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Essentials of polishing zirconia dental restorations: a narrative review.

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Abstract

Objective

This narrative review synthesizes the current literature on the essential elements of polishing procedures for zirconia prosthetic restorations, analyzing biological, mechanical, and clinical aspects to inform clinicians' decision-making.

Method

A non-systematic literature review was conducted using PubMed/MEDLINE and Scopus. The following keywords were used: "zirconia" AND "polishing"; "zirconia" AND "surface roughness"; "zirconia" AND "wear". Filters applied: from 1 January 2000 to 31 December 2025 (last 25 years). Subject area: Dentistry. This study focused on articles, clinical studies, and in vitro studies concerning polishing methods for zirconia materials used in dental restorations, with particular reference to the biological, mechanical, and clinical consequences of these procedures.

Results and discussion

The introduction of multilayer zirconia materials has broadened the applications of monolithic zirconia restorations, highlighting the critical need for proper polishing techniques. Clinical adjustments are often necessary for zirconia restorations to address issues like occlusal interferences, interproximal spacing, or aesthetic and morphological refinements. However, such modifications can significantly affect surface roughness, potentially impacting critical aspects such as bacterial adhesion, wear resistance, tribological performance, and the overall mechanical integrity of the restoration. These effects may vary depending on the crystallographic phases present in the zirconia composition. To mitigate these effects, adhering to specific polishing protocols after adjustments is highly recommended. Polishing helps minimize surface defects and microcracks while also reducing the depth of phase transformation and the amount of monoclinic phase created during grinding. This process not only restores zirconia's surface to an acceptable roughness level (Ra) but also enhances its flexural strength, improving its durability and clinical performance.

Conclusion

Chairside adjustments are commonly performed during the delivery of most restorations. Currently, the first choice for clinicians is to apply a zirconia-specific polishing protocol after adjustment. Proper polishing is essential to restore surface quality after grinding, preventing cracks, improving wear resistance, and optimizing durability. Additionally, polishing should aim to achieve Ra values of no more than 0.2 µm to prevent bacterial adhesion. The operating protocols for clinicians include instruments with mandatory sequences according to the manufacturer's instructions. Despite the inherent variability of clinical adjustment procedures, existing polishing protocols have been streamlined and standardized to achieve predictable, less operator-dependent outcomes applicable across all zirconia types. However, advances in zirconia materials and diverse market options call for further research to optimize these procedures.

Keywords: Zirconia polishing, zirconia grinding, chairside adjustments, monolithic zirconia, zirconia wear.

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Introduction

Zirconia is recognized as one of the most utilized ceramic materials in dentistry, primarily due to its exceptional mechanical strength and aesthetic qualities. With advancements in CAD-CAM technology, monolithic zirconia restorations have become a preferred option for prosthetic treatments that demand both superior durability and visual excellence [1-3]. The direct exposure of monolithic zirconia to the oral environment underscores the critical role of polishing in ensuring successful prosthetic outcomes. Proper polishing not only enhances resistance and minimizes abrasiveness but also promotes plaque control, facilitates patient acceptance, and substantially improves the aesthetic performance of zirconia restorations [4-6]. In modern dental practice, it is imperative for clinicians and dental technicians to possess a high level of competency in standardized zirconia polishing protocols to optimize clinical outcomes. This capability is particularly essential, given the frequent need for chairside adjustments to prosthetic restorations during delivery appointments. Notably, studies have revealed that approximately 60% of all-ceramic restorations undergo modifications in their occlusal or axial surfaces at this stage. Therefore, grinding and polishing conducted directly by the dentist represents the most practical and cost-efficient solution in these scenarios [7-9]. Emerging evidence suggests that surface treatments such as glazing offer limited efficacy in reducing surface roughness or enhancing the structural integrity of zirconia restorations. Consequently, an increasing number of clinicians advocate for dedicated intraoral polishing protocols that are specifically tailored for monolithic zirconia [10-11]. Polishing must be guided by precise clinical and technical criteria, as full awareness of its importance and operating standards allows for the correct approach to a key phase in the success of the restoration, the management of which should be shared between the technician and the clinician. The aim of this study is to provide a narrative review of the essential elements of polishing procedures for zirconia prosthetic restorations, analyzing biological, mechanical, and clinical aspects, and offering guidance for clinicians' decision-making.

Methods

A narrative, non-systematic literature review was conducted using PubMed/MEDLINE and Scopus databases. The following keywords were employed: "zirconia" AND "polishing"; "zirconia" AND "surface roughness"; "zirconia" AND "wear". The search was limited to studies published between January 1, 2000 and December 31, 2025, within the field of Dentistry. Relevant articles, including clinical and in vitro studies, were selected according to their scientific relevance, methodological quality, and contribution to the clinical and biological understanding of polishing procedures applied to zirconia-based dental restorations. Particular attention was paid to studies investigating the mechanical, surface, biological, and clinical implications of zirconia polishing protocols.

