Original Article

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Effect of Surface Finish and Different Immersion Media on Fracture Toughness of Vita-Lumex Veneering Zirconia

(An In Vitro Study)

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Abstract:

Aim: To investigate the impact of finishing protocols and different immersion media on the fracture toughness and hardness of a recently introduced leucite-reinforced, glass-ceramic veneering material for zirconia restoration. **Material and Methods:** Fifty-four square-shaped zirconia specimens (10×10×1)mm were fabricated with a 1-mm layer of leucite-reinforced veneering material and adjusted using 40-µm diamond grinding stones to simulate occlusal adjustments. Specimens were randomly assigned to two groups based on their surface finish: polished and glazed. Specimens were further randomized into three subgroups based on the immersion solution: coffee, citric acid, and artificial saliva. Specimens were immersed in 5 mL of the solutions at 37°C for incubation, with coffee and artificial saliva groups immersed for 14 days and citric acid for 8-hours simulating two years of clinical use. Surface microhardness was evaluated using a Vickers microhardness tester, followed by fracture toughness evaluation through the indentation technique. **Results:** Artificial saliva exhibited no significant difference in fracture toughness, but demonstrated significantly higher surface microhardness compared to the other immersion media. Regarding finishing protocol, no statistically significant difference in hardness or fracture toughness was observed for the leucite-reinforced veneering material. **Conclusion:** The findings of this study suggest that immersion in acidic media, such as coffee and citric acid, can negatively impact the microhardness of zirconia veneered with leucite-reinforced ceramics. Since there were no statistically significant differences in fracture toughness between polished and glazed specimens, polishing can be considered a viable alternative to glazing for improving the surface finish of dental ceramics, potentially offering a more time- and cost-effective approach.

Keywords: Acidic solution,Fracture toughness, Microhardness, Leucite-reinforced, Glass-ceramic.

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Introduction:

In recent years, there has been a significant increase in patient demand for esthetic dental restorations, leading to a shift towards zirconia-based restorations as an alternative to traditional metal-fused to porcelain options.[1]Zirconia is favoured for its outstanding flexural strength and excellent biocompatibility. However, the inherent opacity of zirconia may limit its monolithic use in certain esthetic applications.[2]

While recent advancements in zirconia formulations have resulted in enhanced translucency, its inherent opacity still poses limitations for achieving optimal esthetic in monolithic restorations. To attain more lifelike and esthetically pleasing results, the application of a veneering ceramic layer remains necessary.[3]Feldspathic porcelain, leucite-reinforced ceramics, and fluorapatite ceramics are the commonly utilized materials for veneering. Veneering techniques typically involve either a layered approach or a press-on method.[2]

Bilayered restorations mitigate some of zirconia's limitations by combining its inherent strength and low thermal conductivity with the enhanced esthetic of high-translucency ceramics in an outer layer.[4]Moreover, advancements in the processing techniques of zirconia, such as improved surface treatments and bonding protocols, have further enhanced the reliability and longevity of bilayered restorations, making them a popular choice in contemporary restorative dentistry.[5]

The long-term success of bilayered zirconia restorations relies on the integrity of the veneering ceramic, as chipping and fracture remain significant clinical concerns. Fracture initiation and propagation in these restorations are often attributed to microcracks induced by occlusal loading, wear, and material fatigue. The clinical performance of zirconia-based restorations is critically influenced by factors such as veneering technique, core design, and the mechanical properties of the veneering ceramic.[6]

Given the susceptibility of veneering ceramics to fracture, enhancing their mechanical strength is paramount for improving the long-term clinical success of zirconia-based restorations. [6]Fracture toughness, a critical mechanical property for dental materials, quantifies their resistance to crack propagation. It serves as an important parameter in material selection, design considerations, flaw tolerance assessment, and overall quality control.[7]

Surface finishing techniques, including polishing and glazing, can significantly influence the surface characteristics and, consequently, the fracture toughness and long-term durability of dental ceramics. Furthermore, exposing the restoration to various immersion media, which simulate the complex oral environment, may further impact the mechanical properties of the material.[9], [10]

Hence, the aim of this study was to investigate the impact of finishing protocols and different immersion media on the fracture toughness and microhardness of a recently introduced leucite-reinforced, glass-ceramic material as a veneering material for zirconia. Understanding the relationship between surface finishing techniques and immersion media is essential for predicting the long-term clinical performance and longevity of VITA LUMEX AC restorations. This research aims to identify key factors that influence durability, ultimately providing valuable insights for optimizing their clinical utilization.

