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Original article

Comparative Evaluation of Microhardness between Monolithic and Multilayered Zirconia: An *in-vitro* Study in Prosthodontic

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ABSTRACT

This study aimed to evaluate and compare the microhardness of monolithic zirconia and multilayered zirconia to investigate the influence of material composition and structural design on their mechanical properties. Cylindrical specimens were designed using AutoCAD software and fabricated from monolithic zirconia (Group A) and multilayered zirconia (Group B blocks via CAD/CAM milling systems. The specimens were sectioned into discs with a diameter of 10 mm and a thickness of 1.5 mm. Microhardness testing was performed on these discs using a standardized protocol. Statistical analysis was conducted using a student's t-test (P < 0.05) with a sample size of 10 specimens per group to ensure 80% power and 95% confidence. Results revealed significant differences in microhardness between monolithic and multilayered zirconia. Monolithic zirconia exhibited superior hardness, attributable to its single-layered structure, which enhances its mechanical strength and wear resistance. In contrast, multilayered zirconia, while exhibiting lower microhardness, demonstrated esthetic advantages due to its gradient layering and maintained sufficient durability for clinical use. The findings underscore the impact of zirconia composition and structural design on mechanical properties, providing clinicians with valuable insights for material selection. While monolithic zirconia is ideal for high-load posterior restorations, multilayered zirconia offers an esthetic solution with adequate mechanical performance, making it suitable for anterior applications.

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INTRODUCTION

Zirconia-based ceramics have revolutionized restorative dentistry due to their excellent mechanical properties, biocompatibility, and esthetics. Among zirconia materials, monolithic zirconia and multilayered zirconia represent two prominent advancements in dental restorations, each with unique structural and functional characteristics. Monolithic zirconia (Monolithic Zr) is a single-layered zirconia ceramic fabricated as a full-contour restoration. It is well-regarded for its superior mechanical strength, particularly its high flexural strength and fracture toughness, which make it suitable for load-bearing areas in posterior restorations [1]. However, concerns regarding esthetics due to its opacity remain a challenge for highly visible anterior regions [2]. Conversely, (multilayered zirconia) commonly referred to as Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) is designed with gradient layers to improve optical properties while maintaining mechanical performance. Multilayered zirconia features a transition in color and translucency from the cervical to incisal layers, enhancing esthetics while retaining structural integrity [3]. Yet, the introduction of gradient layers could potentially alter the microhardness and mechanical stability of the material when compared to monolithic zirconia. The microhardness of zirconia materials plays a crucial role in their clinical performance, as it is indicative of wear resistance and surface durability. Variations in microstructure, processing techniques, and layer composition could influence the hardness and subsequent behavior under occlusal forces [4].

Understanding these differences between monolithic and multilayered zirconia is essential for clinicians to make informed choices regarding material selection for long-term success in restorative treatments. Thus, the purpose of this study is to compare the microhardness of monolithic zirconia and multilayered zirconia, examining how material composition and structural layering influence their mechanical properties. This investigation aims to contribute to the body of knowledge regarding zirconia restorations and provide evidence-based guidance for their clinical applications.

METHODS

Study design

This *in-vitro* study compared the microhardness of two types of zirconia: monolithic zirconia (Group A) Noritake Kurary and multilayered zirconia (Group B) Noritake Kurary. A total of 20 specimens, with 10 from each group, were prepared using a standardized methodology.

Samples preparation

The specimens were designed in the form of cylinders with predetermined dimensions. Discs with a diameter of 10 mm and a thickness of 1.5 mm using AutoCAD software. The geometrical specifications were stored in a stereolithography (STL) file format, a widely used 3D model format compatible with Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) systems [5].

The STL files were imported into a CAD/CAM milling machine, where zirconia blocks of the respective types (monolithic zirconia for Group A and multilayered zirconia for Group B) were processed. Milling was performed in a standardized sequence according to the manufacturer's guidelines to produce the cylindrical specimens. Following the milling process, the discs were sectioned into slices to meet the required dimensions for the microhardness testing [6,7].

