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Review

CAD/CAM or conventional ceramic materials restorations longevity: a systematic review and meta-analysis

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ABSTRACT

Purpose: This systematic review and meta-analysis aimed to evaluate the difference in longevity of tooth-supported ceramic prostheses designed by conventional and computer-aided design/computer-aided manufacturing (CAD/CAM) techniques.

Study selection: Two reviewers searched the Web of Science, PubMed, SCOPUS and LILACS databases between 1966 and October 2017. Clinical studies that compared the survival rate of CAD/CAM against conventional restorations were included.

Results: Eleven randomized controlled trials and three prospective studies were included, n = 14. Three types of tooth-supported restorations were searched in the included studies: single crown, multiple-unit and partial ceramic crown. The follow-up of patients in the studies ranged from 24 to 84 months. A total of 1209 restorations had been placed in 957 patients in the included trials, and failures were analyzed by type and material restoration. From a total of 72 restoration failures, the CAD/CAM system resulted in a 1.84 (IC95%: 1.28–2.63) higher risk than conventional manufacturing of ceramic restoration. Nevertheless, when drop-outs were included as a failure risk, the CAD/CAM system resulted in a risk of 1.32 (IC95%: 1.10–1.58). Multilevel analysis of tooth-supported ceramic restorations, considering drop-outs as successes, resulted in rates of 1.48 and 2.62 failures per 100 restoration-years for the controls and CAD/CAM groups, respectively. Considering drop-outs as failures, we found rates of 4.23 and 5.88 failures per 100 restoration-years for the controls and CAD/CAM groups, respectively.

Conclusions: The meta-analysis results suggest that the longevity of a tooth-supported ceramic prostheses made by CAD/CAM manufacturing is lower than that of crowns mad by the conventional technique.

1. Introduction

The evolution of computer-aided design/computer-aided manufacturing (CAD/CAM) technology and use ceramics in dentistry allow industrial production following secondary milling [1–4]. CAD/CAM prosthetic treatment with high performance became an alternative to traditional techniques because of the quickness of chairside fabrication of the final restoration [2,5–10]. Use of CAD/CAM technology has been increasing, as verified in a German survey in which approximately 35,000 bridges, crowns, onlays, and inlays were placed over a period of 3.5 years [11].

Despite the fact that CAD/CAM technology has significantly improved over time and has been shown to be approximately 16% more time efficient in ceramic prosthesis fabrication than the conventional method, ceramic adaptation, the differences in the ceramic material and restoration position should be considered [12,13]. CAD/CAM resulted in the worst results in terms of internal fit compared to conventionally manufactured lithium disilicate [14]. Furthermore, the difference between the veneer and framework could result in an inadequate veneer thickness, firing and cooling rate errors and surface damage from CAD/CAM ceramic restoration production [15].

Differences in ceramic material manufacturing techniques bring into question which method presents higher survival rates [16–18]. The estimated five-year survival of all-ceramic crowns

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ranges between 90.7% and 96.6% (feldspathic/silica based ceramics and leucite or lithium-disilicate reinforced glass ceramics), whereas the clinical performance of CAD/CAM single tooth restorations has been reported to be an estimated total survival of 91.6% after five years [19,20]. Nevertheless, there is scant and unpooled evidence regarding the survival of tooth-supported ceramic restoration comparing the manufacturing techniques of all conventional manufacturing processes (laboratory-produced, conventional waxed-up/pressed ceramic) and CAD/CAM technology.

The purpose of this systematic review and meta-analysis was to evaluate the longevity of conventional and CAD/CAM techniques for tooth-supported ceramic prosthesis (single crown, multiple-unit or partial ceramic crown) and to identify the complication types associated with the main clinical outcomes.

2. Methods

This is a systematic review with an unpublished protocol. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used, and the checklist was followed in this study [21].