Material and methods:

Specimen Size Calculation

A power analysis was conducted to ensure adequate statistical power to detect significant differences between the study groups, if they existed. Specimen size calculation was performed using G*Power software with an alpha level of 0.05, a power of 80% ($\beta = 0.2$), and an effect size (f) of 0.516, as determined based on the results of a previous study by **Choi et al. (2012)**[11]; A total of 54 specimens (27 per group and 9 per subgroup) were included in the study. Sample size was determined using G*Power version 3.1.9.7.

Specimen Preparation

Within the scope of this research, a Ceramill Zolid HT^{+} disc (AMANN GIRRBACH AG, Maeder, Austria), characterized by its specific shrinkage factor, was integrated into the Computer-Aided Manufacturing (CAM) software. A cubic block measuring 12.3 × 12.3 × 16 mm was designed using Blender 4.1 (Blender, New York, USA), exported as an STL file, and subsequently imported into the CAM software for optimal nesting within the virtual disc. Supporting sprues were incorporated into the design before the milling process, ensuring efficient placement of the cubic block within the milling blank.

Eight cubic blocks were fabricated using dry milling on a 5-axis CAD/CAM milling machine (CORiTEC 250i touch, imes-icore GmbH, Eiterfeld, Germany). Dimensional accuracy of the blocks was verified using a digital caliper (Digital Caliper TMT322006, Total Company, China). Zirconia blocks were mounted onto holders using cyano-acrylate adhesive and subsequently sectioned into 54 plates, each with a thickness of 1.25 mm, using a diamond saw (Buehler Isomet 4000, Buehler, USA). The accuracy of the resulting dimensions was verified using a digital calliper.

Sintering of the specimens on beads was conducted in a Tabeo sintering furnace (Mihm-Vogt GmbH & Co, Stutensee, Germany) according to the manufacturer's instructions. Post-sintering, dimensional accuracy was re-evaluated.

VITA LUMEX AC layers were applied using a mold to achieve a 0.7 mm dentine layer and a 0.3 mm enamel layer. A preliminary 0.2 mm layer of power wash material, mixed with a modulating liquid, was applied to enhance adhesion between the zirconia substrate and subsequent layers. This layer facilitated deeper light penetration, improving fluorescence and opacity.Schematic diagram of mold assembly for layering is shown in (**Figure 1**). The firing process was conducted in strict accordance with the manufacturer's guidelines in a Programat furnace (Ivoclar Vivadent Inc., Benderer Str· SchaanLiechtenstein, Germany).

A standardized 0.5 mm layer of dentin was meticulously applied to each substrate using a custom-designed mold. Subsequent to firing according to the manufacturer's protocol, each specimen underwent rigorous visual inspection for defects. Imperfections were corrected by applying additional layers as needed. Digital caliper measurements were utilized to ensure each layer thickness was accurate, ultimately achieving a final restoration thickness of 2 mm **(Figure 2).**

Specimen grouping

A total of 54 specimen were assigned unique sequential identifiers (1-54). To minimize selection bias, a computer-generated randomization table was obtained from (www.random.org) to randomly allocate the specimens into two distinct surface treatment groups. Each group was subsequently subdivided into three equal subgroups (n=9) based on the immersion solution. A schematic diagram illustrating specimen grouping is presented in **(Figure 3)**.

All specimens were ground using 40-µm diamond grinding stones to simulate intraoral occlusal adjustments.A standardized protocol was employed to ensure consistency, with a single operator performing all procedures and a standardized mold used to guide grinding location.

