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ORIGINAL RESEARCH

COMPARING THE FRACTURE STRENGTH OF MONOLITHIC ZIRCONIA VERSUS BILAYERED ZIRCONIA-BASED SINGLE CROWNS AFTER CEMENTATION USING TWO DIFFERENT CEMENTS: IN VITRO STUDY

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ABSTRACT

Background: Because they are considered biocompatible, tough and look great, zirconia crowns are commonly used instead of metal-ceramic restorations. The advantage of monolithic zirconia is that it does not include a veneer which can easily chip in bilayered restorations. Cementation technique can affect the toughness of the material. The purpose of this study was to compare between the fracture strength of monolithic and bilayered zirconia crowns cemented with either resin or glass ionomer cements.

Methods and Materials: Sixteen monolithic zirconia crowns and Sixteen bilayered zirconia crowns were fabricated using CAD/CAM technology and formed two groups called Group A and Group B. Each group was split into two new subgroups (eight each) dependent on the type of used cement, naming the subgroups with AR and BR groups for the adhesive resin cement and AG and BG groups for the glass ionomer cement. All crowns were prepared by air-abrasion and cemented onto epoxy resin dies, after which they were thermocycled (5,000 times, from 5°C to 55°C). Strength at fracture was determined on a universal testing machine and the types of fracture failure were explored using a scanning electron microscope.

Results: The fracture strength was much higher in monolithic zirconia crowns than in bilayered crowns, no matter the cement used. The average fracture strength was 2541 ± 349 N for AR, 2578 ± 339 N for AG, 1557 ± 418 N for BR and 1691 ± 526 N for BG. There were no major differences between adhesive and conventional cements used in crowns of the same type ($p > 0.05$). Even so, there were significant differences ($p < 0.001$) between crowns made from solid material and those made from two layers. Analysis of failures showed that monolithic crowns suffered major fractures, but the layer-separation problem arises with bilayered crowns.

Conclusion: The fracture resistance of monolithic zirconia crowns exceeded that of bilayered zirconia crowns, with this advantage noticeable regardless of the cementation method. Both adhesive resin and glass ionomer cements worked well clinically. For posterior restorations that are best suited to strong crowns, monolithic zirconia may be recommended.

Keywords: Zirconia crowns, monolithic zirconia, bilayered zirconia, fracture strength, adhesive resin cement, glass ionomer cement, thermocycling, CAD/CAM, SEM analysis.

INTRODUCTION

Because more patients want dental restorations that appear natural, all-ceramic materials are being used for fixed prosthodontics more than ever. Metal-containing restorations in the back of the mouth have limited appearance and biocompatibility, so they are driving the change to ceramic and polycrystalline restorations [1]. For years, metal-ceramic restorations were recognized as the best because they were strong and dependable. However, clinicians can now turn to high-strength ceramics, among them zirconia which provide the right strength and beauty for replacement teeth [2,3].

Zirconia-based ceramics are very tough mechanically mainly because they have a high flexural strength and exhibit transformation toughening to hinder crack growth. Y-TZP materials have shown that this method works best of all [4,5]. Zirconia crowns can be produced using bilayered techniques where zirconia is covered with porcelain and also by monolithic procedures, in which the whole crown is made from a single piece of ceramic. Zirconia crowns that are bilayered improve their esthetic appearance, but there is still a frequent problem with veneering porcelain chipping [6,7].

Without an outer veneer, the monolithic zirconia crown strengthens the core material and has better resistance to fracture which makes them suitable for bite areas (8). The advent of CAD/CAM technology makes it easier to manufacture zirconia crowns precisely and with consistent high-quality material.

Long-term clinical performance of dental crowns is largely determined by their fracture strength. Zirconia restoration fracture resistance is influenced by using monolithic structures, different types and design of finish line, the support die, restoration thickness, the taper of the tooth preparation, the cementation method, how they are aged and the die material properties [11–13.]

Because luting agents hold the restoration together and impact stress distribution, they are very important in dentistry [14,15].

Many methods are available for cementation, including glass ionomer cements, self-adhesive resin cements and adhesive resin cements for zirconia restorations. Although zirconia isn't affected by the acid etching process used for other materials, phosphate monomers in bonding primers have greatly improved its bonding to resin cements. Even so, finding what cement is best and how it relates to the restoration design are topics that are ongoing areas of research.