2.1. Population, intervention, control, outcome and time (PICOT) strategy

P: Patients with an anterior and/or posterior tooth-supported single crown (SC) or multiple-unit (MU) or partial crowns (PCC).

I: Patients with at least one ceramic restoration made with the CAD/CAM process.

C: Patients with at least one ceramic restoration made with the conventional manufacturing processes.

O: Longevity of CAD/CAM restorations.

T: Follow-up: at least two years.

2.2. Focused question

"Longevity of tooth-supported ceramic restorations are more influenced by conventional or CAD/CAM techniques?"

2.3. Search methods and selection criteria

In vivo studies that evaluated the survival of milling or CAD/CAM prostheses after a minimum of two years of follow-up time were included. Failure of survival was defined as any need of a restoration replacement, such as loss of retention, loss of vitality, secondary caries, tooth extraction and veneer or framework fracture. The search strategy was performed from 1966 to October 10th, 2017, with no limits. The sources of published studies were the Web of Science, PubMed, SCOPUS and LILACS databases. The following MeSH terms and their combinations were used in the database searches: #1 ceramics, #2 ceramic dental, #3 clinical trial, #4 randomized controlled clinical trials, #5 clinical practice, #6 cad cam, #7 dental milling, #8 (#1) OR (#2), #9 (#3) OR (#4) OR (#5), #10 (#6) OR (#7), #11 (#8) AND (#9) AND (#10). In addition, the references of all of the identified articles were manually searched for further relevant studies.

2.4. Eligibility criteria and data collection

Two reviewers, PF and SR, independently assessed the titles and abstracts of all of the selected articles. The articles were first reviewed by title and abstract and subsequently by a full text reading. This systematic review did not have a language limitation. Studies that did not evaluate the annual failure rate, survival rate or conventional manufacturing (control group) against milling ceramic restorations of a tooth- supported SC or MU or PCCs were excluded. The manuscripts considered to be eligible were selected for a full-text assessment. From this search, a collection of studies to be evaluated by reviewers was created. The reviewers were not masked for included papers. The two aforementioned reviewers extracted data independently; discrepancies in data extraction were solved by consensus.

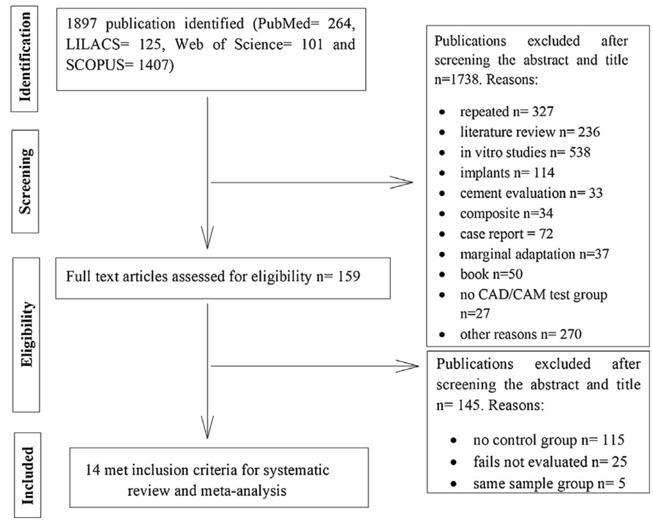

Fig. 1. Flowchart depicting the studies identified, included, and excluded with reasons.

From each study, the following data were obtained: study design, restoration type, follow-up time, mean patient age, material framework and veneer, CAD/CAM system, setting, publication year, failure number and type, initial and final sample size and number of patient drop-outs. Data not shown in published articles were requested from the corresponding author.

2.5. Data analysis

The risk of failure for each group of included studies was calculated based on the number of baseline restorations (number of initial restorations) and the number of failures at the end of the follow-up period. The relative risks (RR) from all studies were pooled in a fixed effect meta-analysis using the default Mantel and Haenszel method for binary variables. Bias was assessed using a funnel plot, and heterogeneity was assessed using I^2. The risk difference was also calculated.

