search within PubMed

Supplementary table 2. Data of plaque and bleeding index.

Author	Period of evaluation	Groups	Plaque results	Bleeding results
Toia et al. 2019 [22]	Baseline 2 years	CAD-CAM milled titanium bars	At baseline, the plaque was present on the surfaces of 34 site out 740 (4.6%), however after 2 years, the plaque was presented on 55 sites out of 740 (7.4%). No statistical significance difference was observed between the times.	The BOP was present on the surfaces of 114 site out 740 (14.41%) at baseline and 165 sites out of 740 (22.3%) after two years. Statistically significant differences were present between periods (p=0.032).
Cordaro et al. 2012 [20]	1 year	Locator® CAD-CAM milled titanium bar	The bar group exhibited 45% of surfaces with plaque, most of them were lingual surfaces. However, the Locator® group showed only 21%. Statistically significant differences were found among groups (p<0.001).	The bars group demonstrated higher frequencies in the bar group (38.4%) than Locator ® group (21.7%). Statistically significant differences were found among groups (p<0.001).
Pozzi et al. 2016 [19]	1 year	CAD-CAM milled titanium bar	Three participants (16.6%) accounting for 5 implants (6.9%) exhibited a slight amount of plaque around the abutments.	BOP was detected in two participants (11.1%) around three implants (4.1%).
Srinivasan et al. 2020 [8]	Baseline 2 weeks 6 months 1 year	CAD-CAM milled titanium bar with distal extension + gold clip Retentive anchors + gold matrices	The baseline data demonstrated no significant differences between groups (p=0.488). However, the values of each period evaluated, demonstrated significant differences in the CAD-CAM milled bars group (p=0.027), differently with the retentive anchors group that did not present significant differences (p=0.808). After two weeks, the cad-cam milled bars presented a significant decrease of plaque when compared with the retentive anchors group (p=0.026), however these differences did not remain over time (p>0.05).	At baseline, no statistical differences were found among groups (p=0.416) but, after evaluation periods, the cad-cam milled bars group decreased significantly the mean values (p=0.019). Contrarily, the retentive anchors group did not exhibit significant decrease (p=0.777). After two weeks of prothesis delivery, the cad-cam milled bars presented a significant decrease of BOP when compared with the retentive anchors group (p=0.005), however these differences did not remain over time (p>0.05).

CAD-CAM, Computer aided design-Computer aided manufacturing; BOP, Bleeding on proving.

Supplementary table 3. Summary of OHIP Scores

Author	Questionnaire	Number of patients	Period of evaluation	Groups	Mean + SD	Result
Pozzi et al. 2016 [19]	OHIP-21	18	Pre-treatment	CAD-CAM milled titanium bar	62.3 ± 12.6	There was a significant decrease in the OHIP scores from the two weeks onwards (p<0.001) and they continue to decrease after one year of prosthesis use, showing significant differences when compared to the values of the two weeks (p=0.016).
			2 weeks		23.5 ± 8.5	
			1 year		20.8 ± 6.9	
Srinivasan et al. 2020 [8]	OHIP-EDENT	20	Baseline	CAD-CAM milled titanium bar + gold clip	NR	After one year of function, the retentive anchors group showed significant improvement (p=.003). However, the cad-cam milled bar group revealed a significant improvement from the 2 weeks after prothesis delivery (p=.002) which leveled with little variation of the median until one year of function (p<.001).
		20	2 weeks	Retentive anchors + gold matrices		
			6 months		NR	
			1 year			
Toia et al. 2019 [22]	OHIP-14	40	Pre-treatment	CAD-CAM milled titanium bars	22.88 ± 9.4	The scores of each follow-up (1 month, 3 months and 2 years) were significantly decrease from the pre-treatment one (p<0.0001), while these scores were not significantly different among them (p>0.05).
			1 month		2.25 ± 3.3	
			3 months		2.35 ± 3.9	
			2 years		2.4 ± 3.9	
Katsoulis, Brunner and Mericske-Stern 2011 [21]	OHIP-14	16	2 years	CAD-CAM milled titanium bar	7.4± 9.3	These outcomes indicated a better quality of life and satisfaction with these treatments, but the implant fixed prothesis group showed a significant improvement when compared with both types of overdentures (p<0.05).
		12		Conventional gold bars	6.7± 9.1	
		13		Implant fixed protheses	1.8 ± 1.9	

CAD-CAM, Computer aided design-Computer aided manufacturing; NR, No reported; OHIP, Oral Health Impact Profile; OHIP-EDENT, Oral Health Impact Profile for Edentulous.

