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SYSTEMATIC REVIEW

Influence of CAD-CAM milling strategies on the outcome of indirect restorations: A scoping review

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ABSTRACT

Statement of problem. The influence of computer-aided manufacturing (CAM) parameters and settings on the outcomes of milled indirect restorations is poorly understood.

Purpose. The purpose of this scoping review was to summarize the current CAM systems, parameters, and setting changes, and their effects on different outcomes of milled indirect restorations and aspects related to their manufacture.

Material and methods. The protocol of this review is available online (https://osf.io/x28ps/). Studies that used at least 2 different parameters (CAM units, number of axes, digital spacers, or protocols with different rotatory instruments, grit-sizes, milling speed, or others) for milling indirect restorations were included. A structured search up to July 2023 was performed by 2 independent reviewers for articles written in English in LILACS, MEDLINE via PubMed, EMBASE, Web of Science, and Scopus.

Results. Of 1546 studies identified, 22 were included in the review. Discrepancies were found between the planned and actual measured cement space, with a decreasing linear relationship impacting restoration adaptation at different points. The CEREC MC XL milling machine was the most used system in the included studies, with variations in bur types, milling modes, and number of burs uses affecting internal fit and surface trueness. The results demonstrated the better adaptation of restorations made with 5-axis over 3-axis milling machines. Lithium disilicate and zirconia were the most commonly used materials, and crowns and inlays were popular designs. Marginal and internal adaptation were the primary outcomes assessed using the various techniques.

Conclusions. The study presented a comprehensive exploration of CAM systems and parameters, and their influence on indirect restorations. The planned cement space was not properly reproduced by the milling. Bur characteristics can affect restoration fit and trueness. The 5-axis units seem to result in better-adapted restorations compared with 3- and 4-axis units. (J Prosthet Dent 2024;131:811.e1-e10)

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Clinical Implications

The planned cement space, the number, format, and grain size of milling burs, and the number of axes in the CAM unit may affect restoration trueness and fit. The findings can help understand the impact of CAM settings on restoration quality and guide future research.

Digitally supported dentistry has changed how indirect dental restorations are provided. Compared with traditional techniques, which depend on the dental laboratory technician's manual skills and abilities, the digital workflow provides a more accurate, reliable, predictable, and cost-effective process.[1] Computer-aided-design and computer-aided-manufacturing (CAD-CAM) systems have led to high-quality prosthodontic treatments in fewer clinical steps.[2]

The CAD-CAM workflow consists of 3 main processes: data acquisition, processing, and manufacturing. The data collection can be performed indirectly, with an elastomeric impression scanned extraorally[3,4] or directly with an intraoral scanner, reported to be more comfortable for the patient.[5,6] Both approaches have been reported to be clinically acceptable.[7] After data collection, a CAD software program is used for planning and designing the restoration.[8] During this step, the operator can set the cement space in different regions of the preparation.[9–11] However, a consensus on the proper space thickness and how it may affect the outcome of the restoration is lacking. Also lacking is a consensus on the clinical parameter of ideal fit,[12] although it should be as small as possible.

The manufacturing step can be performed additively via 3-dimensional (3D) printing or, more commonly, through subtractive milling.[1,13] Milling machines work through a numerically controlled machining process, with a computer program managing the tool path during the milling of a prefabricated block based on a standard tessellation language (STL) file.[3,14] Different brands of milling units have specific features, which can be classified according to the characteristics of the grinding process: use (chairside or laboratory); state of the material (soft or hard); number of axes (3-, 4-, or 5-axis), depending on the amount of disk and tool spindle rotational axis; and number and aspect of the diamond or tungsten carbide rotary instrument used.[3]

The number of axes and tools used have been directly related to the amount of material removed during the milling, as have been the number of revolutions per minute (rpm) and the milling pathway.[8,14] Conventionally, tungsten carbide burs have been used for soft-milling, such as for presintered zirconia in a dry environment, while diamond rotary instruments have been used for the hard-milling of composite resin and glass-ceramics[8] with liquid-cooling. The milling instruments may respond differently to different surface and subsurface characteristics.[15] The instrument design may also affect the restoration, leading to different milling times and possibly over-milled areas.[1,16]

Despite the advantages of the digital workflow, the process requires a learning curve and financial investment.[17] Mastering the steps and outcomes obtained is important because every step of the process may affect the indirect restoration[11] and, consequently, its clinical performance. Recently, a scoping review mapped the evidence of scanners on the accuracy and marginal and internal adaptation of tooth-supported indirect restoration.[18] However, the influence of CAM parameters and settings on indirect restorations is unclear and could be clarified from a scoping review that identifies and maps the possible effects of such variations on the prostheses.[19] This scoping review aimed to map how the changes in setting and parameters of the CAM dental system process could influence the different outcomes of indirect restorations. The null hypothesis was that none of the factors would influence the outcome of indirect restorations.

MATERIAL AND METHODS

This study was based on the preferred reporting items for systematic reviews and meta-analyses extension for scoping reviews (PRISMA-ScR), as specified in the supplemental material.[20] The study protocol was determined prospectively and is available online (https://osf.io/x28ps/). The research question was: "How do the different CAD-CAM milling parameters and settings influence the outcome of indirect restorations?" For this, the population, concept, context (PCC) adopted was indirect restorations, CAD-CAM milling parameter variations and a nonspecific context.