For the sensitivity analysis, we included drop-outs either as failures or as successes [22]. Therefore, all analyses were duplicated to check for possible selection bias and robustness. All analyses were carried out with Stata Software 13.1 (StataCorp LP, College Station, TX, USA).

2.6. Risk of bias assessment

Two reviewers (PF and SR) independently assessed the risk of bias. Randomized controlled trials (RCT) were assessed using Cochrane Collaboration's tool guided by the Cochrane Handbook for Systematic Reviews of Interventions (version 5.1.0) [23]. Six specific domains were assessed: sequence generation, allocation sequence concealment, blinding, incomplete outcome data, selective outcome reporting, and other sources of bias. Judgments of low, unclear or high were used to assess the overall risk of bias in each study. The risk of bias for each entry recording was judged as 'no' to indicate a high risk of bias, 'yes' to indicate a low risk of bias and 'unclear' to indicate either a lack of information or uncertainty over the potential risk of bias. The Newcastle–Ottawa Scale was

Table 1. Study and patients characteristics of the reviewed studies.

Study	Study design	Setting	Mean age (years)	CAD/CAM system	Frame work and veneer (C)	Frame work and veneer (T)	R	Mean follow up[a]	N (C/T)	N Drop-outs (C/T)	Failure (C/T)	Setting position
Monaco et al. [37]	RCT	U	NR	NR	GC	Zr	SC	65.7	45/45	5/0	3/4	Posterior
Akin et al. [33]	RCT	U	29	Cerec	D	D	SC	24	15/15	0/0	0/0	Anterior
Rinke et al. [36]	RCT	PP	49.6	Cercon	MC	Zr	SC	60	50/55	18/9	2/3	Posterior
Passia et al. [31]	RCT	U	42	Kavo everest	GC	Zr	SC	60	100/123	19/37	9/28	Posterior
Vigolo and Mutinelli [29]	P	PP	32	Procera/lava	MC	Zr	SC	60	40/40	10/20	2/7	Posterior
Nicolaisen et al. [35]	RCT	U/PP	51	BEGO	MC	Zr	MU	36	17/17	0/0	3/2	Posterior
Christensen and Ploeger [27]	RCT	PP	50	Cercon/everest/lava	MC	Zr	MU	24/36	96/163	9/12	5/15	Posterior
Pelaez et al. [30]	RCT	U		Lava	MC	Zr	MU	50	20/20	0/0	0/1	Posterior
Sailer et al. [26]	RCT	U	54.4	Cercon	MC	Zr	MU	40	38/38	18/5	0/0	Posterior
Walter et al. [25]	P	U/PP	40	Procera	GC	MC	MU	61	25/22	52/68	0/1	Posterior
Zenthöfer et al. [34]	RCT	U	56	Lava	MC	Zr	C-MU	36	10/11	10/9	2/4	Anterior
Federlin et al. [28]	P	U	37	Cerec	GC	F	PCC's	66	29/29	24/24	1/4	Posterior
Guess et al. [32]	RCT	U	45.5	Cerec	D	L	PCC's	84	40/40	52/52	0/1	Posterior
Molin et al. [24]	RCT	U	37	Cerec	Gold, mirage, empress	F	PCC's	60	60/20	0/0	7/2	Posterior

R: restoration; NR: not reported; RCT: randomized controlled trial; P: prospective; U: university; PP: private practice; SC: single crown; MU: multiple unit; C-MU: cantilever multiple unit; PCC's: partial ceramic crowns; GC: gold crown; MC: metal-ceramic; D: dissilicate; Zr: zirconia; F: feldspar; C: control group; T: test group; L: leucite-based glass-ceramics.
[a] In months.

followed to assess the prospective studies. The methodological quality was based on selection, comparability and outcome.