Supplementary table 4. Patient and professional satisfaction outcomes.

Author	Number of patients	Period of evaluation	Groups	Results
Srinivassan et al. 2020 [8]	20	Baseline 2 weeks 6 months 1 year	CAD-CAM milled titanium bar with distal extension + gold clip Retentive anchors + gold matrices	After one year, there was a significant increase in patient satisfaction in the retentive anchors + gold matrices group. However, participants in the CAD-CAM milled titanium bars group demonstrated a significant increase from two weeks after prosthesis installation.
	20			
Altonbary and Emera 2020 [9]	10	3 months	CAD-CAM zirconia bar	Significant differences were founding between groups regarding appearance, time, hygiene, undergo procedures, recommend procedures and the overall experience standing out the CAD-CAM zirconia bars with better values. However, few differences were observed regarding speech, chewing capacity, restorative procedures, complications, discomfort in surgery, information prior to treatment and satisfaction with the doctor.
	10		Cobalt-chromium metal bar	
Cordaro et al. 2012 [20]	19	1 year	Locator®	It was observed more difficulty in the cleaning of CAD-CAM milled bars instead the locator abutments (p=0.018). Regarding general satisfaction, ability to chew, ability to speak, stability, comfort, appearance, pain around the implants and pain on gingiva no differences was founding.
	20		CAD-CAM milled titanium bar	The locator group presented an average of 5.18 visits and the CAD-CAM milled titanium bar group: 5.6 visits, because in this group is necessary to verify the passive fit of the bar. In front of this, the prosthodontists reported more satisfaction with the use of locator(R) attachments.
Toia et al. 2019 [22]	40	2 years	CAD-CAM milled titanium bar	The prosthodontists were very satisfied about the delivery and the versatility of the milled bars.

CAD-CAM, Computer aided design-Computer aided manufacturing

3 DISCUSSION

3 DISCUSSION

The use of robotic in the manufacture of dental prostheses is increasing every year. Therefore, it is important to investigate what has been the development of prostheses fabricated with this technology. Thus, this study aimed to compare the performance of conventional dentures versus dentures manufactured by the CAD-CAM systems. As a second objective, this work evaluated the clinical performance of bars, used in implant supported dentures, fabricated by the CAD-CAM methods.

In the first instance, the outcomes of article one revealed that the dentures manufactured by the CAD-CAM methods (milling technique) presented better retention than those manufactured by the conventional methods, thus it was rejected the first null hypothesis (AL-HELAL et al., 2017; AL-RUMAIH et al., 2018). Regarding this topic, it's important to emphasize that the resins used in the conventional technique present changes in the polymerization reaction, producing residual monomer molecules. These molecules promote a potentially deleterious effect and change the mechanical and surface properties of the future prosthesis (HARRISON; HUGGETT, 1992; GAD et al., 2019). Furthermore, the PMMA blocks used in the subtractive technique are manufactured under high temperatures and pressure values, forming longer polymer chains with high molecular weight, well-defined complex structures, and lower residual monomer values (SRINIVASAN et al., 2018; MURAKAMI et al., 2013). These chains produce an increase in the polymerization rate, reduce polydispersity and provide the formation of highly condensed resins with low porosity (STEINMASSL et al., 2017). Thus, the precision offered by the subtractive technique and the quality of the material used in the CAD-CAM methods could have influenced the retention outcomes in these studies.

Also, this work observed that the use of the prostheses adhesives significantly reduced the retention of CAD-CAM dentures, but no differences were observed when used in conventional prostheses (AL-RUMAIH et al., 2018). Perhaps, the better adaptation and the intimate contact of the milled CAD-CAM dentures in the maxillary tissues prevented an adequate draining of the adhesives (YOON et al., 2020). Thus, the retention and the adaptation of CAD-CAM dentures should be evaluated together using or not the denture adhesives.

Besides that, this systematic review revealed that the CAD-CAM dentures presented a better adaptation, experience, satisfaction, besides representing a lower time and cost than

conventional dentures; however, there were no statistically significant differences when evaluating the number of unscheduled postinsertion visits. Thus, the second null hypothesis was partially rejected.