All outcomes and study designs comparing at least 2 different CAD-CAM milling units, number of milling axes, digital spacers (space for the cement planned on the CAD), or protocols of milling (different rotary instruments, grit sizes, milling speed, or others) to produce milled restorations, regardless of the material microstructure, geometry, and substrate (tooth or implant analogs) were included. Studies that tested experimental materials or machines or were not written in English were excluded.

The MEDLINE via PubMed, Web of Science, Embase, LILACS, and Scopus databases were searched for articles published up to July 2023 to identify potentially relevant documents. The search strategies based on MeSH terms and free-text specific terms of PubMed, EMTREE terms, and free-text specific terms of EMBASE

Table 1. Search strategy

Database
PUBMED – 716 [Data of last search: 10.07.23]
(((((((((cadcam) OR ("computer aided design"[All Fields])) OR ("computer aided manufacturing"[All Fields])) OR ("subtractive"[All Fields])) OR ("milling"[All Fields])) OR ("machining"[All Fields])) OR ("diamond bur"[All Fields])) OR ("bur"[All Fields])) AND ((((parameter) OR (speed)) OR ("axis"[All Fields])) OR ("setting"[All Fields]))) AND (((((("dental restoration"[All Fields]) OR ("dental prosthesis"[All Fields])) OR ("crown"[All Fields])) OR ("inlay"[All Fields])) OR ("onlay"[All Fields])) OR ("endocrown"[All Fields]))
EMBASE – 447 [Data of last search: 10.07.23]
(cadcam OR 'computer aided design' OR 'computer aided manufacturing' OR subtractive OR milling OR machining OR 'diamond bur' OR bur) AND (parameters OR velocity OR setting OR axis) AND ('dental restoration' OR 'tooth prosthesis' OR 'tooth crown' OR 'dental inlay' OR 'dental onlay' OR endocrown OR 'indirect restoration')
Lilacs – 27 [Data of last search: 10.07.23]
((CADCAM) OR ("computer aided design") OR ("computer aided manufacturing") OR ("milling") OR ("machining") OR ("subtractive") OR ("diamond bur") OR ("bur")) AND (("parameter") OR ("setting") OR ("axis") OR ("speed")) AND (("dental restoration") OR ("dental prosthesis") OR ("crown") OR ("inlay") OR ("onlay") OR ("endocrown") OR ("indirect restoration"))
Web of Science – 377 [Data of last search: 10.07.23]
((ALL=(cadcam OR "computer aided design" OR "computer aided manufacturing" OR subtractive OR milling OR machining OR "diamond bur" OR bur)) AND ALL=(speed OR axis OR parameter OR setting)) AND ALL=(dental restoration OR dental prosthesis OR crown OR inlay OR onlay OR endocrown OR indirect restoration)
Scopus – 655 [Data of last search: 10.07.23]
TITLE-ABS-KEY (cadcam OR "computer aided design" OR "computer aided manufacturing" OR subtractive OR milling OR machining OR "diamond bur" OR bur) AND TITLE-ABS-KEY (parameter OR speed OR setting OR axis) AND TITLE-ABS-KEY ("dental restoration" OR "dental prosthesis" OR crown OR inlay OR onlay OR endocrown OR indirect AND restoration)

were drafted by the first author (R.O.P.) and further refined through discussion (Table 1). The references of the included articles were also checked.

The results were transferred to a reference manager software program (EndNote Online; Clarivate Analytics) where duplicates were removed. Using the Qatar Computing Research Institute Rayyan platform, 2 independent and blinded researchers (R.O.P., R.V.M.) screened the studies' titles and abstracts to evaluate the eligibility criteria. The studies were categorized into included, excluded, or uncertain (when there was insufficient information). The same reviewers carried out a second round by reading the full text of the included and uncertain articles. Any discrepancy during the screening was resolved by discussion, and a third reviewer (G.K.R.P.) was invited to give an opinion if needed.

First, 3 included studies were selected to test data extraction and ensure consistency. Next, a pilot test was conducted through a discussion between the reviewers involved. Then, data from the included articles were collected by the 2 trained researchers (R.O.P., R.V.M.), with each researcher collecting half of the included articles. A spreadsheet (Excel; Microsoft Corp) was used with the following data: general study characteristics (authors, year of publication, country, and study design), material (product name, manufacturer, and microstructure), intervention (product name of the scanner device); product name of the CAD-CAM milling machine, setting parameters (number of axes, protocol of milling, grit size, digital spacers); characteristics of the luting procedure and agent if present; characteristics of the tooth or tooth analog if present; outcome (specific characteristics of methodologies, aging method, sample size and estimation method, presence or not of randomization); study main findings; data on funding source, and conflict of interest.

