Impact of Finishing and Polishing Procedures on CAD/CAM *In Vitro* Milled Ceramics Surfaces: A Systematic Review

Keywords

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ABSTRACT

Introduction and objectives: CAD/CAM prostheses may be produced in prosthetic laboratories or directly by practitioners. Quality of ceramic polishing procedures is a controversial topic and it would be interesting for practitioners working with CAD/CAM devices to determine which method is the most efficient regarding finishing and polishing. This systematic review aims to evaluate the impact of different finishing and polishing procedures on the surface of milled ceramics. Materials and methods: A precise request was launched on the PubMed database. Studies included if they met the criteria of a specifically prepared PICO search. A first selection was performed by analysing titles and abstracts: the articles presenting a study conducted on non-CAD/CAM milled ceramics and research not containing comparisons of finishing procedures were not included. Roughness was evaluated in 15 articles. Nine papers recommended mechanical polishing over glazing regardless of the type of ceramic used. However, no significant differences were detected between the surface roughness of glazed and polished ceramics in nine other publications. Conclusions: there is no scientific evidence demonstrating the superiority of hand polishing over glazing on CAD/CAM-milled ceramics.

INTRODUCTION

The interest in computer assisted design and computer assisted milling (CAD/CAM) technologies has consistently increased over the last fifteen years.[1] They represent an important part of contemporary prosthetic dentistry[2] which has undergone much progress in terms of efficiency, precision and choice of materials.[3,4] It has been validated that these technologies have become reliable alternatives to conventional methods in clinical practice due to their precision and the speed of manufacturing.[5–7]

In parallel with the development of new technologies, aesthetic demand from patients has increased, explaining the production of numerous new ceramic materials.[4,8,9] The choice of the most suitable material for each clinical situation and the most suitable finishing procedure on the item's surface have therefore become more difficult decisions for both dentists and their technicians[10] to make.

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These prostheses may indeed be produced in prosthetic laboratories or also directly by practitioners in their dental offices.[2] However, the milling process itself does not achieve a perfect surface ready to be bonded in the patient's mouth.[2]

Burs act by producing roughened surfaces that then need a meticulous finishing protocol to ensure long-term clinical success.[11] Obtaining a smooth surface for ceramic restorations is important not only for patient comfort but also for aesthetic and biological reasons.[12–14] Rough surfaces encourage plaque buildup[15] which increases the risk of developing gingivitis or secondary caries.[16–18] Moreover, roughness may have a negative impact on ceramic flexural strength[19,20] and risk of fracture[12]. Ceramic finishing and polishing are also important to improve colour and aesthetics, minimise shade variations[21,22] and ensure a bright surface.[2] This is essential in terms of reducing the wear of antagonist teeth and biomaterials.[23,24] All are key factors for the long-term oral success of CAD/CAM restorations from biological, aesthetical and mechanical points of view.[25]

Literature shows that the quality of ceramic polishing procedures is a controversial topic.[26] In 2020, Monaco *et al.* adequately confirmed the need to be precautious when polishing ceramics to avoid the adverse effect of surface alteration[27] but there is not much documentation on the efficacy of instrumentation, materials or procedures available in private practice for dentists working with CAD/CAM devices.[2] There is no reference protocol to apply for the final finishing of milled ceramic surfaces[10] when carrying out mechanical polishing or performing a glaze.[22,28] Moreover, the two mechanisms and goals are completely different.[5] On the one hand, the glazing procedure aims to bring a natural brilliance to reduce pigmentary macromolecules and bacteria retention[10] as well as achieve shade and translucency stability.[29,30] On the other hand, mechanical polishing gives a smoother surface[21,31] and eliminates the various imperfections it may present.[5] Results concerning the two procedures and their performances are often discordant mainly due to the differences that exist in the evaluated variables.[26]

It would therefore be very interesting for practitioners working with CAD/CAM devices daily to determine which method is the most efficient in terms of finishing and polishing their ceramic restorations. This study aims to evaluate the impact of different finishing and polishing processes on the surfaces of milled ceramics through a systematic review of the literature.

MATERIALS AND METHODS

This study has been designed as a systematic literature review in line with "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) guidelines.[32]

REVIEW STRATEGY

A precise request (Supplementary File 1) had been launched on November 2022, the 14th one made on the PubMed database. No limit was decided concerning the year of publication.