The adaptation of the surfaces is relevant for the rehabilitation success treatment and is directly related to the retention and stability of the prostheses. According to Yoon et al. (2020) the dentures manufactured by milling and DLP techniques provided a significant adaptation to the maxillary ridge and hard palate. In addition, the DLP dentures presented a better adaptation in the stress-bearing areas than milling and conventional dentures. Moreover, it was established that the conventional methods tended to press the center of the palate in contrast with the CAD-CAM methods (YOON et al., 2020). These outcomes were similar to the findings of Hwang et al. (2019), that observed a better precision and surface adaptation in dentures manufactured by the DLP technique, showing a misfit within 100 µm (HWANG et al., 2019). Similarly, other studies corroborated these findings in CAD-CAM milled dentures (STEINMASSL et al., 2018; GOODACRE et al., 2016).

In terms of the chairside time, the CAD-CAM system presented a significant advantage over conventional methods. The treatment with this technique represented 2 to 3 visits to conclude the treatment, but it's relevant to note that this fact depends on the system and the protocol used by the professional (STEINMASSL et al., 2017; SRINIVASAN et al., 2017). According to Kattadiyil et al. (2015), the CAD-CAM dentures manufacturing represented 205 minutes less of chairside time than conventional dentures (KATTADIYIL et al., 2015). Similarly, with these outcomes, Srinivasan et al. (2018) reported a mean of 233 minutes less in favor of the CAD-CAM complete dentures. Otherwise, the conventional dentures require 5 to 6 visits to conclude the treatment, which may introduce difficulties, particularly for less experienced clinicians (SRINIVASAN et al., 2018). Therefore, the versatility of the CAD-CAM methods, the potential to obtain definitive impressions, interocclusal relationship records, and tooth selection at the first appointment, are the main causes that would justify these findings.

Regarding the treatment cost, SRINIVASAN et al. (2018) demonstrated that the material costs were less in the conventional dentures than the CAD-CAM dentures. However, in terms of clinical fees and laboratory costs, the CAD-CAM milled dentures were more cost-effective than conventional dentures. It's important to note that this study was conducted in Switzerland and one limitation of this work was the difficulty to extrapolate these data to other

countries, for the particularities of variations in costs (SRINIVASAN et al., 2018). These results were consistent with the findings of other studies, that showed lower prices in the dentures manufactured by the CAD-CAM methods (ARAKAWA et al., 2021; SMITH et al., 2020).

Respecting the patient experience and level of satisfaction with conventional and CAD-CAM complete dentures, Kattadiyil et al. (2015) indicated significantly higher preferences for the CAD-CAM dentures in terms of comfort, chewing, prosthesis selection, and technique efficiency. However, fewer complications were found in both types of prostheses (KATTADIYIL et al. 2015). According to these outcomes, Wei et al. (2020) revealed higher scores in the general satisfaction of patients rehabilitated with CAD-CAM complete dentures (WEI et al., 2020). However, other studies did not significantly find differences (INOKOSHI et al., 2012; SAPONARO et al., 2016). The outcomes may be related to complications encountered during the treatments in both techniques, which may have influenced patient perceptions. Furthermore, the lower number of clinical visits and steps required by the CAD-CAM workflow may also have influenced patient perceptions on treatment.

Regarding unscheduled postinsertion adjustment visits required for the manufacturing of the conventional and milled CAD-CAM dentures, no differences were found in both prostheses. Thus, these outcomes partially rejected the second null hypothesis of this study. The authors suggested that this may be related to the adequate standardization in both treatment protocols or the location of the clinical practice, which may be distant and difficult for patients to access because only 20% of patients attended scheduled visits. The average number of unscheduled visits recorded was 1.7 for CAD-CAM and 1.8 for conventional dentures. Conversely, Bidra et al. (2016) reported an average of 3.3 adjustments following insertion however, this article applied a 2-visit protocol, which included a small sample size and conventional and implant-supported dentures (BIDRA et al., 2016). These factors may have produced different outcomes thus, standardized protocols to assess postinsertion visits should be applied in further studies.

Respecting to the second article, the outcomes supported the third null hypotheses of this project: The CAD-CAM bars used in overdentures presented a substantial potential to be use in the edentulism rehabilitation. To reach this result, this systematic review aimed to evaluate some terms such as the implant survival rates, biological complications, prosthesis survival, marginal bone level, plaque, and bleeding index, OHIP scores, patient satisfaction, and professional satisfaction.