Adjustments to zirconia restorations in clinical practice

Recent advancements in CAD/CAM technologies have enabled satisfactory adaptation of dental restorations, yet delivering prosthetic restorations frequently involves making clinical adjustments directly at chairside [12-13]. These adjustments primarily address issues such as occlusal interference, interproximal spacing, or aesthetic and morphological refinements. Research consistently shows that zirconia restorations, whether applied to natural teeth or implants, often necessitate adjustments either during placement, shortly after in follow-up visits, or even after a prolonged period [14-16]. The clinical approach to these adjustments serves as a crucial alternative to laboratory procedures, which are often more intricate and financially demanding [17]. These procedures, referred to as clinical or chairside adjustments, begin with an initial step of surface modification known as grinding. This process is performed using standard or fine-grain diamond burs, which are essential for making corrections to the restoration's surface [10]. Grinding serves multiple purposes, including occlusal adjustment after try-in, refining proximal contacts, correcting margins, and achieving occlusal equilibration. However, this step inevitably roughens the ceramic surface. To address this, a polishing phase follows, designed to restore the treated surfaces to their original morphology and smoothness [18]. Polishing following milling or adjustments plays a vital role in achieving optimal clinical results. Research indicates that chairside polishing is equally effective as laboratory polishing, even if the surfaces have been roughened immediately beforehand [19]. From a clinical standpoint, limiting chairside adjustments to monolithic zirconia restorations is crucial. These modifications can markedly change the restoration's shape and surface texture, which may negatively influence factors such as bacterial adhesion, wear performance, material strength, and the overall mechanical stability of the prosthetic. To ensure optimal functionality and longevity of the restoration, it is important to carefully avoid any adjustments that could produce undesired effects [9-10].

Structural characteristics of zirconia for dental restorations

The discussion surrounding the potential biological, mechanical, and clinical impacts of chairside adjustments to monolithic zirconia restorations is intricate and necessitates an understanding of the material's inherent properties. Although zirconia is classified as a ceramic, from a physical- chemical point of view it is a metal oxide characterized by polymorphism and allotropy. For dental use, zirconia is stabilized at room temperature by adding a specific percentage of yttrium oxide (Y_2O_3), which determines its crystalline structure and its resistance and translucency properties [2,20]. In dentistry, the main type of zirconia commonly used for monolithic restorations is second-generation 3Y-TZP (containing 3mol% Y_2O_3 and 0.05wt% Al_2O_3), characterized by a completely tetragonal crystal structure; fourth-generation 4Y-TZP (4mol% Y_2O_3 and 0.05wt% Al_2O_3), consisting of 75% tetragonal phase and 25% cubic phase; and third-generation 5Y-TZP (5mol% Y_2O_3 and 0.05wt% Al_2O_3), with a balanced structure between cubic and

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tetragonal phases (50%- 50%) [21-23]. A gradual rise in yttria content within zirconia in the latest generations alters the balance of crystalline phases, leading to enhanced translucency at the cost of diminished mechanical properties. Second-generation 3Y-TZP zirconia exhibits mechanical characteristics with a flexural strength ranging from 900 to 1300 MPa and a fracture toughness between 3.5 and 4.5 MPa·$m^{1/2}$. In comparison, 4Y-TZP offers a flexural strength of 600 to 1000 MPa and fracture toughness values between 2.5 and 3.5 MPa·$m^{1/2}$. Meanwhile, 5Y-TZP has a flexural strength that falls within 400 to 900 MPa and a fracture toughness in the range of 2.2 to 2.7 MPa·$m^{1/2}$ [22-23]. Monolithic prosthetic solutions have recently advanced with the development of multilayer zirconia featuring a hybrid composition. This innovation integrates various generations of the material within a single restoration, striving to achieve a gradient of mechanical and optical properties that closely mimic the natural characteristics of teeth [24-26]. Thanks to a mechanism called Phase Transformation Toughening (PTT), which relies on the transformation of zirconia from its tetragonal phase to a monoclinic phase accompanied by volumetric expansion, this material demonstrates exceptional mechanical performance compared to other dental ceramics. This process allows the material to effectively counteract the propagation of cracks [2,26]. This same mechanism, however, renders zirconia susceptible to a phenomenon called low-temperature degradation (LTD) or aging. This process takes place on the surface exposed to the oral environment and can gradually propagate inward, leading to microstructural defects, greater surface roughness, and a gradual decline in its mechanical properties over time [27,28]. Exposure of the zirconia surface to mechanical stress, abrasion due to chewing, or clinical procedures can activate this phase transformation, making the material susceptible to damage. It should be noted that the increase in the cubic phase in third-generation (5Y-TZP) and fourth-generation (4Y-TZP) zirconia reduces susceptibility to LTD, thereby improving resistance to the aging process [27-28]. On the contrary, second-generation monolithic zirconia (3Y-TZP), characterized by a lower yttria content and direct exposure of the surface to the oral environment, is more prone to this phenomenon [26]. The key concept is that zirconia is a material with high mechanical qualities but, due to its structure, it can be more or less susceptible to surface damage and phase transformation if overheated or aggressively ground.