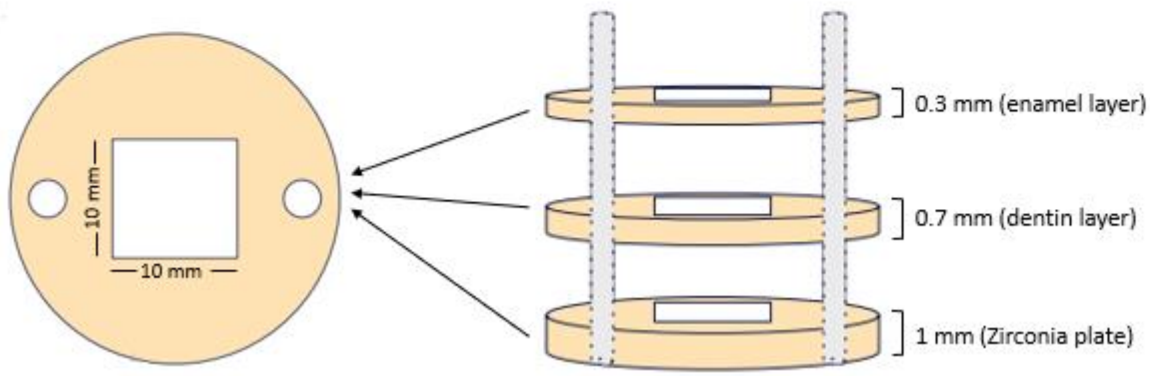

Figure 1: Schematic diagram of mold assembly for layering

Figure 2: The dimensions of each specimen were verified using a digital caliper,

A. After zirconia sintering; B. After dentin firing; C. After enamel firing.

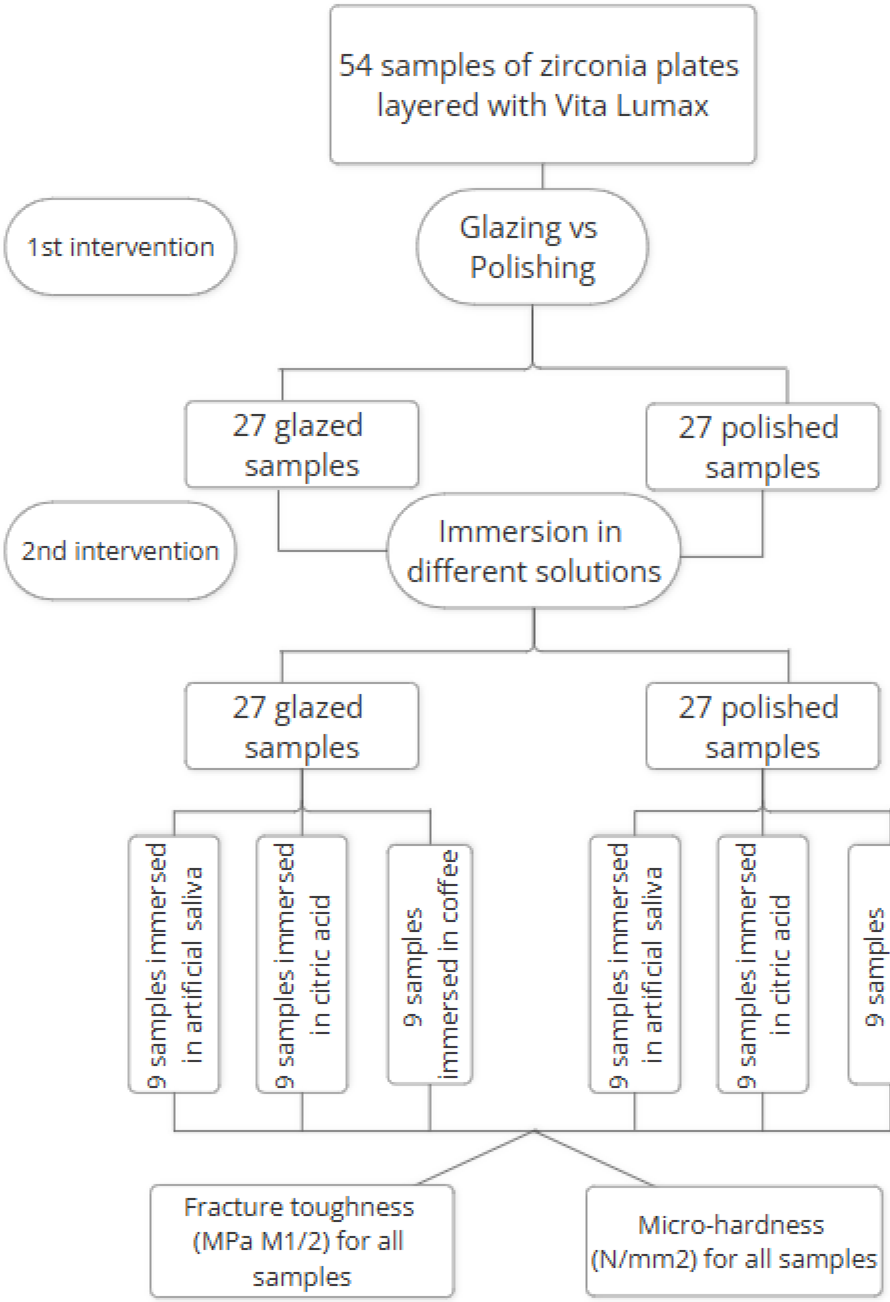

Figure 3: Schematic diagram showing group allocation and workflow

Finishing procedures:

1. Glazing procedure

Glaze firing was conducted following the manufacturer's recommended protocol (the sintering cycle commenced with an initial heating phase to 400°C, followed by a rapid temperature increase of 80°C per minute until reaching 750°C. A holding period of 1 minute at 750°C was followed by a gradual cooling phase to 500°C).

2. Polishing procedures

Polishing was accomplished using a three-step diamond-impregnated polishing system (EVE Ernst Vetter GmbH, Keltern, Germany) at 10,000 RPM under continuous water spray. This method produced a smooth surface finish without the need for subsequent glazing and is compatible with a range of ceramic materials.[12] To ensure consistent results, a standardized protocol was adhered to, including the use of a single operator for all procedures and a standardized mold to ensure consistent grinding locations.

Aging Procedures

The pH levels of coffee, citric acid, and artificial saliva were measured thrice with a pH meter (AD11 Waterproof pH-TEMP Pocket Tester with replaceable electrode Adwa Hungary Kft. 6726 Szeged, Alsó-Kikötő sor 11.C, HUNGARY) for accuracy. Each specimen group was sealed in containers and immersed in respective storage solutions. Artificial saliva was prepared following **Afzali et al. (2015)**[13]. Coffee solutions were prepared according to **Ribeiro et al. (2017)**[14]. Both solutions were replaced maintaining 48-hour replacement schedule simulating two years of clinical use. For citric acid immersion, specimens were incubated at 37°C for 8 hours, following **Demirel et al. (2005)**[15].

Micro-hardness measurements

Using a digital Vickers microhardness tester (Model HVS-50, Laizhou Huayin Testing Instrument Co., Ltd., China) equipped with a 20X objective lens and a Vickers diamond indenter surface microhardness was evaluated. The specimen surface was subjected to a static load of 200 grams for a standardized duration of time—20 seconds [16]**(Figure 4)**. To minimize measurement variability, three indentations were created on each specimen surface, strategically positioned in an equidistant circular pattern with a minimum inter-indentation distance of 0.5 millimeters to prevent interference.

Using a built-in scale microscope, the lengths of the indentation diagonals were measured, and the Vickers Hardness

Number was subsequently calculated using the established formula:**HV=1.854 P/d²**Where HV is Vickers hardness in kgf/mm², P is the applied load in kgf, and d represents the average length of the diagonal indentations in millimetres.

Figure 4: Vickers micro-hardness tester with diamond indenter

Fracture Toughness Measurements

Fracture toughness was assessed via the indentation technique, analysing crack formation around a Vickers diamond indenter under load.

The fracture toughness was calculated using : $k_{IC} = 0.016(E/H)^{0.5}(P\,/\,C^{1.5})$ where $K_{IC}$is the fracture toughness, C is the crack length measured from the centre of the indentation, P is the applied indenter load, H equal the Vickers hardness, and E is the elastic modulus.[17]

Statistical Evaluation

Data normality was assessed using the Shapiro-Wilk test and visual inspection of data distribution. All data were found to be normally distributed. Statistical analysis was performed using two-way ANOVA followed by simple effects comparisons to assess the interaction between factors. P-values were adjusted for multiple comparisons using the False Discovery Rate (FDR) method. Statistical analysis was performed using R statistical analysis software version 4.4.2 for Windows, with a significance level of $p < 0.05$.[18]

Results:

1. Fracture toughness

A. Effect of finishing protocol

Fracture toughness values for different finishing protocols are presented in **Table (1)** and (**Figure 5)**. Although glazed specimens exhibited slightly higher fracture toughness values in artificial saliva (2.39±0.06 MPa.m1/2) compared to polished specimens (2.26±0.28 MPa.m1/2), and polished specimens showed slightly higher values in coffee (2.29±0.18 MPa.m1/2) and citric acid (2.31±0.06 MPa.m1/2) compared to glazed specimens (2.25±0.07 MPa.m1/2 and 2.23±0.11

MPa.m1/2, respectively), these differences were not statistically significant across the immersion media ($p > 0.05$).