A descriptive analysis of the studies' main characteristics was performed. To analyze the discrepancy of the planned cement space compared with the actual marginal fit measured in the primary studies, a ratio analysis was made in a spreadsheet (Excel; Microsoft Corp) by considering the studies' descriptive results. The information of the measured cement space and the planned cement space was collected from the articles and then calculated as a percentage using the equation: $\frac{\textit{actual measured value}}{\textit{planned cement space}} \times 100$. These data were plotted and analyzed through a linear regression trend line. Tables and figures were created to illustrate the relevant data. Additionally, an artificial intelligence-based CAD software program (Dentbird; Imagoworks Inc) was used to simulate posterior crown planning and design to illustrate the variations with different cement space settings.[21]

RESULTS

The flowchart of the study selection is represented in Figure 1. Of 1546 studies, 57 were selected for full-text analysis. After reading the manuscripts, 22 studies were included and 35 studies were excluded, as these studies tested different scanners or restorative materials,[22–33] did not measure the research question,[34–41] did not use CAD-CAM milled restorations,[42–48] did not vary the milling protocol,[49–52] did not mention the CAD-CAM system,[53,54] used experimental machines,[55] or were not written in English.[56]

Different cement space settings (n=8), milling burs (n=5), and machines (n=10) were the factors evaluated (Table 2). All were in vitro studies except for a systematic review of in vitro studies.[12] Crowns were the most frequently evaluated designs (n=15) (Table 3), followed by inlays (n=5). Only 2 studies used different preparation designs in the same research question,[16,57] and only 1 evaluated multi-unit restorations.[17] Lithium disilicate was the most evaluated ceramic (n=8) (Table 3) and zirconia the second most (n=5). Few studies (n=5) considered the factor "materials" and their different machinability.[9,58–61] Only 1 reported that materials influence the crown fit: lithium disilicate resulted in the highest misfit, while zirconia and composite resin the lowest.[61] One study did not compare them statistically,[60] and 2 reported that the material did not affect the fit of onlays[9] and occlusal veneers.[59] Similarly, 1 of the studies

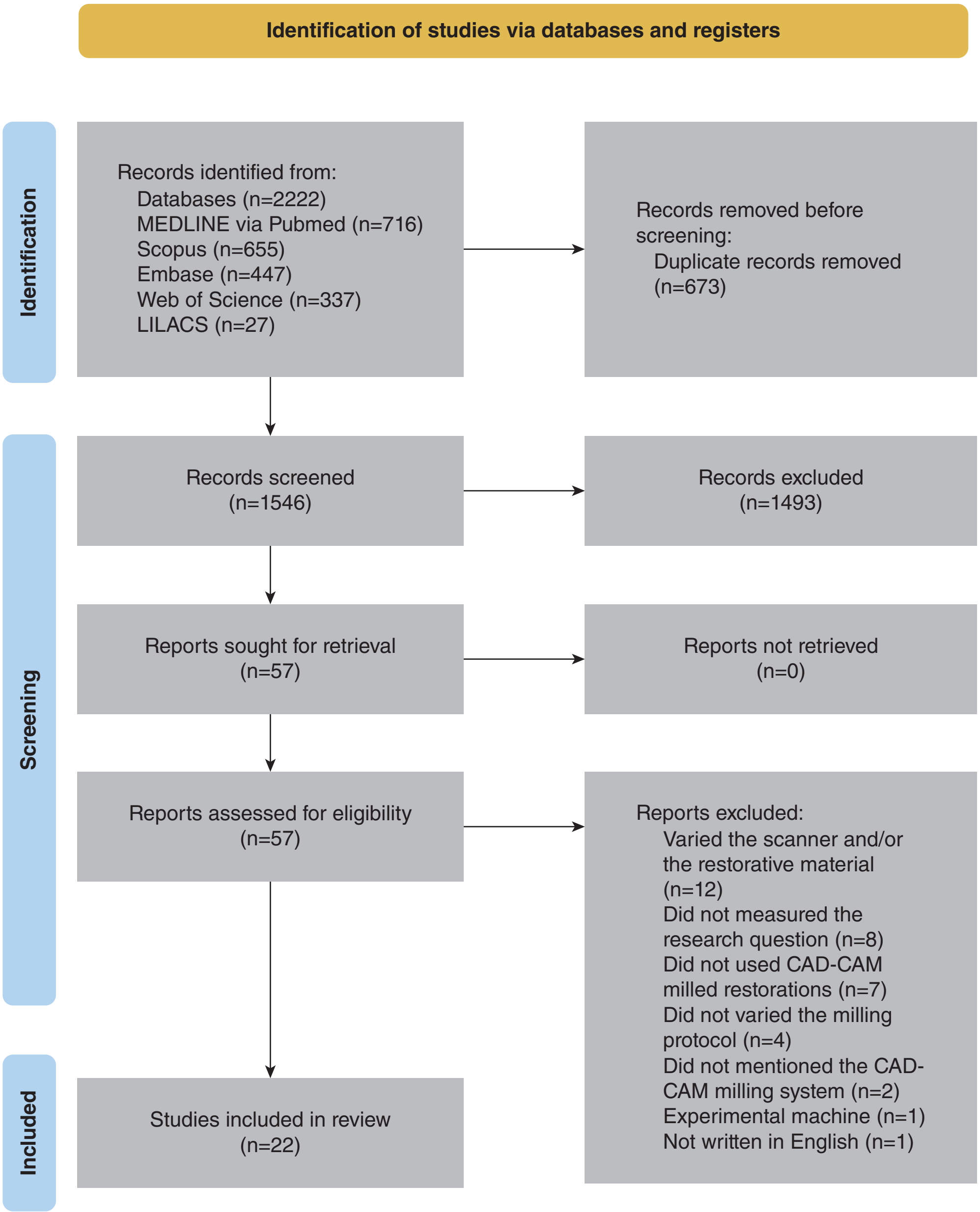


Figure 1. Flow diagram of included studies after screening in databases and assessing for eligibility.