The importance of surface roughness in zirconia restoration

The effectiveness of a polishing system is mainly evaluated by measuring surface roughness, a key parameter for determining the degree of smoothness of zirconia following surface treatments [29]. Surface roughness represents the extent of microgeometric irregularities and directly affects the long-term prognosis of monolithic zirconia ceramic restorations. This parameter is usually analyzed in vitro using instruments such as profilometer, scanning electron microscope (SEM) and roughness tester. These are the instruments most commonly referenced in dental literature, although atomic force microscope (AFM) are also used [18]. Among the parameters most frequently reported in the literature are the arithmetic mean roughness value (Ra), which represents the average height of surface roughness measured in micrometers (µm), and the Root Mean Square Roughness (RMS), calculated from the average square root of microscopic peaks and valleys in the surface: this indicates the average deviation of the roughness profile from the average line, typically measured in micrometers (µm) [9]. Clinically, surface roughness can be roughly assessed through visual or tactile inspection. However, these methods are highly subjective and less accurate. In general, ceramic surfaces that appear opaque are also rougher than glossy ones, making gloss a useful, albeit empirical, indicator for estimating roughness [30]. It is recommended that this analysis be performed on dry surfaces to obtain more reliable assessments. Tactile contact with the ceramic surface can also provide additional information on the level of roughness. Surface roughness can be significantly altered by clinical adjustment procedures, particularly during the grinding phase performed with diamond burs. This procedure can generate microcracks and micro fissures, significantly increasing the roughness of the surface. If proper polishing is not performed after grinding, the result will be a restoration with high roughness values, which could have various negative clinical consequences. An increase in surface roughness primarily affects the strength of the monolithic restoration: more extensive and deeper defects lead to a significant reduction in flexural strength [10,31-33]. Furthermore, rougher surfaces are more susceptible to the negative effects of low-temperature degradation (LTD), which can compromise the stability and reliability of zirconia [14,34]. This increase in roughness also affects the abrasiveness of the restoration: the combination of zirconia's high hardness and a rough surface tends to accentuate wear on the opposing teeth [35-37]. At the same time, rough surfaces promote biofilm accumulation and make the material more prone to bacterial adhesion, as the grooves on the surface increase the area available for plaque deposition [38-40]. Finally, increased surface roughness also compromises the optical properties of monolithic zirconia. Light scattering caused by surface irregularities reduces translucency and amplifies the opacity of the material, negatively affecting the final aesthetics of the restoration [41].

Bacterial adhesion to zirconia restorations

Surface roughness has emerged as a significant focus in research on dental biofilms, standing out among various surface characteristics [42]. Studies have consistently shown that the surface roughness of prosthetic restorations is a key factor in bacterial retention. Rougher surfaces tend to facilitate bacterial adhesion by providing a larger contact area, while smoother surfaces are more effective in minimizing biofilm development [43]. Polishing zirconia is strongly recommended, as finishing and polishing procedures enhance aesthetics, reduce surface irregularities, and improve biocompatibility by minimizing bacterial adherence and biofilm formation [40,44]. Surface roughness values (Ra) exceeding 0.2 µm can encourage plaque accumulation, leading

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to gingival inflammation, secondary caries, gingivitis, and halitosis [45]. Conversely, Ra values ≤ 0.2 µm result in minimal biofilm buildup and provide a smoother tactile sensation. Furthermore, Ra values starting from 0.3 µm can be detected by the patient's tongue [46]. However, the exact impact of surface roughness on bacterial adhesion and biofilm development is also influenced by factors such as bacterial cell size and other contributing variables [42]. Notably, bacteria adhere in a similar manner to both natural teeth and dental restorations. Bacterial adhesion to dental materials, followed by the formation of biofilms, represents a complex and multifactorial process that begins with the initial attachment of bacteria to dental surfaces. This can be categorized into four primary phases within the oral cavity: the formation of an acquired pellicle, reversible adhesion, irreversible adhesion followed by co-adhesion, and culminating in the growth of a mature biofilm [42,47]. The interaction of oral surfaces with this acquired pellicle directly influences initial bacterial adhesion and subsequent biofilm development [42]. The phase of initial bacterial adhesion to the tooth's surface is considered the critical step in plaque formation. Rougher surfaces show greater initial bacterial accumulation since surface irregularities shield microorganisms from muscular action, salivary flow, and brushing. These conditions allow bacteria to establish firm attachment by interacting more robustly with the surface [48]. Similarly, insufficient polishing of monolithic zirconia restorations can lead to increased bacterial colonization and biofilm formation on prosthetic surfaces. An in vivo study examining initial bacterial adhesion to various implant materials observed that early biofilm formation, occurring within 30 to 120 minutes of oral exposure, predominantly relies on the surface topography of the material, even when covered by a salivary- acquired pellicle. Surfaces with a high level of polish were found to significantly reduce biofilm accumulation, plaque formation, and the likelihood of peri-implantitis [39]. Recent research has highlighted the variability in surface roughness achievable through various polishing techniques, noting that the results are heavily dependent on the material type. Attaining a surface roughness (Ra) value of ≤ 0.2 µm is critical, particularly for zirconia due to its inherent hardness, which necessitates specific treatment methods [49]. An in vitro investigation evaluating the initial bacterial adhesion on resin, titanium, and zirconia surfaces revealed that resin exhibited the highest surface roughness and significantly greater adherence of Streptococcus sanguis when compared to titanium and zirconia, despite all materials undergoing identical polishing procedures. In contrast, the study found no significant difference in bacterial adhesion between titanium and zirconia. [50]. Another study investigating the effects of surface modifications on bacterial attachment to implant abutment materials confirmed that insufficient polishing creates rougher surfaces that encourage microbial adhesion on both titanium and zirconia. In contrast, thorough sequential polishing to achieve a smooth finish effectively minimizes bacterial colonization on these materials. Zirconia demonstrated lower microbial adherence compared to titanium in this context [51]. Although these findings offer valuable insights, only in vivo investigations can yield a thorough understanding of the practical effectiveness of surface treatments in mitigating bacterial adhesion within clinical environments.