3. Results

3.1. Study selection and description of studies

Electronic database searches from all sources (PubMed, SCOPUS, LILACS and Web of Science) identified 1897 publications (Fig. 1). After evaluating the titles and abstracts, 159 publications were selected for full text reading. In the end, fourteen studies (published between 1966 to October 10th, 2017) were included in this systematic review and seventeen comparisons groups were included in the meta-analysis (one publication presented one test and three control groups) [24–36]. The included articles were published in English between 1999 and 2017; the characteristics of each study were presented in a descriptive table (Table 1). For all of the studies included, 11 were randomized controlled trials and 3 were prospective trials. Seven of these studies obtained financial support or material donations from industry [25,26,30–32,35,36]. The majority of studies were conducted in universities (9 studies), some were conducted in private practices (3 studies) or jointly between a university and private practice (2 studies). Three types of tooth-supported restorations were searched in the included studies, a single crown (5 studies), multiple-unit (6 studies including in one that presented cantilever) and partial ceramic crown (3 studies). A total of 1209 restorations were placed in 957 patients in the included trials. The follow-up of patients in the studies ranged from 24 to 84 months [32,33]. Considering articles that presented results for the same sample, the most recent study was considered [28,31,32,36].

Trials that used United State Public Health Service (USPHS), modified USPHS and California Dental Association (CDA) as outcome measures, the categories Charlie/Delta and one (i.e., requiring repair or replacement) were counted as failures [26,29]. The types of failure according to the types of tooth-supported restorations are shown in Table 2.

3.2. Methodological quality

The risk of bias in the studies included in the systematic review is summarized in the supplementary material (Tables 3 and 4). For randomized controlled trials (RCTs), ten studies reported using randomly assigned interventions; however, one study did not follow procedures to ensure a random sequence generation [36]. For the allocation concealment strategy, many studies had an unclear or high risk of bias [24,26,30,32–37]. Six studies did not report blinding because it was not possible to differentiate them regarding the color of material (gold and ceramic/metal ceramic and ceramic). The variable blinding was considered to have a low risk in all studies since the outcomes are unlikely to have been influenced by a lack of blinding [38]. All studies correctly reported incomplete outcome data and stated the number and reasons for attrition and exclusion in the control and intervention groups. The studies used pre-specified (primary and secondary) outcomes; all expected outcomes were included. No other sources of bias were identified. For a summary assessment of the outcomes within the studies, only three had a low risk of bias, while five had an unclear risk of bias and three had a high risk of bias. For prospective studies, the quality score for each study was assessed; the major bias in these studies was a risk of bias in the selection of samples because the participants were mostly from university and private dental offices. Furthermore, blinding was not possible in these studies.

3.3. Results of analyses

3.3.1. Fixed effects meta-analysis and multilevel regression

The included studies had different follow-up periods; three studies had differences among their groups [24,27,29]. In addition, the number of drop-outs varied among studies and groups within

Table 2. Failure type and number (control – test) according to the type of restoration.

Study	Surface and color	Secondary caries	Loss of vitality	Loss of retention	Framework/ venner fracture	Extraction	USPHS (C–D score)	Modified ryge criteria	Restoration type
Monaco et al. [37]	0–0	0–0	0–0	0–0	2–4	1–0	0–0	N/A	SC
Akin et al. [33]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0–0	SC
Rinke et al. [36]	0–0	1–0	1–1	0–1	0–1	0–0	N/A	N/A	SC
Passia et al.[a] [31]				9–28			N/A	N/A	SC
Vigolo and Mutinelli[a] [29]	N/A	N/A	N/A	N/A	N/A	N/A	1–7	N/A	SC
Nicolaisen et al.[d] [35]	2–2	0–0	0–0	0–0	1–0	0–0	N/A	N/A	MU
Christensen and Ploeger [27]	0–0	1–2	0–0	0–0	4–13	0–0	N/A	N/A	MU
Pelaez et al. [30]	0–0	0–0	0–0	0–0	0–0	0–1	N/A	N/A	MU
Sailer et al. [26]	N/A	N/A	N/A	N/A	N/A	N/A	0–0	N/A	MU
Walter et al. [25]	0–0	0–0	0–0	0–0	0–1	0–0	N/A	N/A	MU
Zenthöfer et al.[b] [34]	0–0	0–0	1–2	0–0	1–2	0–0	0–0	N/A	Cantilever MU
Federlin et al.[c] [28]	N/A	N/A	N/A	N/A	N/A	N/A	1–4	N/A	PCC's
Guess et al.[c] [32]	N/A	N/A	N/A	N/A	N/A	N/A	0–1	N/A	PCC's
Molin et al.[d] [24]	V	0–0	3–0	0–1	4–1	0–0	N/A	N/A	PCC's