SELECTION CRITERIA

From the results, the studies could be included if they met the criteria of the following PICO search: no criteria for patients/participants (not applicable), CAD/CAM-ceramic glazing as intervention, CAD/CAM-ceramic polishing as comparison and shade, surface aspect and mechanical strength as outcomes. A first selection was performed by analysing titles and abstracts. The integral texts of eligible articles were then studied.

The articles presenting a study performed on non-CAD/CAM milled ceramics and research not containing comparisons of finishing procedures were not included.

DATA EXTRACTION

A standardised form has been applied to extract data from included publications. The authors' names, their country, the year of publication, the biomaterials used, finishing and polishing systems used, outcomes of the studies and their results were noted. All data have been grouped on an Excel spreadsheet (Microsoft Excel 2016®, Microsoft, Redmond, WA, USA).

RISK OF BIAS

The risk of bias has been evaluated by using a specific score, previously validated in several systematic reviews performed on *in vitro* studies.[10,33,34] The four following parameters have been evaluated for each included publication: sample randomisation, sample size calculation, the use of each biomaterial or procedure in line with manufacturer's instructions and calibration in the event of multiple operators. The risk of bias was then calculated with a score rated high (score 1 or 2), medium (score 3) or low (score 4).

RESULTS

SEARCH AND SELECTION

The flow chart summarising the study selection process according to the PRISMA grid is presented in Figure 1. Initially, 84 results were obtained from the PubMed database search. After reading the titles and abstracts of all the articles, 55 references were considered irrelevant to this study and were excluded. The full texts of the remaining 29 articles were then examined and 8 references were again excluded because they did not correspond to the PICO answers previously detailed (i.e. did not only evaluate CAD/CAM machined ceramics but also conventionally layered ceramics, did not directly compare the effectiveness of the finishing and polishing systems used, etc.). For example, Kalia *et al.*[35] included various types of ceramics and performed a comparison between several polishing systems while Özarslan *et al.*[36] took bacterial adherence as the main outcome.