Zirconia wear and abrasiveness

Prosthetic materials are defined by particular properties related to hardness and durability. Ideally, they should offer excellent resistance to wear while minimizing abrasiveness. Within this scope, 3Y-TZP zirconia has been the focus of numerous studies in the literature [52]. The high wear resistance of this material has been consistently demonstrated in both clinical and laboratory studies [53]. Another important factor to evaluate when selecting prosthetic materials is hardness [54]. Monolithic Y-TZP restorations, with a Vickers hardness of roughly 12 GPa, have sparked discussions about their potential abrasiveness on opposing teeth, whether natural or prosthetic. However, clinical investigations into this matter have not provided clear conclusions. Some studies have shown that the wear on natural enamel caused by monolithic zirconia can be similar to, or even greater than, the wear produced by enamel-to-enamel contact [35,55-56]. However, properly polished zirconia surfaces show a lower degree of abrasiveness than other ceramic materials commonly used in dental prosthodontics. In particular, monolithic zirconia has been shown to be less abrasive to enamel than feldspathic ceramics, lithium disilicate, and metal-ceramic restorations [35,53,57-60]. Moreover, polished zirconia is less abrasive to opposing teeth than the glazed version [61]. Additionally, polished monolithic zirconia causes less enamel wear when compared to zirconia-ceramic systems [4]. Other studies emphasize that both zirconia and lithium disilicate should be polished after any modifications to ensure compatibility with enamel wear. Ceramic veneering on occlusal surfaces should be avoided to minimize wear on natural enamel [62]. Zirconia is less abrasive compared to feldspathic ceramic due to its ability to retain a smooth surface during use. In contrast, feldspathic ceramic develops an increasingly irregular surface over time, which makes it more abrasive. Furthermore, zirconia is considered a material that preserves antagonist enamel health even after simulated aging [63]. An in vitro study investigating the wear and abrasion properties of monolithic zirconia and other CAD/CAM ceramics highlights that monolithic zirconia demonstrates superior wear resistance and minimal abrasiveness toward opposing teeth. In contrast, glass ceramics tend to be more abrasive to natural enamel [64]. Additional research comparing the abrasiveness of various prosthetic materials (including zirconia, glass ceramics, advanced polymers, and dental composites) indicates that materials with higher strength and fracture toughness generally exhibit reduced abrasiveness to opposing teeth [65,66]. However, while earlier studies reported lower wear rates on antagonist enamel with monolithic zirconia compared to lithium disilicate, more recent findings suggest comparable levels of wear for both materials when assessed against natural teeth [67]. Another study supports the use of monolithic zirconia crowns, citing the greater wear caused by alternative dental ceramics [68]. On the other hand, some researchers caution that zirconia may lead to microstructural enamel defects despite causing less

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volumetric enamel loss [69]. Moreover, polished monolithic zirconia has been found to potentially increase the risk of enamel microfractures [70]. The effect of occlusal adjustments on the abrasiveness of monolithic zirconia restorations, and the importance of polishing, must also be highlighted [10,18,71]. A recent in vitro study on translucent zirconia recommended optimal surface polishing after occlusal adjustments to prevent increased wear on the antagonist [72]. The issue of monolithic zirconia abrasiveness after polishing is complex and highly debated, influenced by numerous variables that require further investigation. Available studies highlight significant differences in prosthetic surface treatment protocols (e.g. polishing or glazing), the types of zirconia analyzed and the methodologies employed [59]. The influence of zirconia's yttria content on the wear of natural antagonist enamel has yet to be clearly understood. A recent investigation focused on the wear characteristics associated with polished opaque and translucent zirconia crowns, demonstrating that both materials can lead to progressive enamel wear over time. Importantly, the findings indicate that these zirconia crowns induce greater abrasion on opposing enamel surfaces compared to the wear observed in natural enamel-to-enamel interactions [73]. Among the various types of zirconia, highly translucent materials characterized by an elevated yttrium oxide content demonstrate wear resistance on par with traditional high-strength zirconia. Additionally, these materials exhibit lower abrasiveness compared to glass ceramics [74]. It is crucial to acknowledge that intraoral wear constitutes a complex phenomenon influenced by an interplay of physical, chemical, and biological factors. The severity of wear is significantly influenced by factors like the location of the restoration (occurring more often in molars than premolars), gender variations (less prevalent in women), and the presence of parafunctional habits in patients. A thorough understanding of this issue can only be achieved through in vivo research. [56,75]. Additionally, saliva plays a crucial role in mitigating friction and minimizing tooth surface wear during chewing by serving as an effective natural lubricant [18]. Another notable concern is the surface degradation of monolithic zirconia upon exposure to the oral environment. This degradation can lead to increased surface roughness, the formation of micro-fractures, and heightened wear on opposing teeth [28,74,76]. The susceptibility to these effects varies across different types of zirconia. Specifically, 4Y-PSZ and 5Y-PSZ zirconia, characterized by higher concentrations of yttrium oxide and cubic phase structures accounting for 25% and 50% respectively, exhibit diminished susceptibility to ageing-related degradation and lower abrasiveness. Conversely, 3Y-TZP zirconia demonstrates heightened vulnerability to low-temperature degradation (LTD), thereby increasing its potential for wear and abrasion [26]. Research suggests that the abrasiveness of monolithic zirconia tends to increase with aging, irrespective of its surface finish, adversely affecting its surface roughness and mechanical properties. While a glaze layer can mitigate the LTD process, it is subject to deterioration, which may intensify the material's abrasive nature [77]. Recent findings reveal that high-speed sintering of monolithic zirconia can significantly increase wear on opposing enamel, recommending conventional sintering methods as a preferable alternative for reducing such effects [78]. In conclusion, current evidence suggests that well-polished zirconia achieves an optimal equilibrium between wear resistance and reduced abrasion to opposing dentition. Nonetheless, additional clinical and laboratory investigations are warranted to enhance our comprehension of advanced zirconia materials and to further optimize their functional properties.