Microhardness testing

Surface Micro-hardness of the specimens was determined using Digital Display Vickers Micro-hardness Tester (Model HVS-50, Laizhou Huayin Testing Instrument Co., Ltd. China) figure 1 with a Vickers diamond indenter and a 20X objective lens. A load of 500g was applied to the surface of the specimens for 20 seconds. Three indentations, which were equally placed over a circle and not closer than 0.5 mm to the adjacent indentations, were made on the surface of each specimen. The diagonals length of the indentations was measured by built in scaled microscope and Vickers values as shown in table 1, were converted into micro-hardness values.

Table 1. Vickers values

Gr_1	**Gr_2**
HV (Kg/mm^2)	HV (Kg/mm2)
617.8855	628.4357
610.9499	590.4151
646.7494	617.8855
672.5941	642.5691
742.9843	623.6583
665.6602	609.3259
742.0996	662.2761
674.2198	621.2695
711.0461	612.909
721.1982	630.2273

Micro-hardness calculation

Micro-hardness was obtained using the following equation:

$$HV=1.854\ P/d^2$$

where, **HV** is Vickers hardness in Kgf/mm^2, **P** is the load in Kgf and **d** is the length of the diagonals in mm

Figure 1. Digital Display Vickers Micro-hardness Tester Hardness were determined by the indentation technique. Three indentations were made on each specimen at widely separated locations with a load of 500 gram for 20 seconds in a micro hardness tester

Analysis methods

The data analysis for this vitro study involved calculating the Mean and Standard Deviation for the micro hardness of two types of zirconia: monolithic zirconia (Group A) and multilayered zirconia (Group B). were investigated. After homogeneity of variance and normal distribution of errors had been confirmed, student t-test was done between main groups. The results were analyzed using Graph Pad Instat (Graph Pad, Inc.) software for windows. A value of $P \leq 0.05$ was considered statistically significant. Sample size (n=10/group) was large enough to detect large effect sizes for main effects and pair-wise comparisons, with the satisfactory level of power set at 80% and a 95% confidence level.

RESULTS

Vickers hardness (Kg/mm^2) results (Mean±SD) for both groups are summarized in table 2. It was found that Gr_1recorded statistically significant higher mean value (680.54 ± 47.74 Kgf/mm^2) than Gr_2 (623.89 ± 19.38 Kgf/mm^2) as revealed with student t-test ($p = 0.0027 < 0.05$).

Table 2. Comparison of Vickers hardness results (Kgf/mm2) between both groups. Comparison of Vickers hardness results (Kgf/mm2) between both groups

Material group	Descriptive statistics		t-test
	Mean±SD	**95% CI (low-high)**	**P value**
Gr_1	680.54 ± 47.74	646.39 – 714.68	0.0027*
Gr_2	623.89 ± 19.38	610.04 – 637.76	

*CI; Confidence intervals, *; Significant (p < 0.05.*

DISCUSSION

The comparison of Vickers hardness between monolithic zirconia (Gr_1) and multilayered zirconia (Gr_2) revealed significant differences, with monolithic zirconia demonstrating superior hardness. The results showed that the mean Vickers hardness of Gr_1 was 680.54 ± 47.74 Kgf/mm², significantly higher than that of Gr_2 (623.89 ± 19.38 Kgf/mm²). The statistical analysis using the student t-test confirmed this difference, with a p-value of 0.0027 (< 0.05), indicating statistical significance. This disparity in hardness can be explained by the structural differences between the two zirconia types. Monolithic zirconia is fabricated as a single homogeneous material, ensuring a consistent microstructure that contributes to its higher mechanical properties, including hardness. The absence of interfacial layers or compositional gradients minimizes potential weak points, enhancing its resistance to deformation under load [8].Conversely, multilayered zirconia, designed to improve esthetics by mimicking natural tooth gradation, incorporates varying material compositions across its layers. These compositional changes and the resulting differences in density may reduce overall hardness. Additionally, the interfaces between layers could act as stress concentration zones, further affecting the mechanical properties [9]. Hardness is a crucial property for dental materials, as it influences wear resistance and the ability to withstand occlusal forces. The higher hardness of monolithic zirconia makes it an ideal choice for restorations in load-bearing areas such as posterior teeth. However, the reduced hardness of multilayered zirconia may provide an advantage in certain clinical scenarios, such as minimizing wear on opposing natural dentition, a consideration particularly relevant for anterior restorations where esthetics are prioritized [10]. The findings are consistent with previous studies. For example, Zhang et al. (2019) [11]. emphasized that monolithic zirconia exhibits superior mechanical properties compared to layered or multilayered zirconia, primarily due to its uniform microstructure. Similarly, Ahmed et al. (2021) [12]. found that the gradation of materials in multilayered zirconia, while designed for enhanced esthetic properties, can compromise mechanical performance, including reduced hardness. Similarly, Kale et al. (2017) [13]. highlighted that the differences in material composition within layered zirconia restorations could lead to decreased hardness and structural integrity compared to monolithic counterpart.