Regarding implant survival, six of eight articles selected for this item showed 100% of implant survival rates until four years on function. However, Rinke et al. (2015) reported 97% between 5 to 19 years on function, but this study did not report what group presented the failure (CAD-CAM milled titanium bar anteriorly located, CAD-CAM milled titanium bars bilaterally placed or prefabricated round bar) (RINKE et al., 2015). It's important to note that, differently from the CAD-CAM groups, Rinke et al. (2015) evaluated prefabricated round bars without distal extensions, additionally, all bars were installed in 4 to 6 implants. Probably, the fact that this group did not have a distal extension could have produced an overload in the last's implants, thus causing greater bone loss around them. These outcomes are similar to findings reported by other studies (KRENNMAIR; KRAINHOFNER; PIEHSLINGER, 2008; KRENNMAIR; PIEHSLINGER, 2009; ANDREIOTELLI; ATT; STRUB, 2010, KRENNMAIR et al., 2012; BRESSAN et al., 2012). Krennmair et al. (2012) reported high implant survival rates in CAD-CAM milled bars using rigid anchoring, however, some complications were noticed in the prefabricated round bars (KREINMAIR et al., 2012). In the same form, Bressan et al. (2012) documented some complications in prefabricated round bars, nonetheless in this case, when supported by two implants (BRESSAN et al., 2012). Tallarico et al. (2018) evaluated the implant survival rates in different bar designs and attachments systems, including the CAD-CAM milled bars, reporting 95.9% implant survival rates after 19 years of follow-up (TALLARICO et al., 2018). In view of these outcomes, bars manufactured by the CAD-CAM methods presented an almost absolute survival of implants.

The prosthesis survival rates were also assessed. The outcomes demonstrated that until 19 years of prosthesis delivery, the CAD-CAM milled bars presented 100% of prosthesis survival but, Katsoulis et al. (2015) and Mangano et al. (2019) reported some problems. Additionally, the meta-analysis revealed that when compared to conventional methods, no significant differences were found.

Katsoulis et al. (2015) documented that between three to four years on function, 9 fractures, located at the extensions, were noticed. Nonetheless, when compared to the control group (gold bars), the CAD-CAM milled titanium bars presented significantly better values ($p<.001$) (KATSOULIS et al., 2015). According to the literature, the use of distal extensions enhances the stability of overdentures, especially if the bars are short, however, some authors reported that fractures in bars occur due to distal extensions and recommended to avoid using them in the rehabilitation treatment (DEN DUNNEN et al. 1998). In view of these data, Katsoulis et al. (2015) concluded that the CAD-CAM bar with distal extensions does not

prevent the occurrence of fractures but reduces it significantly (KATSOULIS et al., 2015). Perhaps, the fact that these bars are manufactured in a single block and do not require welding like required in conventional methods favored these results, because according to this article the fractures of the CAD-CAM milled titanium bars mostly occurred at the access hole for the bar screw, while the gold bars group mostly exhibited fractures at the welding joints (KATSOULIS et al., 2015). In agreement with these outcomes, other studies reported similar results (NAERT; ALSAADI; QUIRYNEN, 2004; FONTIJN-TEKAMP, 2004).

Further, the prosthesis survival of PEEK bars was also assessed. According to Mangano et al. (2019), the PEEK bars exhibited 80% of prosthesis survival because three bars did not present sufficient passive fit, and two overdentures have problems with tooth fractures. Also, it is important to note that the authors used the intraoral scanner to capture the position of implants and, reported that in all three cases of inadequate adaptation, the distal implants were somewhat tilted and unparallel to each other. After new intraoral scan and new PEEK bars were manufactured, and in these cases, all bars showed an excellent passive fit (MANGANO et al., 2019). Maybe, the scanning strategy or the operator's experience could be the main reasons of these outcomes (DEN DUNNEN et al. 1998).