Table (1): Comparisons and summary statistics of fracture toughness (MPa.m$^{1/2}$) for different finishing protocols.

Immersion medium	Fracture toughness (MPa.m$^{1/2}$) (Mean±SD)		p-value
	Polishing	Glazing	
Artificial saliva	2.26±0.28	2.39±0.06	**0.108ns**
Coffee	2.29±0.18	2.25±0.07	**0.553ns**
Citric acid	2.31±0.06	2.23±0.11	**0.296ns**

ns not significant.

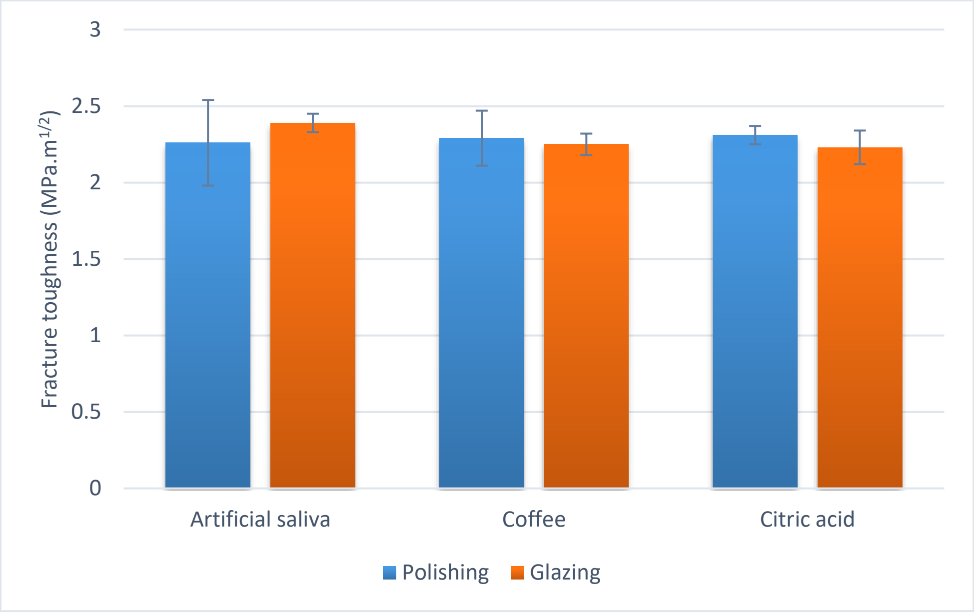

Figure 5: Bar chart showing mean and standard deviation (error bars) fracture toughness (MPa.m$^{1/2}$) for different finishing protocols

B. Effect of immersion medium

Table (2) and **(Figure 6)** present the comparisons and summary statistics of fracture toughness (MPa.m1/2) across different immersion media. Regardless of the finishing protocol (polishing or glazing), no statistically significant differences in fracture toughness were observed among specimens immersed in artificial saliva (2.26±0.28 MPa.m1/2 for polished, 2.39±0.06 MPa.m1/2 for glazed), coffee (2.29±0.18 MPa.m1/2 for polished, 2.25±0.07 MPa.m1/2 for glazed), and citric acid (2.31±0.06 MPa.m1/2 for polished, 2.23±0.11 MPa.m1/2 for glazed) ($p>0.05$ for both polishing and glazing groups).

Table (2): Comparisons and summary statistics of fracture toughness (MPa.$m^{1/2}$) for different immersion media.

Finishing protocol	**Fracture toughness (MPa.$m^{1/2}$) (Mean±SD)**			**p-value**
	Artificial saliva	**Coffee**	**Citric acid**	
Polishing	2.26 ± 0.28^{A}	2.29 ± 0.18^{A}	2.31 ± 0.06^{A}	**0.834ns**
Glazing	2.39 ± 0.06^{A}	2.25 ± 0.07^{A}	2.23 ± 0.11^{A}	**0.083ns**

Values with ***different superscripts*** *within the* ***same horizontal row*** *are significantly different, ns not significant.*