SC: single crown; MU: multiple unit; PCC's: partial ceramic crowns.
[a] Not specified failure type-chipping down the coping and fracture of coping. [b] None C or D score. [c] Modified USPHS. [d] CDA criteria.

Table 3. Cochrane summary assessment of risk of bias for randomized controlled trials.

Study	Adequate sequence generation	Allocation concealment	Blinding	Incomplete outcome data	Selective outcome reporting	Other sources of bias	Risk of bias
Monaco et al. [37]	Yes	Yes	Yes	Yes	Yes	Yes	Low
Akin et al. [33]	Yes	Unclear	Yes	Yes	Yes	Yes	Unclear
Rinke et al.[a] [36]	No	No	Yes	Yes	Yes	Yes	High
Passia et al. [31]	Yes	Yes	Yes	Yes	Yes	Yes	Low
Nicolaisen et al. [35]	Yes	Unclear	Yes	Yes	Yes	Yes	Unclear
Christensen and Ploeger [27]	Yes	Yes	Yes	Yes	Yes	Yes	Low
Pelaez et al.[b] [30]	Yes	No	Yes	Yes	Yes	Yes	High
Sailer et al.[b] [26]	Yes	No	Yes	Yes	Yes	Yes	High
Zenthöfer et al. [34]	Yes	Unclear	Yes	Yes	Yes	Yes	Unclear
Guess et al.[c] [32]	Yes	Unclear	Yes	Yes	Yes	Yes	Unclear
Molin et al.[c] [24]	Yes	Unclear	Yes	Yes	Yes	Yes	Unclear

[a] Patient's preference. [b] List of randomization. [c] Split-month design.

Table 4. Newcastle–Ottawa for quality rating of prospective studies.

Study	Selection				Comparability	Outcome			Total of star
	Representativeness of the exposed cohort	Selection of the non exposed cohort	Ascertainment of exposure	Demonstration that outcome of interest was not present at start of study	Comparability of cohorts on the basis of the design or analysis	Assessment of outcome	Was follow-up long enough for outcomes to occur	Adequacy of follow-up of cohorts	
Vigolo and Muttineli [29]	–	1 star	1 star	1 star	–	1 star	1 star	1 star	6
Federlin et al.[a] [28]	–	1 star	1 star	1 star	1 star	1 star	1 star	1 star	7
Walter et al. [25]	–	1 star	1 star	1 star	–	1 star	1 star	1 star	6

[a] Split-mouth study.

studies. As both issues violate the assumption of a fixed cohort, we incorporated them by calculating the Incidence Rate Ratios (IRR) based on failures per 100 restoration-years. To calculate the time of follow-up (restoration-year), we multiplied the number of restorations by the number of years of follow-up, with drop-outs counting as being followed for half of the period. For this analysis, we pooled all groups in random intercept multilevel Poisson regression.

