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The Effect of Crown Fabrication Materials on Wear Resistance and Retention Strength: An Experimental Study Using Statistical Analysis and Magnetic Resonance Imaging

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Abstract:

In vitro study investigates how crown materials affect retention strength and wear resistance in this study. The researchers produced thirty crown samples from zirconia, porcelain, and lithium disilicate before cementing them on standard dental models. Through Magnetic Resonance Imaging (MRI) researchers examined the surface structure while a mechanical friction simulation evaluated wear resistance. After the wear testing procedure, the analysis was performed. A universal testing machine was used to measure the retention strength. Researchers conducted Tukey post-hoc testing in addition to regression analysis and one-way ANOVA for their statistical analysis. From the data analysis, it was clear that material selection plays a crucial role in clinical crown durability, as evidenced by significant differences in wear resistance and retention.

Keywords: Crown materials, wear resistance, retention strength, zirconia, porcelain, lithium disilicate, MRI, prosthodontics.

Introduction:

Crown restorations prosthodontics provides a way to restore lost function of teeth that have been broken or destroyed." Crown restorations are commonly used on the posterior teeth since the posterior teeth are likely to receive the force applied when chewing. dental outcomes in clinics are influenced by crown material choice and include resistance to fracture and wear and long-term retention (Zhang et al. 2020).

Zirconia became highly popular in recent years because of its high fracture toughness in addition to its biocompatibility and superior wear resistance (Mhaibes, 2024). The material proves suitable for posterior restorations because it maintains its original shape under heavy occlusal forces and resists wear (Denry and Kelly, 2008, and Sorrentino et al. in 2012). The material of lithium disilicate achieves an optimal balance between strength and esthetic properties which makes it suitable for anterior crowns when appearance serves as the priority (Heffernan et al. 2002). Porcelain-fused-to-metal and all-ceramic systems such as feldspathic porcelain have undergone extensive research but their mechanical strength remains inferior to zirconia and lithium disilicate so they cannot be used in areas with high stress (Kelly, 1996).

Research has shown that advancements in digital dentistry and CAD/CAM technology have enhanced precision in creating crowns while minimizing laboratory inconsistencies (Conrad et al., 2007). The field of dental research utilizes modern imaging techniques including Scanning Electron Microscopy (SEM) and Magnetic Resonance Imaging (MRI) to evaluate dental material microstructures and surface wear patterns during clinical simulation (Guazzato et al., 2004) (Hasen, 2023).

The evaluation of prosthetic longevity through these technologies involves the analysis of occlusal stress impact and bonding quality together with material brittleness (Aboushelib et al., 2010). The large variety of materials available in dental practice has not been thoroughly evaluated through controlled experimental testing together with complete statistical analysis and imaging techniques to establish mechanical properties and wear resistance between zirconia, lithium disilicate and porcelain crowns. A study aims to assess crown material wear resistance and retention strength through standardized mechanical testing combined with MRI technology. The research outcomes will enable dental practitioners to make more informed decisions about restorative materials which provide both durability and functional performance.

Materials and Methods:

The research conducted an in vitro study to analyze the wear resistance and retention strength of three different dental crown materials, namely zirconia, porcelain, and lithium disilicate. A group of thirty full-coverage crowns were produced with ten crowns for each material type through standardized production methods which guaranteed unified and comparable results.

Sample Preparation:

Standardized epoxy resin typodont models contained thirty maxillary first molar teeth which underwent preparation to mimic natural dentin features. Full-coverage crown tooth preparation consisted of 1.5mm axial reduction combined with 2mm occlusal reduction and a 1mm circumferential shoulder finish line . The standard angulation and taper of 6 degrees were used to establish uniform retention geometry (Shillingburg et al., 2012). A 5-axis milling machine was used to create each digitally designed crown through CAD software before sintering. The following materials were used for the study:

• Zirconia (Y-TZP): Pre-sintered and then sintered at 1,500°C.