stated that the different restoration design affected the restoration fit depending on the milling unit used,[57] while another did not compare the designs statistically.[16]

The most evaluated outcomes among the studies were the marginal and internal fit (n=18) (Table 4); however, the methodology varied. Seven studies used a digital camera or stereomicroscope to perform the analysis,[9,17,61–65] 6 used microtomography,[10,11,59,60,66,67] and 4 used the silicone replica technique.[8,58,68,69] Only 3 bonded the restorations to evaluate the influence of cement parameters on the fit.[9,11,62]

Considering the planned cement space, variations between 0 and 180 μm were found (Table 2). The milling machine could not reproduce the planned cement space in most areas of the interface evaluated.[9–11,58,59,62,68] Half of the studies used the same cement thickness for the internal and marginal points,[9,11,59,62] while the others used 2 settings.[10,58,68,69] The planned space (Fig. 2) differed greatly compared with the actual measurements, with a tendency for a linear relationship (Fig. 3). For internal and axial fit, the planned cement space was responsible for 87% and 71% of the measured value (Table 5). As for occlusal fit, only 33% was explained by variation in the planned space (Table 5).

The CEREC MC XL was the most studied milling machine for considering different bur settings (n=3; Table 2),

Table 2. Descriptive analysis of included studies and their respective evaluated factors

Evaluated Aspects	
Cement spaces settings (n=8)	**References**
0 µm	[62]
10 µm	[68]
25 µm	[62]
30 µm	[10,59,68]
40 µm	[59,69]
50 µm	[11,58,59,68]
60 µm	[9,10]
80 µm	[11,58,62,69]
100 µm	[10]
120 µm	[9]
180 µm	[9]
Milling burs (n=5)	**References**
DWX-50 5-axis milling machine 3 burs compared with 2 burs	[14]
CEREC MC XL 4-axis milling machine Step Bur 12 + Cylinder Pointed Bur 12S (normal milling mode) Step Bur 12S + Cylinder Pointed Bur 12S (normal milling mode) Step Bur 12 + Cylinder Pointed Bur 12S (two-step milling mode)	[8]
CEREC MC XL 4-axis milling machine Step Bur 12 + Cylinder Pointed Bur 12S (1-step milling mode) Step Bur 12S + Cylinder Pointed Bur 12S (1-step milling mode) Step Bur 12 + Cylinder Pointer Bur 12S (two-step milling mode)	[16]
CEREC MC XL 4-axis milling machine Step Bur 12 + Cylinder Pointed Bur 12S 1st – 3rd 4th – 6th 7th – 9th 10th – 12th 13th – 15th 16th – 18th	[60]
PlanMill 40 Standard (ellipsoidal rotary instrument) Detailed (conical rotary instrument)	[63]
Milling machines (n=11)	**References**
Compartis (chairside) Cercon expert (in-lab)	[65]
CEREC MC XL (4-axis) Artica (5-axis)	[16]
CEREC MC XL (4-axis, 2-step) CEREC MC XL EF (4-axis, 2-step, EF) CEREC MC X5 (5-axis) CORiTEC 450i (5-axis)	[57]
CEREC MC XL (4-axis) Primemill (4-axis)	[61]
PlanMill 30 s (3-axis, 1 spindle, standard) PlanMill 30 s (3-axis, 1 spindle, detailed) PlanMill 40 s (3-axis, 2 spindle, standard) PlanMill 40 s (3-axis, 2 spindle, detailed)	[67]
PlanMill 40 (3-axis) Zenotech Slect Hybrid (5-axis)	[64]
NX Mach (3-axis) Zfx-Sauer 10 (5-axis)	[17]
Wieland Zenotec mini (4-axis) Wieland Zenotec T1 (5-axis)	[70]
E4D (3-axis) Tizian Cut (5-axis)	[66]
4-axis compared with 5-axis	[12]

Table 3. Descriptive analysis of restoration characteristics used in primary studies