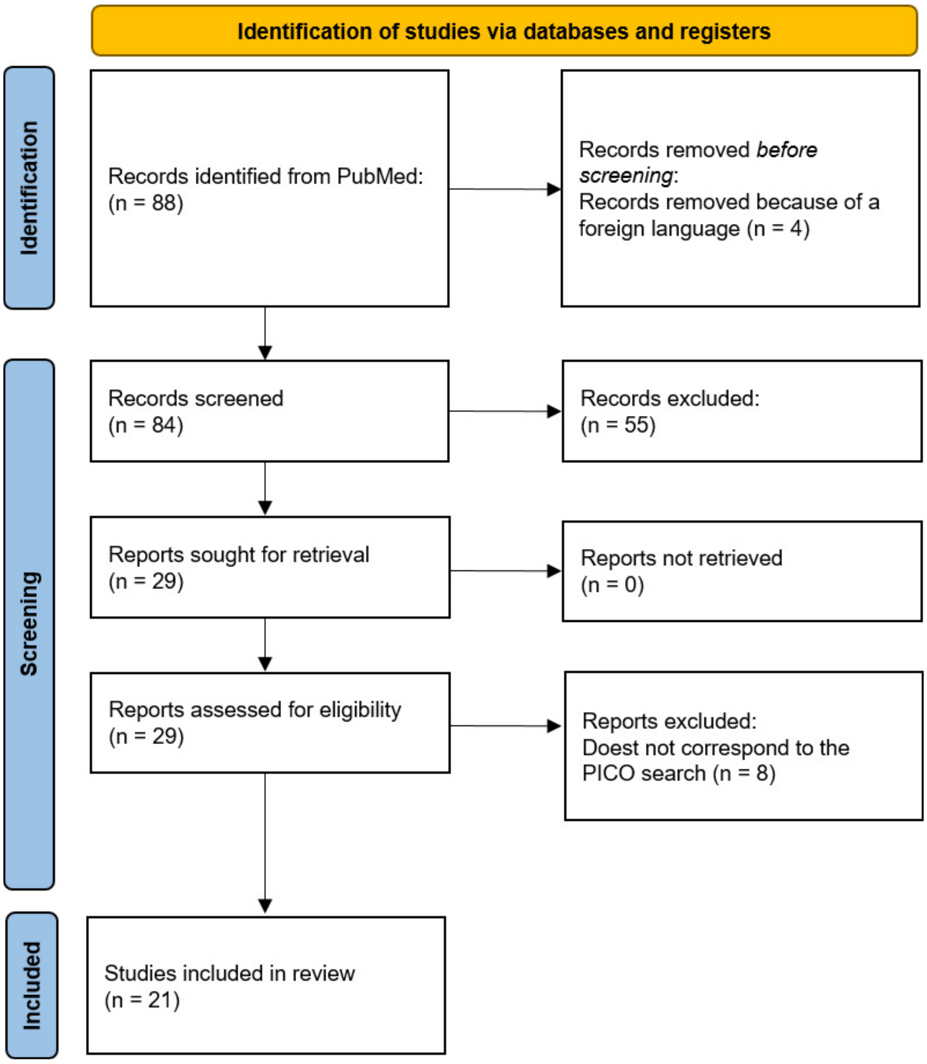

Figure 1: PRISMA flow chart[32] of PubMed research results.

DESCRIPTIVE ANALYSIS

Detailed descriptive data for the 21 included studies are presented in Table 1. All articles were published between 2010 and 2021 including 16 articles (76.19%) between 2019 and 2021. The majority of the studies were conducted in Europe *(Figure 2*). They are all *in vitro* studies.

Materials Used

In the included articles, seven different types of CAD/CAM-milled ceramics were investigated: feldspathic ceramics (VITA Mark II (Vita Zahnfabrik, Germany) and CEREC Blocs C (Dentsply Sirona, Germany), lithium disilicate crystal strengthened glass-ceramics (IPS e. max CAD (Ivoclar Vivadent, Liechtenstein), leucite crystal strengthened glass-ceramics (IPS Empress CAD (Ivoclar Vivadent, Liechtenstein)), zirconium-reinforced materials (especially lithium silicate and zirconium dioxide strengthened glass-ceramics VITA Suprinity (Vita Zahnfabrik, Germany) and LAVA Ultimate (3M Espe, France), Celtra Duo (Dentsply Sirona, Germany)), zirconia (LAVA Plus (3M Espe, France), VITA YZ T (Vita Zahnfabrik, Germany) and ZENOStar ZR translucent (Wieland Dental, Germany)), hybrid ceramics (VITA Enamic (Vita Zahnfabrik, Germany) and CERASMART (GC Dental, Japan)) and a stackable low-fusing nanofluorapatite glass ceramic (Ceram, indicated as "Others" in Table 1).

The most studied ceramics were lithium disilicate crystal-strengthened glass-ceramics (LDRVC) as cited in 12 articles (57.14%) and zirconium-reinforced ceramics which was cited in 11 articles (52.38%). In contrast, the least evaluated ceramics were pure zirconia and leucite crystal reinforced glass-ceramics, used in only 2 and 3 articles respectively.

Finishing and Polishing

Regarding the finishing and polishing systems used as required by the PICO criteria applied to this review, all studies compared glazing with one or more manual polishing techniques: mostly diamond polishers in 18 articles (85.71%), flexible discs with aluminium oxide coating in 5 articles (23.81%) and silicone polishers in 3 articles (14.29%). In fourteen of the included studies (66.67%), the authors also used a diamond polishing paste for the final step in polishing the ceramic surface.

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Table 1. Synthesis of the data collected in the included studies which have been classified according to their publication year. The biomaterials used, the finishing procedures applied and the main outcomes are presented.

Authors	Year	Country	Biomaterials used					Finishing procedures applied							Outcomes					Results
			FC	LDRVC	LRVC	ZRM	Pure zirconia	Hybrid (✓) or others	Diamond polishers	Silicone polishers	Flexible discs	Polishing paste	Glazing	Coloration	Roughness	Brightness	Wear	Flex. Strength	Other mechanical properties	
Porojan et al.[37]	2021	Romania				✓		✓	✓			✓	✓		✓					Polishing for all; glazing discussed
Kara et al.[38]	2021	Turkey				✓		✓	✓		✓	✓	✓	✓	✓					Diamond polisher slightly better
çakmak et al.[44]	2021	Turkey	✓	✓	✓	✓	✓	✓	✓			✓	✓		✓		✓		✓	Depend on the properties
Brescansin et al.[46]	2021	Brazil			✓				✓			✓	✓	✓	✓					Polishing +/- glazing after every adjustment
Aldosari et al.[45]	2021	Saudi Arabia	✓			✓		✓	✓				✓	✓	✓					No difference
Brodine et al.[47]	2021	USA		✓				Others	✓				✓		✓					Depend on the materials
Alao et al.[39]	2021	Australia		✓					✓				✓						✓	Polishing should be preferred
Ozen et al.[52]	2020	Turkey		✓		✓		✓	✓				✓	✓						Glazing recommended for all materials
Kanat-Ertük[22]	2020	Turkey		✓		✓			✓			✓	✓	✓						Glazing recommended for all materials
Abu-Obaid et al.[53]	2020	Saudi Arabia	✓			✓		✓	✓			✓	✓	✓						Glazing recommended for all materials
Wiedenmann et al.[40]	2020	Germany		✓	✓		✓					✓	✓				✓		✓	Polishing should be preferred
Scherrer et al.[48]	2020	Switzerland	✓	✓			✓		✓				✓		✓					No difference