Some studies presented more than one test group, and for this reason, more groups were included in the meta-analysis (seventeen) than in the systematic review (fourteen) [27,29]. The risk of failure among control groups was, on average, 8.5% (IC95%: 5.5–11.5), and among CAD/CAM was 14.4% (IC95%: 8.6–20.1); this meta-analysis led to RR of 1.84 (IC95%: 1.28–2.63), Fig. 2. However, when drop-outs were included as a failure, the risk of failure among the control groups was, on average, 22.2% (IC95%: 14.6–29.9); among

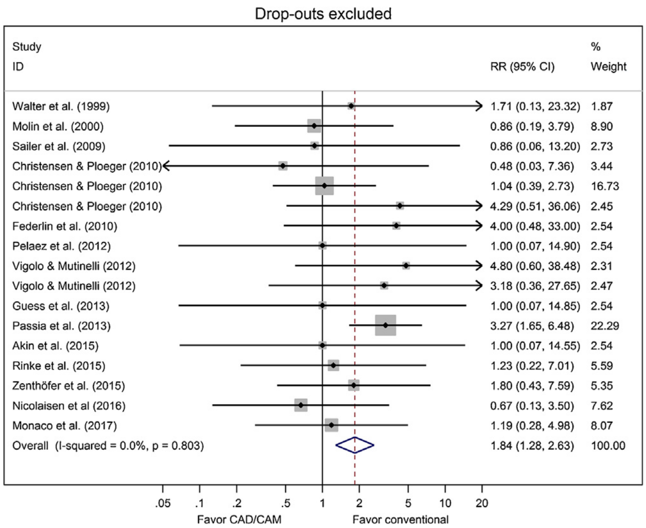

Fig. 2. Forest plot of pooled studies with a relative risk of failure of 1.84 (1.28–2.63) in tooth-supported ceramic restorations not considering drop-outs. The 95% confidence intervals for survival rates are given in parenthesis.

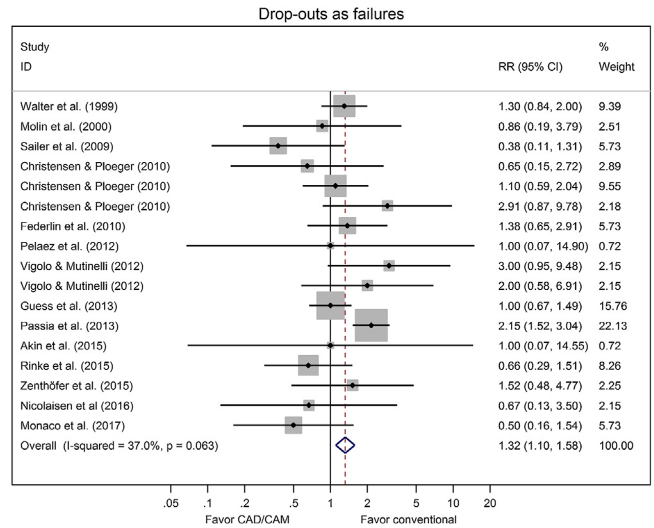

Fig. 3. Forest plot of pooled studies with a relative of risk of failure of 1.32 (1.10–1.58) in tooth-supported ceramic restorations considering drop-outs. The 95% confidence intervals for survival rates are given in parenthesis.

CAD/CAM groups, the risk of failure was 28.2% (IC95%: 18.4–42.7). This meta-analysis led to RR = 1.32 (IC95%: 1.10–1.58), Fig. 3.

Multilevel analysis of tooth-supported ceramic restorations considering drop-outs as successes resulted in rates of 1.48 and 2.62 failures per 100 restoration-years for the controls and CAD/CAM groups, respectively. This led to IRR = 1.76 (IC95%: 1.20–2.59) times higher in the CAD/CAM groups. Considering drop-outs as failures, we found rates of 4.23 and 5.88 failures per 100 restoration-years for the control and CAD/CAM groups, respectively, leading to IRR = 1.39 (IC95%: 1.11–1.74) times higher in the CAD/CAM groups.