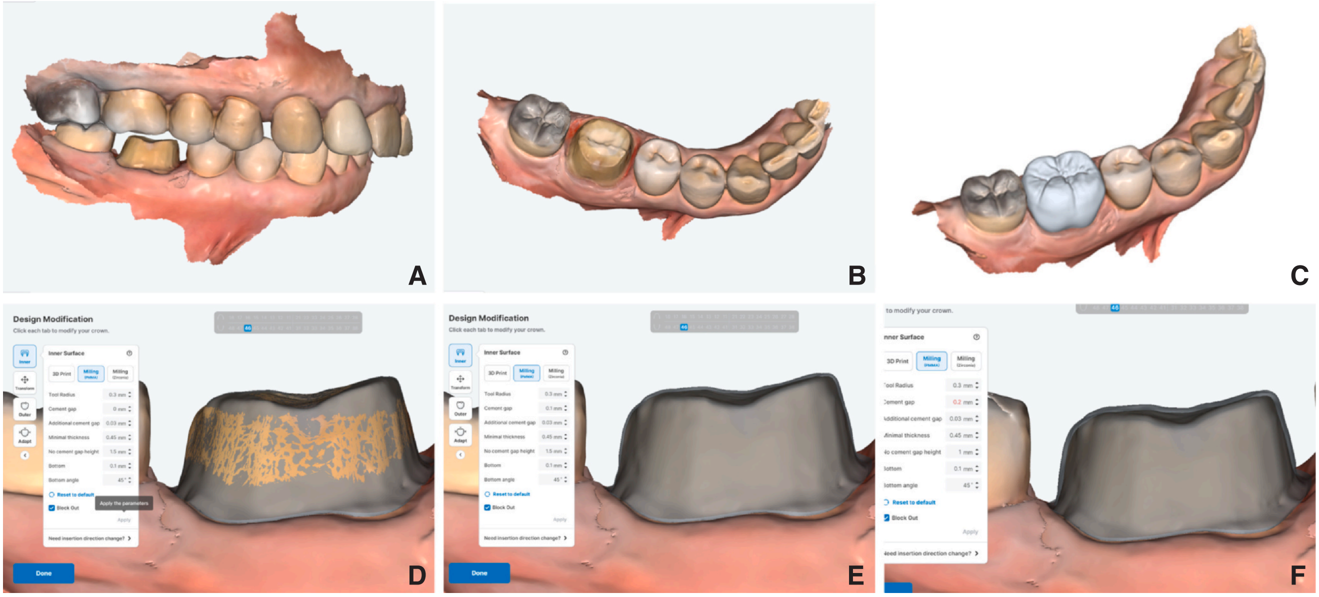
Restoration Design	**n**	**References**
Crown	15	[10,11,14,57,58,60–65,67–70]
Inlay	5	[8,16,57,66]
Onlay	3	[9,16,57]
Occlusal veneer	1	[59]
3-unit Fixed Partial Denture	1	[17]
Restoration Material	**n**	**References**
Lithium disilicate ceramic	8	[9,10,60,61,63,64,66,67]
Zirconia	5	[58,61,62,65,70]
Polymer-infiltrated ceramic network	4	[9,11,59,61]
Feldspathic ceramic	4	[9,57,61,68]
Composite resin	3	[58,61,69]
Zirconia-reinforced lithium silicate	3	[8,59,61]
Metallic alloy	2	[17,58]
Polyether ether ketone	1	[14]
Not reported	1	[16]

Table 4. Descriptive analysis of measured outcomes

Outcome	**n**	**Reference**
Marginal or internal adaptation	18	[8–11,17,58–70]
Trueness	3	[14,16,57]
Resistance to rotation	2	[63,64]
Bond strength	1	[9]
Flexural Strength	1	[17]

while 1 study considered the DWX-50[14] and 1 the PlanMill 40 milling machine.[63] The tested comparisons among the CEREC MC XL considered the following bur variations: Step Bur 12 (tip diameter 0.95 mm; 65 µm-grit size), Step Bur 12S (tip diameter 1.35 mm; 65 µm-grit size), Cylinder Pointed Bur 12S (tip diameter 1.75 mm; 65 µm-grit size)[8,16]; the milling modes: 1-step (restoration milled to its final form) or 2-step (200 µm of the restoration left to be removed in a second process)[8,16]; or the number of bur uses.[60] Both studies described a higher internal fit and intaglio surface trueness for 2-step compared with 1-step with Step-Bur 12S,[8,16] but Zimmermann et al[8] described a higher performance compared with 1-step with Step-Bur 12, not found by Bosch et al.[16] A higher misfit was found as the number of uses of the diamond rotary instruments during milling increased.[60] Kim et al[14] reported that for the intaglio of crowns, the trueness was better when 2 instead of 3 burs were used, while Sadid-Zadeh et al[63] stated that the use of ellipsoidal rotary instruments resulted in lithium disilicate crowns with improved adaptation compared with conical rotary instruments.

Regarding different milling machines, the CEREC MC XL (n=3) (Table 2, Fig. 4) was the most evaluated in the studies, followed by the PlanMill 40 (n=2). Three studies compared 4-axis with 5-axis machines, reporting higher trueness and fit for the 5-axis machines.[16,57,70] Also, 3 in vitro studies compared 3-axis with 5-axis, 2 of them reporting better fit and roughness for 5-axis machines, while 1 reported a lower marginal gap for the 3-axis machine.[17,64,66] The only systematic review reported that a 5-axis milling machine resulted in a better FIR than a 3-axis machine.[12] One study evaluated laboratory compared with chairside milling machines,[65] while 1 evaluated 2 different 4-axis milling machines[61] and 1 used 2 different 3-axis machines.[67] Differences between the milling units were also detected in those studies (Figure 4).