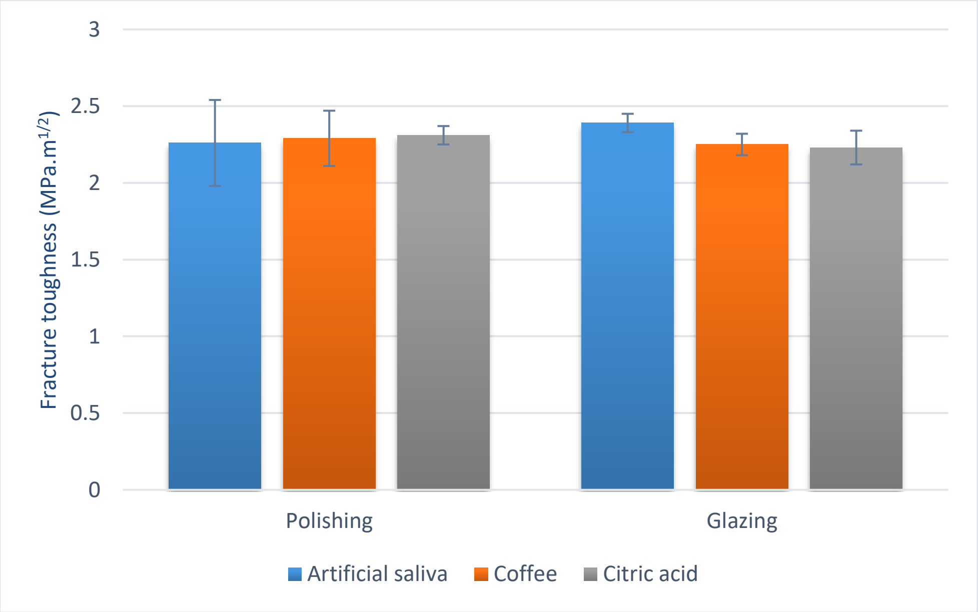

Figure 6: Bar chart showing mean and standard deviation (error bars) fracture toughness (MPa.$m^{1/2}$) for different immersion media

2. Hardness

A. Effect of finishing protocol

Regardless of the immersion medium, no statistically significant difference in surface hardness was observed between polished (artificial saliva: 412.71 ± 13.93; coffee: 408.16 ± 8.65; citric acid: 399.32 ± 8.32) and glazed specimens (artificial saliva: 412.35 ± 13.36; coffee: 405.58 ± 8.96; citric acid: 394.45 ± 6.90) ($p > 0.05$ for all comparisons).

B. Effect of immersion medium

Table (3) present comparisons and summary statistics of hardness for different immersion media. Regardless of the finishing protocol, specimens immersed in artificial saliva exhibited significantly higher surface hardness (412.71±13.93 for polished, 412.35±13.36 for glazed) compared to those immersed in citric acid (399.32±8.32 for polished, 394.45±6.90 for glazed) ($p < 0.05$ for both polished and glazed groups). Post-hoc pairwise comparisons revealed significantly higher surface hardness in specimens immersed in artificial saliva compared to those immersed in citric acid for both polished and glazed groups ($p < 0.001$).

Table (3): Comparisons and summary statistics of hardness for different immersion media.

Finishing protocol	Hardness number (Mean±SD)			p-value
	Artificial saliva	Coffee	Citric acid	
Polishing	412.71 ± 13.93^{A}	408.16 ± 8.65^{AB}	399.32 ± 8.32^{B}	**0.041***
Glazing	412.35 ± 13.36^{A}	405.58 ± 8.96^{AB}	394.45 ± 6.90^{B}	**0.005***

Values with **different superscripts** within the **same horizontal row** are significantly different,

* Significant ($p<0.05$).

Discussion:

The clinical longevity of dental restorations, especially in high-stress areas, is greatly affected by their mechanical properties, including hardness and fracture toughness.[19] Hardness is a crucial mechanical property of dental ceramics, contributing to their resistance to surface wear and abrasion, thereby enhancing their longevity and esthetic appeal. Materials with lower surface hardness are more susceptible to wear and abrasion, which can accelerate surface degradation and potentially compromise the long-term survival of dental restorations. In this study, Vickers microhardness testing was employed to assess the hardness of the investigated leucite-reinforced glass ceramic.[20]

Fracture toughness, a critical parameter for evaluating the clinical performance of dental materials, represents a material's resistance to crack propagation.[21], [22] Since fracture is a major failure mode for dental restorations, it is essential to examine how various immersion solutions affect the fracture toughness of VITA LUMEX AC, particularly regarding their capacity to prevent the propagation of surface flaws caused by erosive acids. To assess fracture toughness, artificially created surface flaws, generated using a Vickers indenter, were utilized.[23]

VITA LUMEX AC is a leucite-reinforced glass-ceramic veneering system that offers a promising alternative for dental restorations. The manufacturer indicates that glazing may be unnecessary, as sufficient strength can be attained through polishing alone, which could lead to time and cost efficiencies for dental practitioners. However, to date, there have been no studies directly examining the impact of finishing protocols, specifically polishing versus glazing, on the fracture toughness and microhardness of this material.