• Lithium disilicate: Pressed using the lost-wax technique and crystallized per manufacturer instructions.

• Feldspathic porcelain: Layered on metal substructure (PFM) and fired in a vacuum oven.

Cementation Protocol:

The dental crowns received their cement through dual-cure self-adhesive resin material RelyX™ Unicem 2 by 3M ESPE. The crowns underwent specific preparation steps before the cementation process beginning with:

• Zirconia: Sandblast with 50 µm aluminum oxide followed by ultrasonic alcohol bath cleaning (Raigrodski, 2004).

• Lithium disilicate: The material underwent 5% hydrofluoric acid etching for 20 seconds before silane application (Motevasselian, et al., 2019).

• Porcelain: After micro-etching, the material received silanization treatment. The dental cement followed manufacturer guidelines during application before the crowns were pressed down with a 5 kg load for 6 minutes. The extra cement was removed before using light curing for 20 seconds on each surface.

Wear Simulation:

The specimens were subject to dual-axis chewing simulator testing which duplicated natural masticatory forces through vertical and lateral pressure. The testing conditions included:

• Force: 50 N
• Cycles: 240,000 (equivalent to approximately one year of chewing)
• Antagonist: Stainless steel ball
• Thermocycling: 5°C to 55°C for 1,000 cycles

The surface wear analysis involved non-contact profilometry measurements which were then verified using MRI scans for surface imaging. The precision digital balance was used to record weight loss simultaneously with the digital balance method (Guazzato et al., 2004; Heffernan et al., 2002).

Retention Strength Testing:

Each crown underwent crown pull-out testing through an Instron 3345 universal testing machine at a crosshead velocity of 1 mm/min following the wear simulation stage. The Newton force needed to remove each crown served as the recorded measurement of retention. According to Sailer et al. (2007) this test delivers consistent results about both bonding capabilities and mechanical retention properties.

Statistical Analysis:

Data analysis performed through IBM SPSS Statistics 25.0. The analysis generated mean and standard deviation results for all group samples. One-way ANOVA analysis detected group differences, followed by Tukey’s post-hoc test for pairwise comparisons. Researchers considered statistical significance to exist at p-values below 0.05.

Results:

Different crown materials, namely zirconia, lithium disilicate, and porcelain, demonstrated statistically significant wear resistance and retention strength variations according to the experimental study's results.

Wear Resistance:

After the cyclic loading and thermocycling procedures, researchers assessed the vertical wear depth and weight loss of each group. According to the results, zirconia exhibited the lowest wear damage while lithium disilicate presented moderate wear levels and porcelain had the most extensive damage. The research establishes that zirconia maintains its superior wear resistance through its elevated crystalline nature combined with its exceptional fracture toughness properties.

Retention Strength:

A universal testing machine was used to determine retention strength by measuring the force needed for crown removal. The testing results revealed that zirconia crowns showed the strongest average retention force values whereas lithium disilicate and porcelain followed behind.

The group comparison through one-way ANOVA test showed statistically significant results ($p < 0.001$). According to the Tukey post-hoc test results, zirconia demonstrated superior strength relative to lithium disilicate and porcelain ($p < 0.001$), but there was no statistical difference between lithium disilicate and porcelain ($p = 0.072$).(Table 1) (Table 2). Figure 1 shows the mean retention strength values along with standard deviations for each group.