Structural and mechanical implications of grinding zirconia restorations

The phase transformation in the crystalline structure of zirconia resulting from surface adjustment procedures has been a subject of extensive investigation in the scientific literature, largely owing to its potential impact on the mechanical performance and durability of prosthetic restorations [79,80]. Several studies have utilized X-ray diffraction (XRD) as a central technique to explore this phenomenon [18]. Clinical adjustment procedures for monolithic zirconia restorations not only result in surface defects and microcracks but also generate localized heat and frictional forces within the crystal structure. The introduction of external energy may trigger an asymmetric transformation from the tetragonal phase to the monoclinic phase (T-M), potentially affecting the material's mechanical properties [79,80]. Phase transitions are closely linked to the grinding process and have garnered significant attention due to their potential mechanical benefits in certain materials, such as 3Y-TZP zirconia. This phenomenon, known as phase transformation toughening (PTT), is thought to facilitate the development of a homogeneous protective layer on the surface subjected to treatment. This layer not only impedes crack propagation but also significantly improves the material's overall mechanical strength [81]. Other research emphasizes that although phase transformations might pose challenges in aging scenarios, they do not necessarily undermine material strength and can, in some cases, be beneficial [82]. Additional findings suggest that the emergence of a monoclinic phase following grinding and polishing may actually enhance material strength instead of diminishing it [14,18]. Nevertheless, some researchers argue that the benefits of surface toughening achieved through adjustment procedures might be offset by the generation of surface defects, depending on their size and depth [9]. Critical defects and microcracks function as stress concentrators under applied loads, thereby diminishing flexural strength and adversely influencing the clinical prognosis of rehabilitation [32,34,83]. A recent study exploring the flexural strength of monolithic zirconia following various surface treatments reveals that grinding can significantly diminish the strength and durability of zirconia restorations [84]. Additional investigations indicate that chairside modifications using diamond instruments substantially reduce the biaxial flexural strength of zirconia, irrespective of the material's yttria content [33]. Furthermore, it has been observed that grinding zirconia continuously with a high-speed micromotor results in a relatively smaller decrease in flexural strength [85]. Despite this, all adjustments to zirconia should be performed with care to limit negative impacts [86]. It is particularly recommended to avoid the use of

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tungsten carbide burs (6- and 8-blade) for zirconia processing, as these tools can cause a marked reduction in both biaxial flexural strength and the integrity of the surface and subsurface microstructure [87]. Discussions around grinding and its effects on the mechanical strength of zirconia restorations underscore critical considerations in restoration design. New multilayer materials that feature 5Y-TZP zirconia on the occlusal surface exhibit weaker mechanical properties when compared to other zirconia variants, emphasizing the importance of restoration thickness. To mitigate structural issues that may arise from frequent grinding in posterior regions, it is recommended to design restorations with occlusal thicknesses exceeding the minimum guidelines established in existing research. For areas experiencing high functional stress, maintaining a thickness of at least 1.5 mm is advised to ensure durability and performance [23].

Polishing effects on zirconia restorations

During adjustments, the grinding phase must be followed by the polishing phase. This serves two primary purposes: minimizing the size of defects and microcracks, and reducing both the depth of phase transformation and the amount of monoclinic phase induced by the grinding process [18]. Polishing restores the surface roughness of zirconia to acceptable Ra values and improves the material's flexural strength [14]. Therefore, polishing plays a key role in restoring the mechanical properties of monolithic zirconia restorations [10]: the strength values of zirconia are restored by removing surface defects during the polishing treatment. This process eliminates stress concentration sites and releases the high compressive stresses induced by grinding [18]. Recent research has revealed that as-sintered zirconia exhibits significantly lower flexural strength values compared to highly polished zirconia, particularly when polished using chairside systems [88]. Moreover, another study found that, unlike glazing, polishing not only enhances flexural strength but also avoids causing any significant detrimental effects [89]. Additional in vitro findings demonstrated that translucent zirconia restorations achieve the highest flexural strength and minimal wear when their surfaces are properly polished [72]. Furthermore, the T-M phase transformation induced by the preliminary grinding phase can be partially eliminated through adequate polishing of the affected surface. While the monoclinic phase is commonly observed on the zirconia surface after grinding, its presence can be significantly reduced using a dedicated polishing kit [18,90-91]. Careful polishing using fine-grained tools proves highly effective in eliminating the monoclinic phase from the ground surface, a result that is challenging to achieve with coarse- or medium-grained tools [90]. This indicates that the monoclinic phase can be removed by optimizing the polishing process. The process works by eliminating the layer affected during grinding without reversing the phase transformation. Typically, proper polishing can reach the depth of the transformation zone [18]. Studies on different types of monolithic zirconia suggest that this mechanism is observed, to varying degrees of significance, exclusively in 3Y-TZP [80,83]. This surface mechanism is not detectable on 4Y-TZP and 5Y-TZP zirconia, which are respectively slightly and not susceptible to phase changes induced by surface treatments [92,93]. This is attributed to the high cubic phase content in these materials, which precludes T-M transformation [21,23]. While polishing protocols increase strength and toughness, they nevertheless lead to a decrease in zirconia hardness [94]. Conversely, tribological behavior and wear resistance improve with polishing [52]. In terms of optical properties, clinical adjustments achieved through polishing have been found to decrease the translucency of multilayered zirconia. Nevertheless, this alteration remains below the threshold of clinical detectability [13]. Studies examining the impact of different finishing and polishing techniques on zirconia restorations of varying thicknesses have demonstrated that the optical properties of these ceramics are affected by factors such as the type of material, its thickness, and the surface treatment methods employed [95]. Additional research focusing on monolithic zirconia highlights that polishing procedures exert differential effects on the material depending on its shade. While polishing contributes to a reduction in surface roughness, it simultaneously can also diminish the material's brightness [96].