Table 1 continued overleaf......

Table 1 continued...

Ludovichetti et al.[49]	2019	Brazil		✓		✓	✓		✓		✓	✓		✓					Glazing for ceramics and polishing for hybrids
Gönüldaş et al.[5]	2019	Turkey	✓		✓			✓		✓	✓	✓		✓			✓		Polishing recommended for all materials
Mohamma-dibassir et al.[41]	2019	Iran		✓				✓			✓	✓		✓			✓		Polishing, even if good flexural resistance with glazing
Daryakenari et al.[50]	2019	Iran	✓	✓		✓	✓	✓		✓	✓	✓		✓		✓			No difference
Kilinc & Turgut[51]	2018	Turkey	✓			✓	✓	✓		✓		✓	✓						Glazing for ceramics and polishing for hybrids
Vichi et al.[42]	2018	Italy		✓		✓	✓	✓				✓		✓	✓				Polishing: at least 60s ec.
Mores et al.[43]	2017	Brazil		✓					✓		✓	✓		✓				✓	Polishing should be preferred
Carrabba et al.[16]	2017	Italy	✓					✓			✓	✓		✓	✓				Glazing or polishing with diamond polishers + paste
Flury et al.[26]	2010	Switzerland	✓		✓			✓	✓	✓	✓	✓		✓					Polishing with diamond polishers or flexible discs

Acronyms have been used as follows: FC for feldspathic ceramics; LDRVC for lithium disilicate crystals reinforced vitroceramics; LRVC for leucite crystals reinforced vitroceramics; ZRM for zirconium-reinforced materials