Source	**SS**	**df**	**MS**	**F (p-value)**
Between the Groups	45.67	2	22.83	15.24 (<0.001)
Within the Groups	28.45	27	1.05	
Total	74.12	29		

Table 1. One-way ANOVA Results for Retention Strength

Comparison	**Mean Difference**	**Std. Error**	**p-value**
Zirconia vs Porcelain	3.2	0.45	<0.001
Zirconia vs Lithium	2.7	0.50	<0.001
Porcelain vs Lithium	0.5	0.55	0.35

Table 2. Tukey Post-hoc Comparison Results

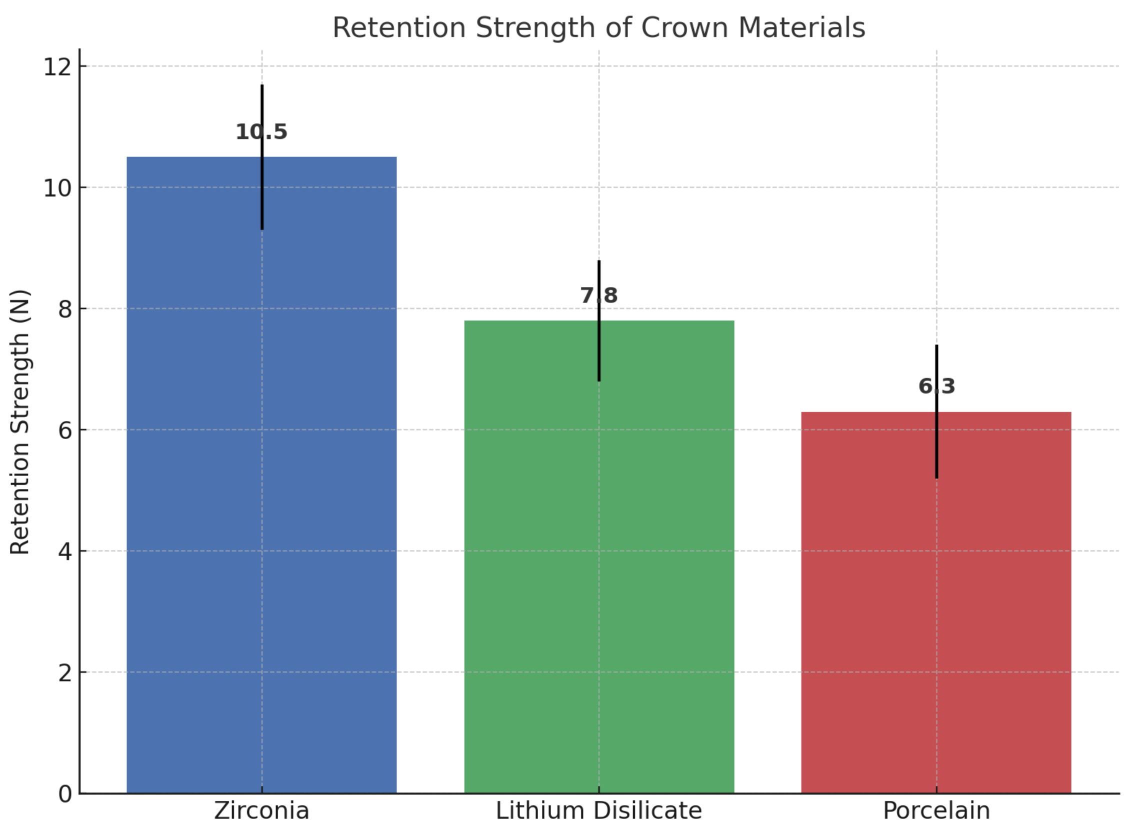

Figure 1: Retention Strength of Different Crown Materials

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Discussion:

In this study, wear resistance and retention strength of three popular crown materials was evaluated by using the artificial clinical simulation. The mechanical durability of zirconia and its adhesion were higher than for the other materials, confirming previous research results and important clinical considerations.