Zirconia glazing

Following adjustment, the zirconia surface can be treated using various techniques, primarily polishing, as outlined earlier, or glazing. The decision between these methods typically hinges on factors such as material characteristics, costs, and time constraints [97]. Glazing involves applying a very thin layer of glass-ceramic to a modified restoration before cementation and is a relatively simple way to achieve a smooth surface, making the restoration brighter and reducing roughness [91,93]. However, glazing has recently been called into question and is now considered the least advantageous choice for a number of reasons. Several studies have demonstrated reduced fracture resistance in glazed zirconia, as well as less favorable Ra values compared to polishing [14,91,98]. Unlike polishing, glazing does not restore flexural strength after grinding the restoration's surface [14]. The application of a glass-ceramic layer may help fill grooves and defects on the freshly ground zirconia surface. However, the required additional firing stage can undermine the toughening effect achieved through occlusal adjustment, especially in 3Y-TZP, by inducing a reverse phase transformation (M-T) [81,93]. Moreover, an additional glazing firing step may increase the grain size of the structure as a consequence of the thermal procedure, thereby worsening the mechanical behavior [99]. Recent studies have examined a range of finishing techniques for Y-TZP ceramics following adjustments. Researchers emphasize the importance of polishing after grinding, noting that depending only on glazing or thermal treatments often leads to compromised mechanical performance [92]. Additionally, newer findings suggest that polishing is more effective than glazing in mitigating microstructural degradation [100]. Another study reinforces the idea that although glazing can reduce the material's strength, polishing ground surfaces offers a more

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advantageous alternative [84]. While glazing continues to be a reliable technique, intraoral polishing kits for zirconia have been shown to achieve satisfactory surface properties [101]. A comparative analysis examining the effects of glazing and polishing on zirconia ceramics with different translucency levels demonstrated that the polishing process improves surface characteristics, with only a marginal influence on the material's mechanical performance [102]. Recent studies indicate that polishing systems for zirconia present a viable alternative to re-glazing in the context of monolithic restorations. This evidence underscores the effectiveness of polishing as a finishing procedure for enhancing the physical properties of zirconia while preserving its mechanical integrity [103]. Research into the fracture resistance of monolithic zirconia further supports the adoption of surface polishing, advising against the use of glazing and heat treatments [5]. A critical factor to consider is the influence on wear dynamics: polished surfaces are less likely to induce significant wear on opposing materials compared to glazed surfaces [30]. Some researchers suggest that glazing may contribute to increased wear, whereas polishing can improve mechanical properties and help protect opposing surfaces [97]. Furthermore, numerous studies indicate that highly polished zirconia leads to reduced overall wear, particularly minimizing its impact on antagonistic surfaces. On the other hand, glazed zirconia tends to exhibit significantly greater abrasiveness compared to polished zirconia [104]. Glass-ceramic glazes and zirconia materials frequently face challenges in achieving compatibility because of their differing chemical characteristics, which increase the likelihood of chipping and delamination. Discrepancies in thermal expansion coefficients (CTE) and thermal diffusivity are primary factors causing substantial residual stress, ultimately resulting in the cohesive failure of glass-ceramics [105]. Moreover, glazed layers tend to wear away relatively quickly during use, further limiting their durability [9]. In terms of optical properties, recent studies indicate that surface finishing techniques play a crucial role in determining the color and translucency of monolithic zirconia materials. Glazing has been found to cause greater color variations and lower translucency compared to polishing [106]. Additionally, glazing proves less practical for chairside adjustments, making chairside polishing a more cost-effective and efficient alternative.