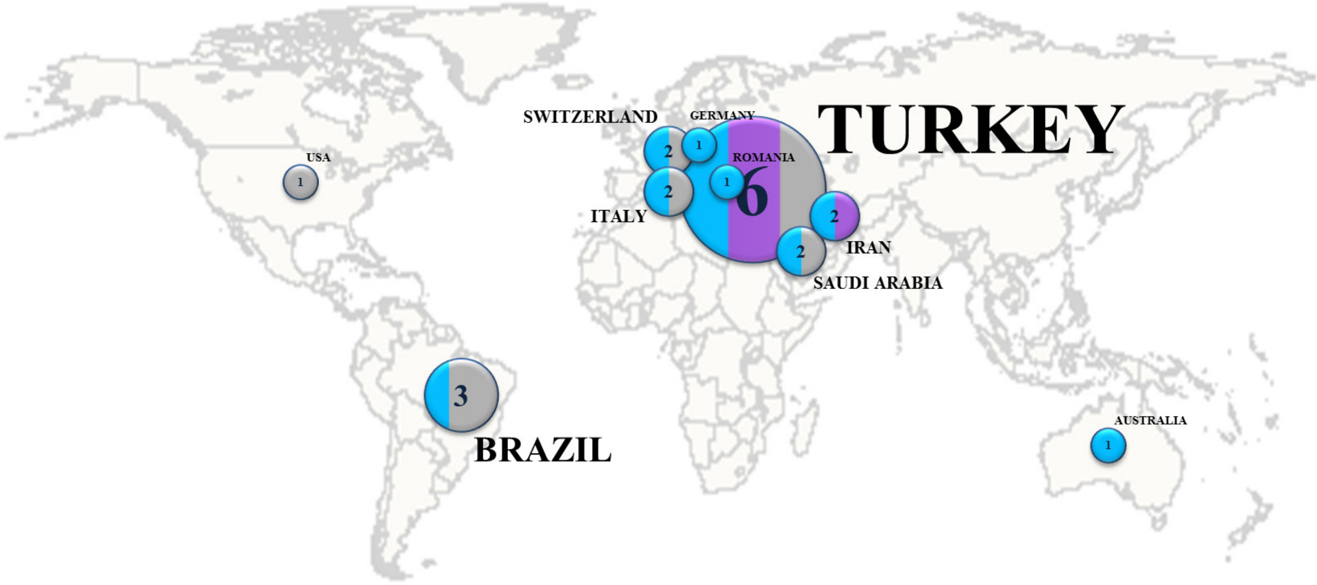

Figure 2: Schematic representation of the geographical places where studies included in this review have been performed worldwide. The size of the circles associated with each country, as well as the number inscribed inside, indicate the number of articles published in that country. The proportion of blue, purple and grey filling the circles illustrates the share of publications that have recommended polishing (blue), glazing (purple) or none of them specifically (grey).

The authors appeared to evaluate numerous criteria. Roughness was evaluated in 15 articles (71.43%) but data on ceramic shade (n=7), brightness (n=2), wear (n=2), flexural strength (n=2) and other mechanical properties (n=3) were also described. Regarding roughness, Flury *et al.* in 2010 recommended diamond polishers as being universally applicable and presenting an increased durability compared to silicone polishers.[26] Nine papers (42.85%) recommended mechanical polishing over glazing regardless of the type of ceramic used.[5,26,37–43] However, no significant differences were detected between the surface roughness of glazed and polished ceramics in nine other publications.[42,44–51] They highlight the important variability in the results, depending on the materials and outcomes. Newly developed polishing systems for CAD/CAM-milled ceramics seem to be a good alternative to glazing since the roughness of the biomaterial does not change or even decreases after the procedure.[50] Finally, three studies (14.29%) recommended glazing for the materials.[22,52,53]

To analyse the potentiality of modifying the shade of the materials, the protocols of two studies were based on immersing the ceramic samples in tea or coffee.[22,53] Colour stability appeared to be better after glazing than post-polishing. When artificial ageing was included in the procedure applied to the samples, manual polishing was mainly recommended for hybrid materials except for VITA Enamic.[51]

Regarding ceramic brightness after finishing, one study recommended either mechanical polishing with diamond polishers or glazing[16] whereas the other concluded that a minimum of 60 seconds polishing was necessary to achieve the highest brightness.[42]

Wiedenmann *et al.* advocated hand polishing and not glazing to improve the mechanical properties of the ceramic while largely preserving the antagonist.[40] However, Çakmak *et al.* and Daryakenari *et al.* showed no significant difference in the materials and their antagonist wear regardless of what finishing systems were used.[44,50] Under flexural stress, the modulus of elasticity of the ceramics was not modified by mechanical polishing with diamond polishers nor by glazing procedures.[5,41] Moreover, it seems that the use of a diamond polishing paste in the final phase of polishing decreased the stress applied on the material.[41] More generally, the fracture strength values of all materials, regardless of the protocol applied to finish them, stood up well to the maximum chewing forces applied by the authors.[40,43]

Risk of Bias

Among the 21 articles included in this review, 2 have been classified at low risk of bias, 6 with a medium risk of bias and 13 have a high risk of bias *(Table 2)*. According to this categorisation, the three studies that assessed the criteria of surface wear all had a high risk of bias. In contrast, studies assessing shade and brightness had a moderate risk of bias.

More precisely, calculation of the sample size was specified in only five publications and randomisation of the samples was specified in ten articles. Three studies did not mention if the materials and/or procedures were used in accordance with their manufacturers' recommendations. The presence of a single operator or calibrated operators during sample preparation was mentioned in 10 articles (47.62%).

Table 2. Bias assessment in the included studies following the same procedures as Moraes et al.[33]

	Randomization	Sample size calculation	Manufacturers' instructions for use respected	Unique operator or calibrated operators	Risk of bias
Porojan et al.[37]		✓			High
Kara et al.[38]			✓		High
Çakmak et al.[44]		✓	✓		High
Brescansin et al.[46]	✓		✓	✓	Moderate
Aldosari et al.[45]			✓	✓	High
Brodine et al.[47]			✓		High
Alao et al.					High
Ozen et al.[52]	✓		✓		High
Kanat-Ertük[22]	✓		✓	✓	Moderate
Abu-Obaid et al.[53]	✓	✓	✓		Moderate
Wiedenmann et al.[40]			✓		High
Scherrer et al.[48]	✓		✓		High
Ludovichetti et al.[49]				✓	High
Gönüldaş et al.[5]			✓		High
Mohamma-dibassir et al.[41]	✓		✓	✓	Moderate
Daryakenari et al.[50]			✓		High
Kilinc & Turgut[51]	✓	✓	✓	✓	Low
Vichi et al.[42]	✓		✓	✓	Moderate
Mores et al.[43]			✓	✓	High
Carrabba et al.[16]	✓		✓	✓	Moderate
Flury et al.[26]	✓	✓	✓	✓	Low