3.3.2. Assessment of heterogeneity

The heterogeneity among the studies was quantified with the I^2-statistic considered to be "high" if the statistical heterogeneity levels were higher than 70% [39]. In this meta-analysis, the heterogeneity in RR among the studies was $I^2 = 0\%$ ($p = 0.80$) when only considering restoration failures and was $I^2 = 37.0\%$ ($p = 0.06$) when drop-outs were considered as failures (Figs. 1 and 2). The cumulative meta-analysis suggests that that since 2013, the association with CAD/CAM restorations has been significant (Figs. S1 and S2).

3.3.3. Assessment of publication bias and influent studies

Publication bias was initially evaluated through an examination of funnel plot asymmetry [40]. Egger's and Begg's tests indicated no evidence of publication bias without drop-outs counted as failures ($p = 0.32$ and $p = 0.97$, respectively) or with drop-outs counted as failures ($p = 0.45$ and $p = 0.71$, respectively). Visual inspection of Begg's funnel-plot (Figs. S3 and S4) also demonstrated that no significant asymmetry was present for either analysis. However, analysis of influence showed that the study of Passia was the most influential; removing it led the association to be not significant ($p > 0.05$), reducing the RR from 1.84 to 1.42 (IC95%: 0.92–2.20) when drop-outs were considered as failures [31].

4. Discussion

This systematic review investigated the longevity of ceramic restorations according to techniques (conventional or CAD/CAM) using a tooth-supported single crown, multiple-unit and partial single crown. The fourteen studies included in the meta-analysis indicated that the CAD/CAM system resulted in more chances to fail compared to conventional manufacturing of a ceramic restoration, considering losses of follow-up as failures or as successes.

The RR was calculated as the ratio of the proportion of failures in CAD/CAM to that in conventional ceramic restorations according to the meta-analysis, providing a consolidated value for failure compared with ceramics. A funnel plot was drawn to identify any publication bias within the studies; none were observed (Figs. S3 and S4). Of the two meta-analyses performed, one analyzed the RR of failures that were reported by the authors and the other analyzed the RR of failures including drop-outs as failures, simulating the worst possible outcome. The inclusion of drop-outs as failures decreases the difference among groups and increases the sample size [22]. If most drop-outs were true failures, then conventional manufacturing would still have a significantly lower risk of failure than CAD/CAM.

Comparing implant-supported versus tooth-supported fixed dental prostheses restorations, the most frequent complication of a conventional tooth-supported prosthesis was caries and loss of pulp vitality [16]. However, the most frequent reason for failure in this study was veneer chipping fractures (Table 2), in corroboration with previous studies [20,41]. Most likely, the tooth position, type of material and process were responsible for these results since all of the studies included in the meta-analysis used conventional impressions during the clinical assessment [4]. Most of the studies that reported the failure of CAD/CAM restorations exceeded the control group except for the studies by Akin and Sailer (which reported no failures in the control and test) and Molin (which reported more failures in the control) [24,26,33]. From the selected studies, seven used zirconia as the framework; no study used a monolithic zirconia crown. A recent systematic review showed that monolithic crowns led no incidence of chipping compared with bi-layered crowns [42]. Tensile or compressive residual stress between the framework/veneer interface (zirconia/feldsphatic) can happen as a result of the difference in the thermal coefficient of materials [1]. Moreover, the lack of framework support, inadequate experience with ceramics, veneer thickness, firing and cooling rate errors and surface damage from CAD/CAM production are the usual causes of failures in zirconia frameworks [15]. On one hand, the internal fit (between the tooth and prosthesis), type and properties of ceramics and prosthetic treatment may increase the number of failures among CAD/CAM systems [14]. Although clinical data on monolithic zirconia restorations are still sparse, these restorations are an option for eliminating the increased risk of veneer ceramic failure. In contrast with this study, another technical problem observed in zirconia-based single crowns was a loss of retention [20]. On the other hand, conventional manufactured systems may decrease chipping failures as a result of the stronger bonding between the framework and veneer layer (feldspathic veneer and metal, gold and disilicate framework).