Regarding biological complications, three of nine selected articles reported some problems, however not serious. Also, a meta-analysis of this item was performed and showed an overall event rate of 7.6%. Toia et al. 2019 reported that one implant, rehabilitated with CAD-CAM milled titanium bars, presented peri-implant mucositis (TOIA et al., 2019). Katsoulis et al. (2015) reported that only one patient rehabilitated with CAD-CAM milled titanium bars presented this condition, differently from soldered gold bars group that demonstrated significantly more implants with soft tissue hyperplasia (KATSOULIS et al., 2015). Furthermore, Rinke et al. (2015) documented that between 5 to 19 years on function, 20 implants presented peri-implantitis however, these authors did not report what group presented these problems (CAD-CAM milled titanium bars or prefabricated round bars) (RINKE et al., 2015). According to some authors, the higher incidence of mucosal hyperplasia associated with bars used in overdentures can be attributed to the design of bars, because, if the bar is placed close to the mucosa, the soft tissue would be significantly affected by negative pressure in the death space. This fact appears to be the main reason for the poor mucosal response. However, the patient's reluctance to remove their prostheses could be another factor to contribute with this condition (JOHNS et al., 1992; ENGQUIST et al., 1988; JEMT et al., 1992; LACHMANN et al., 2007). Although Rinke et al. (2015) did not report what groups presented peri-implantitis,

the prefabricated round bars without distal extensions may have presented this condition due to the possible overload in the distal implants (RINKE et al., 2015). However, long-term studies should be developed to confirm this hypothesis.

In terms of peri-implant marginal bone loss, two articles reported no significant differences in the mean values of the CAD-CAM milled titanium bars, until two years on function, except for the study of Pozzi, Tallarico, and Moy (2016) that demonstrated significant differences in this type of bar during the first year. Nonetheless, these authors reported that the data obtained were considered satisfactory (POZZI; TALLARICO; MOY, 2016). Also, it is important to note that this work splinted the implants with a rigid connecting bar, which may have contributed to these differences (SADOWSKY, 2001; KRENNMAIR; KRAINHOFNER; PIEHSLINGER, 2008). Moreover, according to the meta-analysis, the overall pooled mean rate was 1.09mm (p=0.00); however, these values were considered optimal in all evaluated studies.

Plaque and bleeding index were also investigated in this review. Pozzi, Tallarico, and Moy (2016) evidenced the presence of plaque and detected bleeding in a few participants rehabilitated with CAD-CAM milled titanium bars (POZZI; TALLARICO; MOY, 2016). Similarly, Toia et al. (2019) registered similar outcomes in their study, standing out that no statistical differences were found (TOIA et al., 2019). In the same form, Srinivasan et al. (2020) documented that the CAD-CAM milled titanium bars had less plaque and bleeding than the control group (retentive anchors + gold matrices) during the first year of function, however, no statistical differences were founding. These findings can be justified due to the advantage that overdentures have in being removed, especially when they are used by elderly patients whose dexterity is limited. It is known that inaccessible restorations are significantly associated with implant loss and a high rate of peri-implantitis (SERINO; STROM, 2009). Nevertheless, Cordaro et al. (2013) compared the plaque and the bleeding index between the CAD-CAM milled titanium bars and the locator® attachments, with the latter having the lowest values (P<0,001) (CORDARO et al., 2013). In line with these outcomes, other studies reported similar values and emphasized that the hygienic maintenance is more complicated around the implants supported by bars (ROMEO et al., 2002; NAERT et al., 2004). However, these values are not relevant enough to contraindicate their use in rehabilitation treatment.

Also, this work contemplated evaluating the impact of oral disorders in patients who received CAD-CAM milled titanium bars. For this, the OHIP questionnaire was employed in the four articles selected for this item, demonstrating a significant decrease in the OHIP scores