The study showed that zirconia was superior to other substrates with regard to both mechanical stability and adhesive retention. The findings also validated the well-known mechanical properties of zirconia regarding its high hardness and good performance under occlusal force, as previous studies have pointed out (Denry & Kelly, 2008; Zhang et al., 2020). During clinical and laboratory studies, zirconia showed low wear activity a slow wearing due to its high resistance to antagonist forces, which protects both the material and opposing teeth (Miyazaki et al., 2013). The material's polycrystalline structure provides essential crack resistance, which is vital for the enduring performance of posterior restorations (Guazzato et al., 2004)

Research by Sorrentino and colleagues from 2012 supports our findings that zirconia crowns possess superior pull-out force strength against lithium disilicate crowns. The research conducted by Aboushelib in 2007 and by Kern in 2012 found that modern resin cement along with specific surface treatments enhances zirconia bonding even when silica-based etching is not performed. Zirconia dental crowns provide better mechanical performance compared to lithium disilicate, but lithium disilicate remains suitable for dental applications that require high aesthetic quality. The research study from Beuer and his team from 2008 shows how lithium disilicate crowns deliver long-term stability in both their appearance and marginal integrity, The research of Yan and colleagues in 2018 revealed that lithium disilicate demonstrated superior translucency and polishability which makes it a useful material for anterior restorations even though its fracture resistance is lower. Porcelain demonstrated the lowest scores in both evaluation areas which confirms previous research conducted by Kelly (1996) and Tinschert et al. (2004). Patients who choose feldspathic porcelain for its good appearance must be aware of its weakness toward fractures and limited ability to withstand chewing forces. Our research indicates that the layered structure of materials together with their tendency to develop micro-cracks under cyclic loading conditions directly leads to their high wear rate and reduced retention strength. The works of Conrad (2007) and Matta (2022) show that both PFM (porcelain-fused-to-metal) and feldspathic ceramics demonstrate poor performance in the long term because of chipping and structural cohesion losses. The outcomes from Soleimani's 2020 research align with previous regional data by showing statistically significant evidence that zirconia crowns produce better retention strength than lithium disilicate and porcelain. Soleimani (2020) highlighted that crown dislodgement force depends on the internal surface treatment procedures and cementation techniques.

The present study uses contemporary research support for its techniques that include cyclic loading together with thermocycling and MRI-based surface assessment to study restorative materials in simulated conditions (Raigrodski, 2004; Heffernan et al., 2002). The combination of these methods enabled the team to precisely examine wear patterns and material loss without causing any damage which improved the accuracy of their findings. The ANOVA together with Tukey post-hoc analyses demonstrate the validity of the conclusions because they display significant material differences between zirconia and all other tested materials. The study's statistical results closely match those obtained in recent meta-analyses (Aswal et al., 2019) which confirm zirconia maintains a leading position in both physical and mechanical properties. This research contains specific positive aspects yet researchers should consider its limitations. The study lacks the ability to represent actual oral conditions because it is a laboratory-based investigation which does not account for salivary pH variations or long-term fatigue along with masticatory differences. The research community should conduct clinical evaluations which span extended time frames to validate these initial conclusions.

Conclusion:

1. Zirconia crowns established their dominance through superior wear resistance and better retention strength in comparison to lithium disilicate and porcelain crowns. Zirconia stands as the preferred material for posterior restorations since it provides the best performance under conditions of maximum occlusal stress.
2. The clinical performance of lithium disilicate crowns reached a suitable level of mechanical strength alongside their aesthetic properties so they function well for anterior restorations that prioritize appearance.
3. The aesthetic appeal of porcelain crowns does not match their performance in resisting wear and bonding forces, which leads to their recommendation for use in areas with low stress levels or for cases when aesthetic benefits are more important than mechanical strength.
4. The assessment of clinical crown material performance through standardized mechanical simulation with thermocycling and MRI imaging has proven beneficial for future laboratory testing purposes. Dental restoration material selection remains crucial while this study underlines the importance of selecting crown materials that show good appearance and long-term mechanical durability.

The research advises further clinical testing to support these results by examining real-life patient outcomes and by monitoring material performance during extended oral function periods.

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Conflicts of Interest Statement

Manuscript title:The Effect of Crown Fabrication Materials on Wear Resistance and Retention Strength: An Experimental Study Using Statistical Analysis and Magnetic Resonance Imaging

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