DISCUSSION

Our study summarises *in vitro* data on the impact of mechanical polishing and glazing on CAD/CAM-milled ceramics. This systematic review was designed to determine which finishing procedure provides the best results in terms of shade, surface finishing and mechanical properties. The results highlight that there is no scientific evidence demonstrating the superiority of hand polishing over glazing on CAD/CAM-milled ceramics.

Glazing by firing has traditionally been considered the 'gold-standard' and therefore the best way to achieve the smoothest possible ceramic surface finishing.[2] However, the current literature, in agreement with the results of this review, shows that mechanical polishing can achieve surfaces as smooth as or even smoother than glazing.[54] According to the conclusions of a recent systematic review which investigated the shade stability of CAD/CAM-milled ceramics after manual polishing or glazing, only two studies out of six selected showed superior shade stability efficiency with the application of glaze.[10]

Studying the potentiality of polishing or glazing a ceramic involves taking into account the structure of these materials which is highly implicated in the variability of the results retrieved between the different publications. Indeed, lithium silicate and zirconia-reinforced glass-ceramics showed easier polishability than LDRVC.[42] In addition, feldspathic ceramics tend to be less smooth than the previous two, unrelated to glazing or polishing.[48] This dissimilarity could be explained by differences in the microstructure of the materials as leucite content seems to play a role. Indeed, ceramics with low leucite content tend to present lower roughness after polishing compared to those with higher leucite content.[55] The structure of the materials can also influence the wear of the ceramics, including the differences in wear between hybrid materials and other ceramics.[56] For example, hybrid ceramics that have two interconnected networks (the dominant ceramic reinforced by a polymer network) showed higher wear than ceramics without a polymer network.[57] However, they can be considered more favourable to the antagonistic enamel wear compared to other ceramics.[58]

Therefore, significant heterogeneity exists between the articles included in our review due to the various ceramics employed as well as the different protocols and materials used in finishing and polishing their surfaces. It is therefore difficult to draw a definitive conclusion regarding the influence of glazing and mechanical polishing on CAD/CAM-milled ceramics. For example, all the authors have not used polishing kits from the same material manufacturers. In more specific detail, Sof-Lex flexible discs (Sof-Lex Pop-On Polishing Discs, 3M Espe, France) seems to provide the smoothest surfaces on ceramics.[26] They have been described as an effective manual polishing method for ceramics.[61,62] However, they are not the most suitable systems for polishing all restorations due to their rigid and flat shape.[26] Polishers with diamond abrasive particles or brush/diamond polishing paste systems are universally applicable and have increased durability compared to flexible discs.[61] Within this family of diamond polishers, lower surface roughness was observed for the Optra Fine system (OptraFine Assortment, Ivoclar Vivadent, Germany) in comparison with the D+Z polishing system (Composite polishing kit, D+Z).[41] The former consists of two polishers followed by a brush with diamond polishing paste whereas the latter contains three polishers: coarse, medium and fine. The application of diamond paste could therefore decrease the surface roughness and brush/diamond paste polishing systems also seem to have a significant clinical advantage: they tend to respect the newly created anatomy and contours while creating a smooth surface.[2] Therefore, the roughness of the ceramic was similar[62] or significantly lower[41] than that of the glazed material when polishing was completed with diamond paste, demonstrating the importance of this step when clinical adjustments are made to the biomaterials.[49] The use of polishing paste is also recommended for maintaining shade stability of the ceramics.[22]

No differences could be detected after polishing zirconia and lithium disilicate ceramics with 2-step or 3-step polishing kits.[48] In addition, some steps involved in the mechanical polishing methods do not contribute to improving the surface roughness and could therefore be omitted. For example, in the Jota diamond polishing system (Composites Diamond Polishers, Jota, Switzerland) consisting of three polishers (coarse, medium and fine), the first polisher (coarse) did not significantly reduce the surface roughness.[26] Therefore, the reduction of the Jota protocol to a two-stage polishing system could be considered.