The tooth position also influences veneer chipping fractures; most restorations of the included studies were located in the posterior region [20,41]. Exceptions included two studies that placed the prosthesis in the anterior region [33,34]. Crowns placed in anterior teeth have a longer survival time than those placed in the posterior region as a result of the different direction of occlusal forces [13]. The outcomes of anterior and posterior single crowns were compared, and no statistically significant differences of survival rates were found for metal-ceramic crowns, leucit or lithium-disilicate reinforced glass ceramic crowns, and alumina or zirconia-based crowns. Crowns made out of feldspathic or silica-based ceramics, however, exhibited significantly lower survival rates in the posterior region than in the anterior region (87.8% vs. 94.6%) [17]. According to the framework design, one study considered the anatomical design of the framework and an adequate thickness of the veneer and found that these factors cannot be considered critical factors for chipping in the zirconia group [30].

Two studies used a press lithium-disilicate glass ceramic crown as the control group [32,33], and one used a CAD/CAM lithium-disilicate glass ceramic crown as the experimental group [33]. Both CAD/CAM and press crowns demonstrated a survival rate of 100% over the observation period. The lower failure rate of the present study can be attributed to the improved flexural strength of the pressed system (400 MPa) and the homogeneity of the CAD/CAM material. The success rates of both materials, CAD/CAM and press lithium-disilicate glass crowns, were comparable over time [16,32].

Failures resulting from extensive fractures of the veneering ceramic and loss of retention were frequently found technical problems for all-ceramic and multiple unit zirconia crowns compared with metal-ceramic crowns [20,41]. Consequently, based on this study and previous reviews, zirconia-based restorations should not be considered as the primary treatment option. The biological and manufacturing differences between materials may be considered to be one of the key decisive factors for the choice of ceramics as reconstructive material for rehabilitation.

The included studies used different criteria to detect failure that may lead to certain measurement biases. Homogeneous data for comparison in any systematic review is difficult and has been reported in a review on standardizing criteria for failure, success and survival of ceramic prostheses [18]. The lack of detailed information on technical complications, such as chipping fractures, refinishing, repairs, and bulk fractures, represents a major deficiency of previous reports on the performance and survival of ceramic restorations. Therefore, to compare and obtain the RR of the studies, we took the reported failures by the authors into account, which allowed a value to be placed on outcome and comparison.

The methodological quality of the included studies was verified, and only those with a low risk of bias in all domains were considered in the meta-analysis [23]. However, this decision usually results in a limited number of studies and, consequently, of ceramic restorations that can be included in the study, posing the possibility of under-powering the study's outcomes. The studies included in this systematic review had some design limitations, and several studies involved small sample sizes (range, 10–163). One included study had a limitation of no patient randomization [25]. The selection of restoration type was based on the patient's preference after information was presented on the two types of restorations; thus the recruitment of patients in private practice was accelerated. Despite the fact that this selection mode could be a possible risk, the numbers of the two types of restorations were similar in both groups (metal-ceramic, n = 41 and zirconia, n = 50), and no gender or age-related effects on the selected type of restoration was detected in this study. Additionally, the outcome was determined by the examiner and not by patients, eliminating the bias of the selective outcome report [38]. Thus, this study was considered to have a high risk of bias for adequate sequence generation and allocation sequence concealment. Moreover, the authors of the included studies rarely described the method used to conceal the allocation sequence, which made most key domains 'unclear'.

5. Conclusion

The results of this meta-analysis suggest that the longevity of tooth-supported single crown, multiple unit or partial ceramic crowns made by CAD/CAM is lower than that of crowns made by conventional techniques. The material type and process were the most frequent reasons for CAD/CAM failures. However, studies that evaluate the difference between CAD/CAM generations and software limitations should be performed to elucidate the reasons that CAD/CAM results in a higher risk of failure.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jpor.2018.11.006.

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