Design Modification
Click each tab to modify your crown.
Inner Surface
3D Print | Milling (PMMA) | Milling (Zirconia)
Tool Radius 0.3 mm
Cement gap 0 mm
Additional cement gap 0.03 mm
Minimal thickness 0.45 mm
No cement gap height 1.5 mm
Bottom 0.1 mm
Bottom angle 45°
Reset to default
☑ Block Out
Apply
Need insertion direction change?

Design Modification
Click each tab to modify your crown.
Inner Surface
3D Print | Milling (PMMA) | Milling (Zirconia)
Tool Radius 0.3 mm
Cement gap 0.1 mm
Additional cement gap 0.03 mm
Minimal thickness 0.45 mm
No cement gap height 1.5 mm
Bottom 0.1 mm
Bottom angle 45°
Reset to default
☑ Block Out
Apply
Need insertion direction change?

to modify your crown.
nner Surface
3D Print | Milling (PMMA) | Milling (Zirconia)
ool Radius 0.3 mm
ement gap 0.2 mm
dditional cement gap 0.03 mm
inimal thickness 0.45 mm
o cement gap height 1 mm
ottom 0.1 mm
ottom angle 45°
Reset to default
☑ Block Out
Apply
eed insertion direction change?

Figure 2. Restoration planning and design digital flow – image acquisition through intraoral scanner. A, Interocclusal space analysis. B, Tooth preparation. C, Restoration external surface design. D-F, Different settings of cement space (D, 0 μm; E, 100 μm; F, 200 μm).

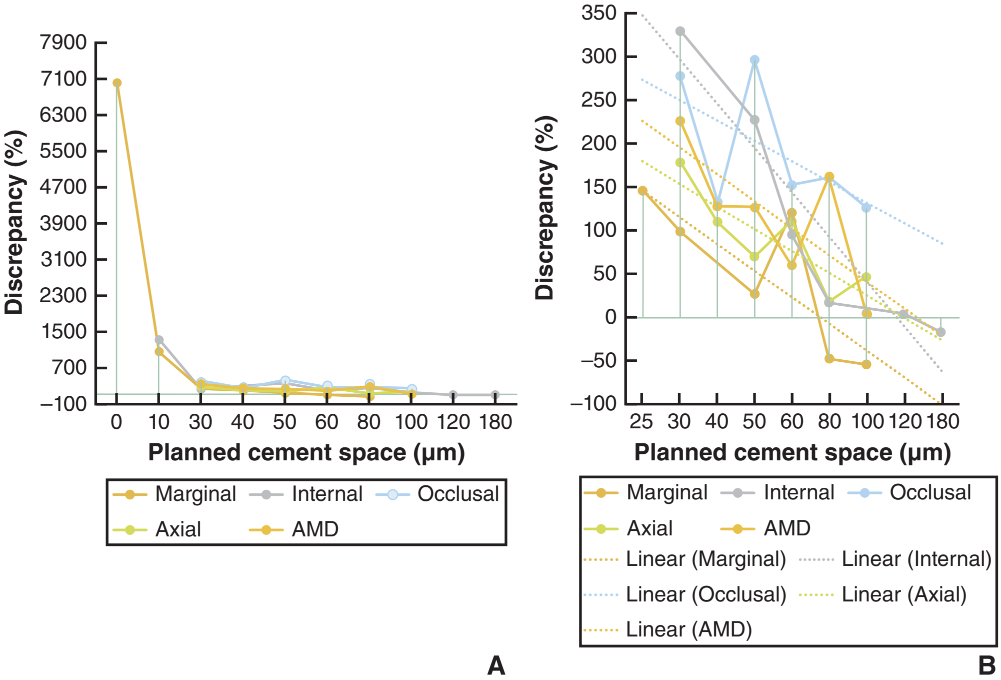


Figure 3. Representative graph of relationship between planned cement space and resultant space after milling in primary studies and trendline. A, Full picture of all planned cement spaces. B, Higher magnification focusing only on the range between 25 and 180 μm. AMD, average marginal discrepancy.

DISCUSSION

This scoping review provides information on CAM milling parameters in the aspect of indirect restorations. Based on the included studies, the planned cement space was not well reproduced by the milling machine; the number, format, and grain size of the burs used affected the restoration fit and trueness; and 5-axis milling machines resulted in better-adapted restorations compared with 3- and 4-axis machines. Thus, the hypothesis that none of the factors would influence the outcome of indirect restorations was rejected.

The accuracy and efficiency of the CAD-CAM process depends on every step that precedes that phase,