After studying the different polishing protocols used in the articles, we also looked at the time of use of the polishers. Indeed, surface roughness tends to reach a plateau as the polishing time increases.[48] 60 second mechanical polishing for each step would provide satisfactory results in a reasonable interval of time.[16] This allows ceramic materials to achieve the highest brightness and the lowest roughness.[42]

From a clinical point of view, the main advantage of manual polishing systems is that the restoration can be completed in dental offices in one session which speeds up and simplifies the overall workflow. To apply a glazing procedure, the restoration needs to be sent to the dental technician's laboratory which implies a considerable delay for cementation with a second appointment.[16] As approximately 60% of all-ceramic restorations require at least minor adjustments to the occlusal surfaces after cementation,[65,66] a new step involving polishing will be necessary even if the ceramic has already been submitted to glazing.

The main limitation of our review was to understand whether the results of *in vitro* studies are comparable to clinical situations. Standardised protocols allow comparison of specimens within the same group but do not normally represent clinical situations. Further research on other ceramic and polishing systems are needed to reach a unanimous conclusion for all CAD/CAM-milled ceramics. Various factors such as practitioner and technician skills, applied pressure, rotation speed, type of polisher used, polishing time, grain size and glaze layer thickness can affect the results of polishing or glazing procedures.[5,67] In addition, several others factors can significantly affect the surface roughness, flexural strength and translucency of materials in the oral environment.

Finally, it is important to mention that to our knowledge no randomised clinical trials have yet evaluated the impact of surface finishing protocols for CAD/CAM-machined ceramics on long-term material stability.

CONCLUSION

To date, there is no scientific evidence to justify the superiority of hand polishing over glazing or to determine a unique clinically applicable finishing protocol.

For clinicians, most studies have shown that both mechanical polishing and glaze application can prevent significant alterations in the colour, surface smoothness and mechanical properties of CAD/CAM-milled ceramic restorations. With regard to manual polishing, the procedures that seem to give the best results for long-term clinical success are diamond polishing systems in combination with diamond brush and polishing paste systems.

However, due to the relatively limited evidence to support this conclusion, it appears that different kind of ceramics might require different polishing techniques and further *in vitro* and clinical studies are thus required. The large number of variables that can influence the final outcome of polishing must be considered. It would be necessary to standardise methodologies to allow comparison between researches.

CLINICAL RELEVANCE

This systematic review highlights that there is no scientific evidence demonstrating the superiority of hand polishing over glazing on CAD/CAM-milled ceramics in terms of roughness, shade and mechanical strength. Although there is no difference, it is clinically most important to always apply one of these two to increase the chance for long-term success of ceramic restorations.

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Supplementary File 1: Request strategy applied for the PubMed request

#1: "CAD-CAM"[Title/Abstract] OR "CAD-CAM"[Title/Abstract] OR "computer aided design"[Title/Abstract] OR "computer aided design"[Title/Abstract] OR "computer assisted design"[Title/Abstract] OR "computer assist*"[Title/Abstract] OR "computer assist*"[Title/Abstract] OR "computer aided manufacturing"[Title/Abstract] OR "computer aided manufacturing"[Title/Abstract]	37,953
#2 : "ceramic"[Title/Abstract] OR "hybrid"[Title/Abstract] OR "vitroceramic"[Title/Abstract] OR "polycristal*"[Title/Abstract] OR "emax"[Title/Abstract] OR "feldspathic"[Title/Abstract] OR "feldspatic"[Title/Abstract]	233,112
#3: "glazing"[Title/Abstract] OR "polishing"[Title/Abstract] OR "polisher"[Title/Abstract] OR "finishing"[Title/Abstract] OR "finisher"[Title/Abstract]	18,259
#4: "roughness"[Title/Abstract] OR "unevenness"[Title/Abstract] OR "stainability"[Title/Abstract] OR "color stability"[Title/Abstract] OR "staining resistance"[Title/Abstract] OR "wear"[Title/Abstract] OR "surface topography"[Title/Abstract] OR "topography"[Title/Abstract]	100,676
#5: #1 AND #2	2,453
#6: #5 AND #3	143
#7: #6 AND #4	88
#8: ((((((Chinese[Language]) OR Polish[Language]) OR Japanese[Language]) OR German[Language]) OR Portuguese[Language]) OR Russian[Language]) OR Review[Publication Type])	5,500,771
#9: #7 NOT #8	84