in all studies. The OHIP questionnaire has become a popular and reliable instrument to measure the quality of life in dentistry (LOCKER; ALLEN, 2002). It can be used regardless of the type of prosthesis or dental status and most patients are able to fill it (JOHN et al., 2006). The fact of the OHIP scores decreased would mean that patients significantly improved their quality of life. In view of this, Pozzi, Tallarico, and Moy (2016) reported that after two weeks on function, it's possible to observe a significant decrease of the OHIP scores and their outcomes were continuing to decrease until one year of prosthesis use (POZZI; TALLARICO AND MOY, 2016). In the same form, Toia et al. (2019) reported that the CAD-CAM milled titanium bars significantly decreased the OHIP scores after 1 month of protheses delivery until two years of prosthesis function ($p<0.0001$) (TOIA et al., 2019). Similarly, Srinivasan et al. (2020) reported a significant improvement in the quality of life in both groups evaluated: retentive anchors + gold matrices (control group) and the CAD-CAM milled titanium bars. However, the control group presented this change only after one year of protheses delivery ($p=0.003$), and the CAD-CAM milled titanium bar group from the two weeks after protheses delivery ($p=0.002$) continued to decrease until one year of prothesis function ($p<0.001$) (SRINIVASAN et al., 2020). Finally, Katsoulis, Brunner, and Mericske-Stern (2011) revealed a significant improvement in the CAD-CAM milled titanium bars group however, the patients who received implant fixed prosthesis demonstrated better values ($p<0.05$) (KATSOULIS; BRUNNER; MERICSKE-STERN, 2011). These outcomes may be justified by the improvement of the esthetic, phonetic, and by chewing efficiency loss that overdentures offer to toothless patients. However, it's necessary to notice that the implant-fixed prostheses presented better values than overdentures. This can be explained by the fact that the implant-fixed prostheses presented a greater chewing efficiency and stability than the overdentures. Also, the overdentures are supported by implants and by the oral mucosa, producing more discomfort when compared to fixed implant-supported prostheses. (OH et al., 2020; MÜLLER et al., 2001).

Regarding patient satisfaction, three studies were contemplated for this item. Srinivasan et al. (2020) and Cordaro et al. (2013) evaluated the performance of the CAD-CAM milled titanium bars and showed a significant improvement in the general satisfaction, ability to chew, ability to speak, stability, comfort, appearance, pain around the implants and pain on the gingiva (SRINIVASAN et al., 2020; CORDARO et al., 2013). However, Cordaro et al. (2013) reported significant difficulty in the cleaning of bars, standing out the locator groups with better values ($p=0.018$) (CORDARO et al., 2013). In the other form, Altonbary and Emera (2021) evaluated the CAD-CAM zirconia bars and compare them to cobalt-chromium metal bars after 3 months

of function. These outcomes documented significant differences regarding appearance, time, hygiene, and the overall experience. Nonetheless, no significant differences were found regarding speech, capacity, restorative procedures, complications, discomfort in surgery, information prior to treatment, and satisfaction with the doctor (ALTONBARY; EMERA, 2021). According to these outcomes, Bühler et al. (2011) documented that the CAD-CAM zirconia bars were more acceptable for the patients when compared with metal displays (BÜHLER et al., 2011).

Finally, this systematic review aimed to evaluate professional satisfaction. According to Cordaro et al. (2013), the professionals prefer the locator attachments because these components presented better soft tissue conditions than the CAD-CAM milled bars. Therefore, in relation to hygienic maintenance and for the retention of protheses, the locator group appeared to be superior (CORDARO et al., 2013). When comparing the number of chairside times, the locator group requires fewer visits to complete the treatment, without a doubt, this fact influenced the clinicians' preferences (CORDARO et al., 2013). Otherwise, Toia et al. (2019) reported that the prosthodontists were very satisfied with the use of CAD-CAM milled titanium bars, however, in this case, the authors did not compare it with another type of bar or attachments (TOIA et al., 2019).

In relation to the first systematic review, one limitation was the small number of clinical studies published. Also, the small sample sizes and the differences among methodologies prevented the development of a meta-analysis. Considering these facts, more studies should be developed, especially studies that evaluate the adaptation and the retention of the CAD-CAM dentures and conventional dentures, thus as the role of denture adhesives in their application. Furthermore, clinical studies addressing longer follow-up periods should be developed to compare differences among techniques.

Similarly, the second systematic review presented some limitations such as the few published clinical studies on the subject to date. Furthermore, the lack of participant randomization and sample size calculations were lacking in most of the studies. In addition, some of the selected studies did not include the control group. In view of these facts, more studies comparing the differences between the methodologies and long-term articles evaluating the performance of the CAD-CAM bars should be developed to confirm these outcomes.

4 CONCLUSION AND FINAL CONSIDERATIONS

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In relation with the first article, the findings observed suggested that:

The complete dentures manufactured by the CAD-CAM methods presented a better performance than those manufactured by the conventional methods. Also, it was corroborated that the use of denture adhesives impairs the retention in CAD-CAM complete dentures, due to the better adaptation demonstrated by these kinds of prostheses.

Further, it was confirmed that the CAD-CAM complete dentures required less chairside time and represent fewer costs than conventional complete dentures.