Thus, the aim of this study was to investigate the impact of finishing protocols and different immersion media on the fracture toughness and hardness of a recently introduced leucite-reinforced, glass-ceramic material.

The oral environment presents a complex and dynamic environment characterized by fluctuating pH levels. This dynamic environment can significantly impact the mechanical behavior and esthetic properties of dental restorations, particularly due to the frequent consumption of acidic beverages and foods.[24], [25] Moreover, given the high staining potential of caffeine-containing beverages, this study included coffee (pH 5.8), a weak acid containing caffeine, tannic acid, citric acid, and chlorogenic acid.[26]

Citric acid was chosen as an immersion medium to mimic the acidic environment encountered in the oral cavity, particularly due to the consumption of acidic fruits like mangoes and pineapples. Its pH closely aligns with the levels associated with gastroesophageal reflux disease (GERD), where pH values are typically below 4.0. GERD episodes often last 15-20 minutes during sleep, with esophageal pH potentially remaining under 4.0 for up to 60 minutes before normalization. Additionally, acidic beverages, including those containing citric and phosphoric acids, represent some of the most commonly consumed drinks with low pH.[27], [28] Consequently, both citric acid and coffee were utilized as immersion solutions in this study.

No statistically significant differences in fracture toughness were observed among specimens immersed in the different media (artificial saliva, coffee, and citric acid), irrespective of the finishing method (polishing or glazing). Although minor variations in fracture toughness were observed across the different immersion media for both polished and glazed specimens, these differences did not reach statistical significance.

This may be attributed to incorporation of leucite crystals within the feldspar glass matrix of VITALUMEX AC which enhances the mechanical properties of dental ceramics. Leucite crystals contribute to increased fracture toughness by absorbing fracture energy and inhibiting crack propagation. Furthermore, the presence of leucite within the porcelain matrix increases its viscosity during the firing process, minimizing flow and reducing the development of transient and residual stresses during cooling, thereby enhancing the overall strength and stability of the material.[29], [30]

Finishing protocols play an important role in achieving optimal outcomes in ceramic restorations. While both mechanical polishing and glazing techniques are commonly employed, the literature offers conflicting evidence regarding their relative superiority in terms of surface characteristics and mechanical properties.[31]

Mechanical polishing and glazing are two distinct surface finishing techniques commonly employed in the fabrication of ceramic restorations.[32], [33] Polishing is a subtractive process that removes surface irregularities such as scratches, thereby reducing surface roughness. [34] In the auto glaze, porcelain glazes itself by forming a surface layer containing a smooth glass phase [35] Previous studies have yielded inconsistent results regarding the superiority of specific finishing protocols in achieving optimal surface smoothness and mechanical properties. **(Alencar-Silva et al., 2019 [32]; Maciel et al., 2019 [36]; Kanat-Ertürk, 2020 [37]; Kurt et al., 2020 [33])**, suggesting that the optimal finishing protocol may depend on various factors, including the specific materials, techniques, and evaluation methods employed.

In the current study, no statistically significant differences in fracture toughness were detected between polished and glazed specimens, regardless of the immersion medium used. The existing literature primarily focuses on glazing effect on flexural strength, with limited research focused specifically on its effects on fracture toughness, hindering direct comparisons with previous findings.

Previous studies have reported inconsistent findings regarding the effect of glazing on the flexural strength of dental ceramics.[38], [39], [40], [41] For instance, **Aurélio et al. (2015)**[41] noted that prolonged glaze firings increased the flexural strength of leucite-reinforced ceramics. This improvement can be attributed to several factors, including reduced surface roughness, enhanced stress distribution, improved thermal stability among ceramic phases, and glazing techniques that may affect crack propagation. These findings suggest that glazing creates a vitreous surface layer, sealing surface defects and potentially improving the long-term durability and clinical performance of dental restorations.[42]

Conversely, **Fraga et al. (2015)**[43] reported a decrease in ceramic strength post-glaze firing, which they attributed to changes in microstructure, such as the development of an amorphous phase during glazing.