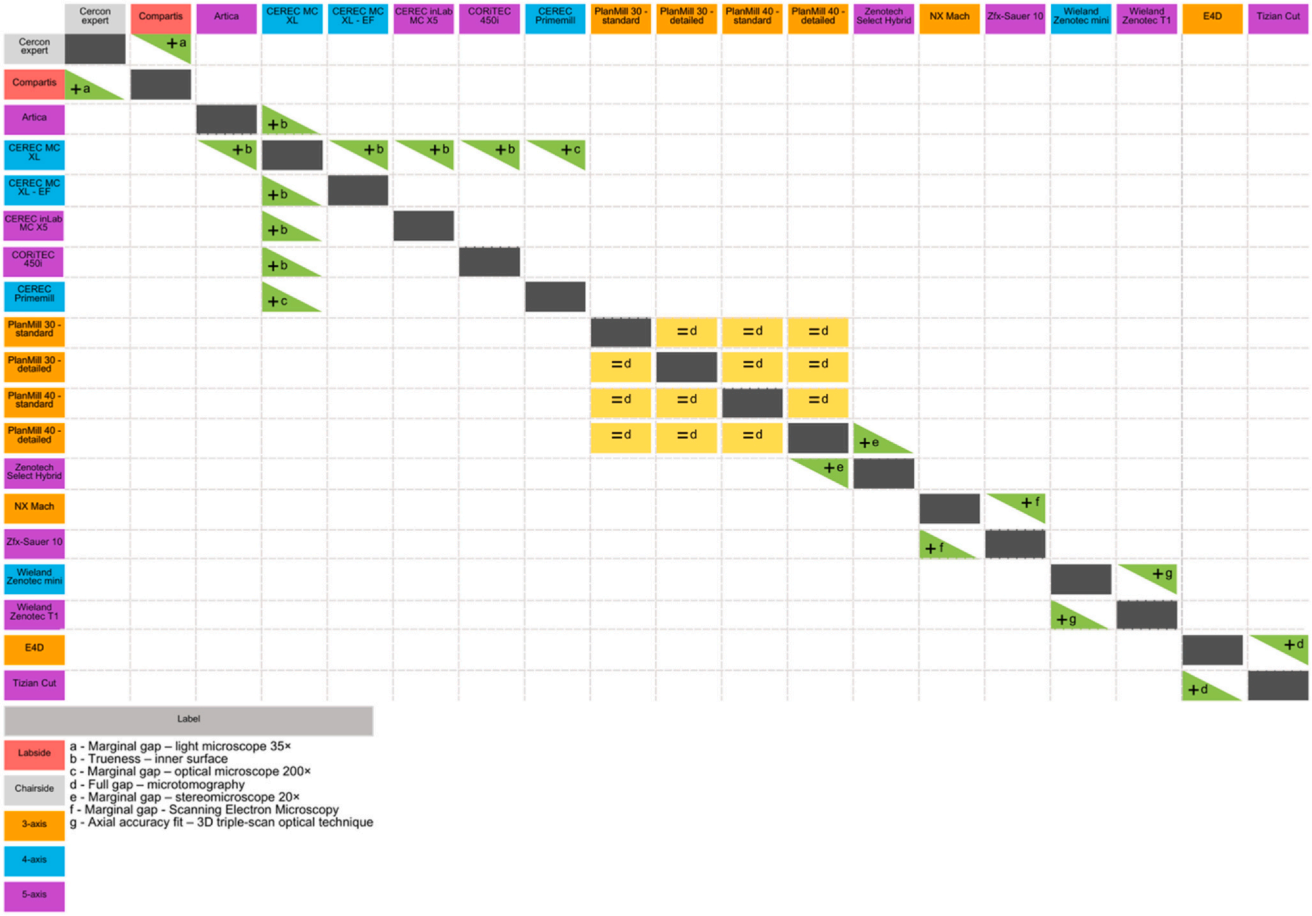
Table 5. Linear regression analysis comparing planned cement space settings and measured value

Measured Points	Linear Regression Equation	R^2
Marginal	$y=-30.736x + 176.9$	0.6692
Internal	$y=-51.14x + 399.96$	0.8748
Occlusal	$y=-23.55x + 298.18$	0.3336
Axial	$y=-25.69x + 205.35$	0.7138
Average Marginal Discrepancy	$y=-30.776x + 257.08$	0.5456

R^2, Coefficient of determination

factors that are within that process, and postprocessing protocols. However, some factors need to be further explored by primary studies. Studies are still needed on the restorative material, although, depending on the microstructure, surface topography, fit, marginal chipping, and machinability may differ.[12,15,61] Only 1 study tested multiunit restorations,[17] but complex designs led to a less precise and accurate digital workflow.[71] Thus, studies comparing different preparation designs, including multiunit ones, and the effect on different milling protocols, are needed.

The current milling machines were unable to reproduce the cement space accurately. If the cement space is too small, contact between the restoration and the prepared tooth may prevent seating; and if it is too large, the stress distribution may be adversely affected and cement dissolution, secondary caries, and periodontal health affected.[68,72–74] However, a consensus on the clinically ideal cement space for indirect restorations is lacking,[12,75] although the planned cement space was found to be poorly reproduced by milling, consistent with a previous systematic review.[12] For internal and axial locations, a linear relationship was found between what was planned and the fit (Fig. 3, Table 5), indicating that the lower the cement space setting value, the higher the misfit.[59,69] Planned values between 100 and 120 µm seem to result in lower discrepancy. For other points, although the coefficient of determination (R^2) was not high, there was a similar linear trend (Fig. 3), although the low number of studies and the discrepancies between methodologies may make this trend tenuous. This lack of correlation may also be explained by the