CONCLUSION

While monolithic zirconia offers better hardness and durability, its application should be weighed against esthetic demands, particularly in anterior restorations. Multilayered zirconia remains a viable option when esthetics take precedence, provided the functional demands are not excessively high. Future research should aim to enhance the mechanical properties of multilayered zirconia without compromising its esthetic appeal, potentially through advancements in material engineering or processing techniques.

Conflicts of Interest

The authors declare no conflicts of interest

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التقييم المقارن للصلابة الدقيقة بين الزركونيا الأحادية الطبقة والزركونيا متعددة الطبقات: دراسة مختبرية

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المستخلص

أصبحت السيراميك المصنوعة من الزركونيا جزءًا أساسيًا في طب الأسنان الترميمي، نظرًا لخصائصها الميكانيكية الممتازة، والتوافق الحيوي، والجمالية. تركز هذه الدراسة على نوعين بارزين من الزركونيا: الزركونيا الأحادية الطبقة والزركونيا متعددة الطبقات، حيث يتمتع كل منهما بخصائص هيكلية ووظيفية مميزة. الزركونيا الأحادية الطبقة (المجموعة أ)، وهي مادة مكونة من طبقة واحدة، معروفة بقوتها الكبيرة في التحمل وكفاءتها في مقاومة الكسر، مما يجعلها مثالية لترميمات الأضراس ذات التحميل العالي. ومع ذلك، فإن شفافيتها المحدودة تمثل تحديًا لاستخدامها في المناطق الأمامية. في المقابل، تتميز الزركونيا متعددة الطبقات (المجموعة ب) بطبقات متدرجة تتراوح من منطقة العنق إلى الأطراف، مما يعزز الجمالية مع الحفاظ على الأداء الميكانيكي. ومع ذلك، تثير التركيبة متعددة الطبقات بعض القلق بشأن التغيرات المحتملة في الصلابة الدقيقة واستقرار المواد الميكانيكي. في هذه الدراسة، تم تصميم عينات أسطوانية باستخدام برنامج AutoCAD وتصنيعها من كتل الزركونيا الأحادية والمتعددة الطبقات عبر أنظمة الطحن باستخدام الكمبيوتر (CAD/CAM). تم تقطيع العينات إلى أقراص (قطر 10 مم، سمك 1.5 مم) لاختبار الصلابة الدقيقة. تم إجراء التحليل الإحصائي باستخدام اختبار t للعينات المستقلة ($P < 0.05$) مع حجم عينة يبلغ 10 عينات لكل مجموعة لضمان قوة إحصائية بنسبة 80% وثقة بنسبة 95%. اظهرت النتائج وجود فروقات ملحوظة في الصلابة الدقيقة بين الزركونيا الأحادية الطبقة والزركونيا متعددة الطبقات، مما يبرز تأثير تركيبة المادة وهيكلها على مقاومة التآكل والمتانة. توفر هذه النتائج للأطباء معلومات حيوية لاختيار المواد المناسبة من الزركونيا لضمان النجاح طويل الأمد في العلاجات الترميمية.

الكلمات المفتاحية. الزركونيا المتجانسة، الزركونيا متعددة الطبقات، الصلابة الدقيقة.