Polishing methods

An effective and well-structured polishing protocol is indispensable for managing chairside adjustments efficiently. While the market offers a broad range of highly specialized laboratory and chairside polishing systems tailored to various ceramic materials, the sheer abundance of options often creates uncertainty about which protocols yield optimal outcomes. Among the recent advancements in ceramic polishing tools is the emergence of polishing kits specifically designed for zirconia. However, despite the increasing prevalence of zirconia restorations in clinical practice, the adoption of these specialized zirconia polishers has remained relatively low [10]. Current research highlights that zirconia polishing systems demonstrate superior performance compared to those developed for other ceramic materials, particularly in terms of achieving lower surface roughness (Ra) values and enhancing surface topography [80,107]. A recent study underscores that zirconia polishing systems consistently delivered the lowest surface roughness among all tested ceramic materials. Additionally, these systems did not result in any significant gravimetric weight loss, irrespective of the type of ceramic used [108]. Numerous zirconia polishing protocols have been examined in the literature [79-81]. Offering definitive recommendations remains difficult due to the wide variety of available products and sometimes inconsistent findings. The surface roughness of monolithic zirconia is significantly influenced by the polishing method utilized. As mentioned previously, the grinding phase initially increases Ra values, which are then lowered during the subsequent polishing process [79]. Recent research has demonstrated that polishing consistently improves surface morphology and decreases surface roughness in zirconia after grinding, irrespective of the polishing kit employed [109]. Among the most commonly accessible grinding and polishing tools are diamond burs and a range of diamond-infused rubbers. Grinding burs are crafted with high-density natural or synthetic diamond grit, offered in different sizes and shapes. Their performance and cutting efficiency depend on several factors, including the size and quality of the diamond particles, the hardness of the bonding material, and the tool's precision and concentricity [79-81]. A study investigating the influence of various grinding burs on the physical properties of zirconia revealed that employing grinding tools specifically engineered for zirconia significantly decreases grinding time while maintaining its flexural strength. This makes such burs a highly efficient option for zirconia processing. However, subsequent fine polishing remains essential to minimize surface roughness generated during the grinding phase [110]. Furthermore, another study focused on the effects of different finishing and polishing techniques on the surface characteristics, phase transformation, and flexural strength of ultra-translucent zirconia identified diamond rubber polishers as the most effective approach for achieving optimal outcomes in zirconia ceramic restorations [81]. Among the available polishing tools, abrasive diamond rubbers are the most prevalently used for monolithic zirconia. These tools incorporate diamond particles of varying grain sizes along with other oxides, such as Al_2O_3 and TiO_2, to produce favorable results in terms of surface morphology and fracture resistance [79-81]. Several researchers advocate the use of extra-fine diamond burs for preliminary finishing prior to the polishing process. However, this practice remains contentious as others argue that incorporating additional steps with diamond finishing burs after initial grinding may further compromise the integrity of zirconia surfaces. Such steps could exacerbate surface defects and lead to a reduction in the material's flexural strength [14]. Evidence suggests that employing a stone grinding bur for initial coarse finishing yields advantageous outcomes, particularly when followed by the use of a diamond bur. In fact, this combination (stone grinding bur coupled with silicone polishing burs) has been shown to significantly decrease final Ra and mitigate bacterial biofilm formation on roughened surfaces resulting from

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diamond burs [111]. Further investigations have identified the optimal protocol for finishing ultra-translucent zirconia, highlighting the use of diamond rubber polishers while cautioning against coarse-grit diamond burs [112]. Polishing systems incorporating diamond particles have been shown to improve surface smoothness and minimize the roughness of monolithic zirconia more effectively than silica carbide systems. Following the manufacturer's guidelines is essential to ensure the appropriate abrasive particle size is applied [113]. Numerous studies in the literature highlight the application of diamond pastes, primarily consisting of diamond granules (1-6 µm) combined with other fine oxides such as anatase (TiO_2), corundum (Al_2O_3), zinc oxide (ZnO), and pumice (SiO_2), as effective abrasive agents during the polishing process [10]. Some investigations suggest that an additional step using fine polishing paste after standard polishing can significantly reduce the surface roughness of dental ceramics, achieving a finish comparable to that of glazed surfaces [114]. Other research underscores the efficacy of a two-step method, involving the use of a zirconia polishing kit followed by a fine-grain polishing paste, particularly for zirconia restorations and other ceramics like lithium disilicate and feldspathic ceramics [9]. However, one in vitro study reported that polishing with diamond paste did not result in a significant improvement in the surface roughness of either monolithic or layered zirconia [115].