	Cercon expert	Compartis	Artica	CEREC MC XL	CEREC MC XL - EF	CEREC inLab MC X5	CORITEC 450i	CEREC Primemill	PlanMill 30 - standard	PlanMill 30 - detailed	PlanMill 40 - standard	PlanMill 40 - detailed	Zenotech Select Hybrid	NX Mach	Zfx-Sauer 10	Wieland Zenotec mini	Wieland Zenotec T1	E4D	Tizian Cut
Cercon expert	■	+a																	
Compartis	+a	■																	
Artica			■	+b															
CEREC MC XL			+b	■	+b	+b	+b	+c											
CEREC MC XL - EF				+b	■														
CEREC inLab MC X5				+b		■													
CORITEC 450i				+b			■												
CEREC Primemill				+c				■											
PlanMill 30 - standard									■	=d	=d	=d							
PlanMill 30 - detailed									=d	■	=d	=d							
PlanMill 40 - standard									=d	=d	■	=d							
PlanMill 40 - detailed									=d	=d	=d	■	+e						
Zenotech Select Hybrid												+e	■						
NX Mach														■	+f				
Zfx-Sauer 10														+f	■				
Wieland Zenotec mini																■	+g		
Wieland Zenotec T1																+g	■		
E4D																		■	+d
Tizian Cut																		+d	■

Label

Labside
Chairside
3-axis
4-axis
5-axis

a - Marginal gap – light microscope 35×
b - Trueness – inner surface
c - Marginal gap – optical microscope 200×
d - Full gap – microtomography
e - Marginal gap – stereomicroscope 20×
f - Marginal gap - Scanning Electron Microscopy
g - Axial accuracy fit – 3D triple-scan optical technique

Figure 4. Pairwise comparison of different milling machines (column compared with line). Color blocks associated with symbols represent result according to primary studies, whereas *green triangle* with "+" symbols represent machine that was better than other, while *yellow square* with "=" represents no difference found between two milling machines. Letters represent outcome evaluated.

inability of the CAM milling machines to reproduce the cement space accurately,[11] depending on bur diameters and pathways during grinding.[8,14]

The characteristics of the rotary instruments were found to affect the shape of the restoration. Different milling strategies with distinct burs and steps are available with the CEREC MC XL system. The Step Bur, responsible for the milling of the intaglio surface, is available in 2 different diameters (12: Ø=0.95 mm; 12S: Ø=1.35 mm); however, when testing the same milling mode, Bosch et al[16] did not report a significant difference in the intaglio surface trueness of inlays and onlays, unlike Zimmermann et al[8] for axial and occlusal fit. Zimmermann et al[8] only reported differences in the inlay marginal fit (the smallest diameter resulted in the best fit), which can be explained by the larger bur tip that possibly resulted in overmilling with poor fit areas.[8] A smaller tip (Ø=0.6 mm) may facilitate detailing on the external surface of the restoration despite resulting in similar trueness to a larger tip (Ø=1 mm).[14] The milling pathway and time seem to be important aspects. When comparing 1-step to 2-step milling with the same instruments, (with almost twice the milling time), the faster process was reported to induce more marginal chipping, since more material was being removed at a high feed rate and rotational speed, producing a less accurate restoration.[8,16] The higher misfit of lithium disilicate crowns has been reported with increased milling without replacing the bur set.[60,76] In contrast, milling 18 restorations with the same bur set has been reported not to affect the topography or fatigue behavior of milled lithium disilicate,[77,78] which may be explained by the different burs used – Step Bur 12[60] and Step Bur 12S.[77,78] Consequently, further studies are warranted to understanding the effect of tool wear.

Despite the 10 included in vitro studies that investigated the milling machine, data from only a few could be extracted because of the absence of a comparison group with the same milling unit (Fig. 4). However, 5-axis milling units seem to result in better-adapted restorations compared with 3-axis[17,66] and 4-axis units.[16,57,70] The design of 5-axis milling machines, which can move in the X, Y, and Z directions and also rotate around 2 axes, typically the A-axis and C-axis, enables milling complex contoured surfaces and intricate geometries without repositioning the work piece. Only 1 study reported better marginal integrity and smaller gaps for a 3-axis than a 5-axis machine.[64] Therefore, a milling unit with an additional axis achieves better angles, more effective and accurate processing, and better surface topography and finishing, especially for multiunit restorations.[12,16,17,57] Studies comparing 3-, 4-, and 5-axis milling machines in the same context are lacking, making it impossible to rank the efficiency of the machines.

The most evaluated outcome in the included studies was marginal or internal fit. Despite being a relevant and indispensable theme, the milling process and its variations may affect other outcomes such as mechanical behavior, surface topography, and the impact of and need for postmilling processes.[79] However, studies that investigated the impact of CAM variations on these outcomes are lacking. Thus, more studies are essential for a better understanding of the influence of the milling process and variations on the performance of indirect restorations.

Limitations of the review included that the search was limited to studies published in English and that the influence of the sintering protocol and the regular calibration of the instruments were not evaluated. Considering the inherent primary data limitations and heterogeneity, more studies investigating standardized milling units and comparing different materials and restoration designs are necessary.

CONCLUSIONS

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

1. The unique parameters of CAM dental systems can affect the results of indirect restorations.
2. Particularly, the planned cement space, the number, format, and grain size of the milling burs and the number of milling unit axes are important factors in the trueness and fit of the restoration.

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