Significant differences in surface hardness were noted among the immersion media in both polishing and glazing groups ($p=0.041$ and $p=0.005$, respectively). Specimens immersed in artificial saliva exhibited the highest surface hardness, while those in citric acid showed the lowest. Notably, microhardness values for both glazed and polished groups decreased with lower pH levels of the immersion media.

Fahmy et al. (2009)[44] observed a significant increase in microhardness after a

3-week immersion in saliva, attributing this to ion exchange processes in the silica-rich layer on the ceramic surface. This is consistent with our findings, which showed significantly higher surface hardness in specimens immersed in artificial saliva compared to those in citric acid, irrespective of the finishing method.

This study reported that citric acid exhibited the most negative effect on microhardness, likely attributed to its chelating properties. Furthermore, citric acid ions have a propensity to bond with metal oxides within the ceramic material, leading to the dissolution of these oxides and subsequent material degradation.[28], [45]

This aligns with findings by **Kukiattrakoon et al. (2010)**[46], who demonstrated a significant decrease in the microhardness of various ceramics following immersion in acidic solutions, attributed to the leaching of key elements. such as potassium, aluminum, and silicon from the ceramic matrix, this study observed significantly higher surface hardness in specimens immersed in artificial saliva compared to those immersed in citric acid.

Similarly, **Al-Thobity et al. (2021)**[28] significant differences in microhardness were observed among the tested ceramic materials (lithium disilicate, monolithic zirconia, and feldspathic porcelain) following exposure to acidic agents in comparison to artificial saliva.

While polished specimens exhibited slightly higher surface hardness values compared to glazed specimens in all immersion media (artificial saliva: 412.71 ± 13.93 vs. 412.35 ± 13.36; coffee: 408.16 ± 8.65 vs. 405.58 ± 8.96; citric acid: 399.32 ± 8.32 vs. 394.45 ± 6.90), these differences were not statistically significant ($p > 0.05$ in all cases). Consequently, polishing may offer a viable alternative to glazing as a surface finishing technique for leucite-reinforced glass ceramics.

While fracture toughness is calculated using an equation that incorporates hardness values, the resulting fracture toughness measurements were statistically insignificant, despite the hardness values themselves being statistically significant. This suggests that the relationship between hardness and fracture toughness may not be as strong as anticipated. This was also suggested by**Seghi et al. (1995)**[47] who found that hardness values of ceramics with improved fracture toughness varied widely from control groups, indicating a lack of direct correlation between these properties.

One potential source of discrepancy arises from the different measurement methods employed, where hardness is assessed based on the diagonal length of indentations, while fracture toughness calculations involve both hardness and crack length measurements originating from the center of the indentation. [48] This disparity in measurement methods may influence the observed relationship between these two properties.

These in vitro findings provide valuable insights into the influence of finishing techniques and immersion media on the mechanical properties of leucite-reinforced glass-ceramics. However, further in vivo studies are warranted to evaluate the long-term clinical performance of these materials under the dynamic and complex conditions of the oral environment.

Limitation of this study:

This in vitro study, while providing valuable insights into the effects of finishing and immersion media on the surface characteristics of dental ceramics, has certain limitations. The use of flat specimens may not fully reflect the complex surface geometries encountered in clinical situations, where restorations exhibit irregular shapes with convex and concave surfaces. The efficiency of polishing techniques may also vary under these more complex clinical conditions.

Furthermore, the study did not account for several crucial in vivo factors, including occlusal loads, and the presence of bacterial biofilm, which can significantly influence the long-term performance of dental restorations. Therefore, further research is warranted to fully elucidate the impact of these factors on the long-term clinical performance and surface characteristics of dental restorations.

Conclusion:

The findings of this study suggest that immersion in acidic media, such as coffee and citric acid, can negatively impact the microhardness of zirconia veneered with leucite-reinforced ceramics.

Since there were no statistically significant differences in fracture toughness between polished and glazed specimens, this study suggests that polishing can be considered a viable alternative to glazing for improving the surface finish of dental ceramics, potentially offering a more time- and cost-effective approach.

Conflict of Interest:

The authors declare no conflicts of interest.

Funding:

This research was conducted independently, without external funding

from public, commercial, or non-profit sources.

Ethics:

The study protocol was approved by the Research Ethics Committee of the Faculty of Dentistry, Cairo University, Egypt (Approval number: 15622)

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