In relation with the second article, the findings concluded that:

The CAD-CAM milled titanium bars presented an acceptable performance in clinical practice. However, the bars manufactured with PEEK revealed some complications with the overdentures in the first year of function. Additionally, the patient's and prosthodontist's satisfaction were very high with overdentures involving bars manufactured by the CAD-CAM methods.

Further investigations should be developed to confirm these outcomes.

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ANNEX

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THE JOURNAL OF PROSTHETIC DENTISTRY

SYSTEMATIC REVIEW

Evaluation of the clinical performance of dentures manufactured by computer-aided technology and conventional techniques: A systematic review

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ABSTRACT

Statement of problem. The introduction of computer-aided design and computer-aided manufacturing (CAD-CAM) technology for complete denture fabrication may have improved clinical outcomes compared with conventional techniques. However, systematic reviews comparing these techniques are lacking.

Purpose. The purpose of this systematic review was to identify, compare, and synthesize the outcomes of published clinical studies related to complete denture fabrication, with respect to the differences between CAD-CAM technology and conventional techniques.

Material and methods. A comprehensive search of studies published up to March 16, 2020, was conducted by using the PubMed/MEDLINE, Web of Science, Cochrane Library, SciELO, and Embase databases according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement criteria and was registered in the International Prospective Register of Systematic Reviews (PROSPERO ID 42020202614). The population, intervention, comparison, and outcome (PICO) question was: Do CAD-CAM complete dentures have a similar functional performance to those fabricated by conventional techniques? The quality of publications was appraised by using the Critical Appraisal Skills Program (CASP) checklists.

Results. Of the 1232 titles, 6 articles were selected. The studies reported better retention of digitally manufactured complete dentures without denture adhesives than that of conventional complete dentures with or without denture adhesives. Other studies reported that dentures manufactured with digital systems were better adapted to tissue surfaces, required less clinical time, were lower in cost, and provided better experience and satisfaction to patients.

Conclusions. The assessment of CAD-CAM planning and manufacturing through clinical studies is ongoing. However, preliminary results indicate better clinical performance and lower overall costs of digital complete dentures than conventional dentures. (J Prosthet Dent 2021;■:■-■)

Computer-aided design and computer-aided manufacturing (CAD-CAM) technology has revolutionized clinical and dental laboratory procedures, with improved clinical outcomes.[1] It has multiple applications, including in prosthetic dentistry, enabling the manufacturing of digital casts through scans, planning with specific software programs, building of prototypes, and manufacturing of parts from various materials in an automated and expedited way.[2]

CAD-CAM complete dentures (CDs) can significantly reduce clinical time and allow the storage of digital casts and designs in a digital library. The digital record can be stored in a database as a standard tessellation language (STL)

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Clinical Oral Investigations

A systematic review and meta-analysis of the clinical performance of computer-aided design–computer-aided manufacturing bars used in implant-supported dentures

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Abstract:	Objectives To evaluate the performance of computer-aided design–computer-aided manufacturing (CAD-CAM) bars used in implant-supported overdentures. Materials and Methods A comprehensive search of studies published up to April 2021 was performed in the PubMed/MEDLINE, Web of Science, Cochrane Library, and SciELO databases according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses criteria and registered in the International Prospective Register of Systematic Reviews (PROSPERO: CDR 42021284190). The population, intervention, comparison, and outcome question was “How is the clinical performance of the overdenture bars fabricated by the CAD-CAM system?” The meta-analysis included clinical studies based on the effect size and test of null (2-Tail) with 95% confidence interval. Results Nine out of 64 studies were selected. The outcomes revealed 100% implant and prosthesis survival rates; however, polyether-ether-ketone bars showed 80% prothesis survival. The marginal bone loss and plaque and bleeding index were considered acceptable; however, few biological complications were registered in the CAD-CAM group. The Oral Health Impact Profile scores significantly decreased after prosthesis

	delivery; however, the fixed implant prosthesis demonstrated better data (1.8 + 1.9). Therefore, patients and prosthodontists demonstrated important clinical acceptance with CAD-CAM bars. Conclusions The CAD-CAM-milled titanium bars exhibited excellent performance in daily clinical practice. Moreover, patient and prosthodontist satisfaction was very high when this method was used. Clinical Relevance CAD-CAM bars have shown great potential for use in clinical practice.
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