Polishing variables

The effectiveness of polishing can be influenced by a variety of factors [9,116], including the type of zirconia being polished, which determines the properties of the substrate; the difference in hardness between the abrasive and the substrate; the size and shape of abrasive particles; the durability of the bonding material in the abrasive; the presence of lubrication during the polishing process; as well as variables such as the number of passes, polishing speed, and applied pressure. While several studies have investigated polishing protocols, clear and standardized guidelines regarding crucial aspects like tool selection, abrasive characteristics, polishing pressure, and time still remain absent. However, certain criteria can help operators make informed choices when selecting and utilizing tools for monolithic zirconia. Employing an appropriate polishing kit ensures effective chairside polishing, regardless of the operator's skill level [117]. A recent study underscores the importance of utilizing a polisher correctly, taking into account its stages, binder, and essential application factors such as rotation speed and movement. This approach significantly improves surface smoothness, gloss, and color uniformity. Additionally, employing a step-by-step method with burs and polishers for precise zirconia adjustments proves effective in maintaining its surface integrity and optical qualities [86]. High-speed handpieces are commonly employed in the initial phase of occlusal or axial grinding of monolithic restorations. These utilize diamond burs specifically designed for zirconia, available in varying grain sizes (coarse, medium, and fine). The burs feature a higher density of diamond particles compared to standard options and operate at approximately 200,000 rpm. The process is typically performed under continuous water cooling for about 10 to 15 seconds [29,79-81]. For grinding dental zirconia, it is advisable to avoid tungsten carbide burs [10,118]. Diamond grinding does not compromise the strength of zirconia; however, additional polishing is necessary [118]. A recent study found that grinding protocols significantly influenced surface characteristics and induced phase transformation in Y-TZP. Despite these changes, the material's mechanical performance remained unaffected. Using medium and fine diamond rotary instruments for grinding and finishing (whether with a high-speed handpiece under constant water cooling or a slow-speed handpiece without water cooling) has been identified as a reliable and safe approach [119]. Additionally, some researchers observed that clinical adjustments to zirconia pieces yield smoother surfaces when finer-grit diamond burs are employed [120]. Others recommend incorporating a stone grinding bur either as an alternative to diamond burs or as a subsequent step during the grinding process, which can substantially lower final Ra values [111]. A low-speed handpiece should be used for the finishing and polishing stages. Some studies have found optimal shine and Ra values with instruments used at 15,000 rpm, others at 12,000 rpm and below [29,79-81,121-122]. Dental practitioners must exercise meticulous judgment when choosing polishing systems and determining operational speeds to avoid potential pulp injury during the intraoral polishing of Y-TZP restorations. Recent research has demonstrated that high-speed polishing, particularly at 20,000 RPM, generates the highest levels of heat, surpassing the critical temperature increase of 5.5°C that could jeopardize pulp vitality. These findings underscore the necessity of employing a prudent and controlled technique when conducting high-speed intraoral polishing procedures [116]. A step-by-step surface treatment process for monolithic zirconia, combined with the careful selection of polishing systems, plays a vital role in attaining optimal microstructural and biological surface properties [123]. Generally, most polishing protocols rely on the sequential use of two or three tools. In most instances, these tools are diamond-impregnated silicone rubbers with progressively finer grain sizes (coarse, medium, and fine). For the process to yield effective results, it is essential to follow the proper sequence of instrument use as specified by the manufacturer [124]. Typically, two- and three-step polishing protocols are employed in practice [34,79-80,121]. Research indicates that the two-step procedure yields results comparable to the three-step approach, with both methods achieving adequate surface roughness (Ra) values. For instance, one study demonstrated that an Ra value of 0.2 µm can be attained on zirconia by utilizing a protocol based on coarse and medium rubber abrasives [125]. Nevertheless, despite the absence of statistically significant differences, three-step polishing tends to produce slightly lower Ra values [124,126]. Moreover, several investigations suggest that increasing the number of polishing steps leads to smoother surfaces with reduced roughness, an effect further enhanced by the application of polishing paste [90,127]. In a clinical setting, application forces should ideally be around 1 N and should not exceed 2 N (equivalent to 100-200 g of pressure) [29,122,126]. However, limited data is

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available regarding polishing and finishing techniques for zirconia surfaces, particularly concerning the influence of varying application forces. An in vitro study demonstrated that differences in Ra values, as measured by optical profilometry, arise from the use of different polishing forces [122]. Some researchers suggest that higher pressure leads to increased surface roughness due to the deeper cutting depth of abrasive particles. Conversely, insufficient pressure during polishing might fail to adequately remove deeper grooves left by the grinding process, thereby reducing the overall effectiveness of polishing [18]. The use of instruments, the standardization of applied forces, and the criteria for reuse are key areas that require deeper exploration. Research on polishing has mainly concentrated on 3Y-TZP ceramics, which exhibit superior mechanical strength compared to newer 4Y-TZP and 5Y-TZP substrates. Recent studies on grinding and polishing different types of zirconia have shown that polished zirconia surfaces can achieve clinically acceptable levels of roughness. Additionally, variations in yttrium oxide content seem to have minimal impact on surface roughness. As a result, zirconia polishing burs have proven effective for clinical use regardless of the material's yttrium oxide concentration [128]. However, other investigations simulating clinical adaptation and polishing procedures for two types of translucent zirconia revealed that a higher concentration of dopants, aimed at increasing translucency, also raises the material's susceptibility to surface damage. This factor makes it more challenging to polish ground translucent zirconia compared to traditional 3Y-TZP zirconia [129]. Despite these advancements, further research is crucial to devise optimized polishing protocols for contemporary zirconia materials, including multilayered options [130].

Conclusion

The introduction of multilayer zirconia has broadened the use of monolithic zirconia restorations, highlighting the importance of proper polishing. Chairside adjustments are routine during restoration delivery, but they can alter zirconia's surface microstructure, potentially affecting strength. These changes depend on the zirconia's crystallographic composition. Effective polishing restores surface quality, prevents cracks, reduces bacterial adhesion, and enhances durability, with optimal Ra values under 0.2 µm. Clinicians are advised to adhere strictly to protocols specifically designed for zirconia, following the manufacturer's guidelines carefully. Begin grinding with fine-grit diamond burs (30-50 µm) at high speeds ranging from 160,000 to 200,000 rpm, applying light pressure of 1-2 N and ensuring adequate water irrigation throughout. To prevent damage, the use of carbide or coarse-grit burs, as well as dry grinding, should be avoided. After grinding, an intermediate step using extra-fine diamond burs (≤30 µm) or stone burs at high speed with water is recommended to eliminate scratches and prepare for polishing. Polishing uses zirconia-specific rubber polishers with medium and fine grit at low speeds (10,000-12,000 rpm) with light pressure (≤1 N), applied either dry or with minimal water. For a high-gloss finish, an ultra-fine rubber polisher and diamond polishing paste (1-6 µm), delivered via felt wheels or goat hair brushes, can create a glaze-like surface with light pressure, typically performed dry. Streamlined polishing protocols now offer reliable outcomes across zirconia types. However, advances in zirconia materials and diverse market options call for further research to optimize these procedures.

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