The need for more evidence on how different luting agents affect the mechanical performance of monolithic and bilayered zirconia led to this laboratory study. It examines how these crown types respond to the fracture strength after being cemented with either adhesive resin or conventional glass ionomer cement.

MATERIAL AND METHODS

The following materials were utilized in this in vitro study:

1. **Monolithic zirconia blocks**: Ceramill® Zolid HT preshade (Amann Girrbach AG, Koblach, Austria; LOT: 1707000)
2. **Bilayered zirconia blocks**: Ceramill® Zi LT+ White (Amann Girrbach AG, Koblach, Austria; LOT: 1708002)
3. **Veneering ceramics**: Dentine and enamel porcelains from VITA VM® 9 series (Vita Zahnfabrik, Bad Säckingen, Germany)
4. **Adhesive resin cement**: Multilink® N self-curing resin cement (Ivoclar Vivadent, Schaan, Liechtenstein; LOT: Z02F8M)
5. **Universal primer**: Monobond® N (Ivoclar Vivadent, Schaan, Liechtenstein; LOT: Z02F8M)
6. **Conventional cement**: Glass ionomer cement (Promedica, Neumünster, Germany; LOT: 2044327)
7. **Die material**: Devcon 5 Minute® Epoxy (USA)

Master Die Fabrication

A stainless steel die simulating a mandibular first molar was custom-machined. The die featured a deep chamfer finish line (1 mm), cylindrical axial walls (5 mm height), a 7° convergence angle (14° total taper), and flat occlusal surface. This die served as the reference for all subsequent impressions and sample preparations.

Die Replication

Using a single-step double-mix technique, 32 impressions of the master die were made with polyvinyl siloxane material (Zhermack HD+ Putty and Light Body). These were boxed with modeling wax and poured with type IV dental stone to generate uniform dies for crown fabrication.

Crown Design and Fabrication

Each die was digitally scanned using the Ceramill® Map 400 scanner. Using Ceramill® Mind CAD software, two types of restorations were designed: full-contour monolithic crowns and zirconia copings for bilayered crowns. The cement space was set to 50 µm, 1 mm above the margin.

Monolithic crowns (1.5 mm occlusal thickness) and bilayered copings (0.5 mm uniform thickness) were milled from respective zirconia blocks using a Ceramill® Motion 2 CAM unit. All restorations were oversized to compensate for sintering shrinkage. Sintering was done at 1450°C for 10 hours using the Ceramill® Therm 3 furnace.

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Bilayered crowns were manually veneered with standardized layering using feldspathic porcelain and subsequently glazed (VITA AKZENT® PLUS). A vacuum-formed polyethylene index, derived from a monolithic crown, was used to ensure consistency in anatomical form and dimensions.

Epoxy Resin Die Preparation

Impressions of the stainless steel die were made and poured with Devcon 5 Minute® Epoxy, allowed to cure for 24 hours and aged for 7 days, resulting in 32 standardized resin dies. Each crown was trial-fitted and evaluated for passive seating using magnification.

Surface Treatment and Cementation

All crown intaglio surfaces were air-abraded with 50 µm aluminum oxide at 2 bar pressure from a 10 mm distance for 15 seconds. Samples were divided into two main groups (monolithic and bilayered zirconia, n=16 each), and further into two subgroups (n=8 each) based on the cementation protocol:

- **Subgroup AR**: Monolithic crowns + adhesive resin cement
- **Subgroup AG**: Monolithic crowns + glass ionomer cement
- **Subgroup BR**: Bilayered crowns + adhesive resin cement
- **Subgroup BG**: Bilayered crowns + glass ionomer cement

Adhesive cementation involved priming the internal crown surface with Monobond® N for 60 seconds followed by cementation with Multilink® N. Glass ionomer cement was mixed per manufacturer's instructions and applied directly to the crowns. A static load of 3 kg was applied using a custom-designed jig to ensure standardized seating.

Thermocycling

All cemented samples underwent thermocycling for 5000 cycles between 5°C and 55°C with a dwell time of 1 minute per cycle in a programmable thermocycler (SD Mechatronik, Germany), simulating oral temperature fluctuations for 6 month duration.

Fracture Testing

Each crown-die unit was embedded in self-cure acrylic resin (Vertex, Netherlands) and mounted in a universal testing machine (Instron 5969, USA). A compressive load was applied with a 4 mm steel ball at the central fossa at a crosshead speed of 0.5 mm/min until failure. Fracture loads (in Newtons) were recorded for all specimens.

SEM Examination

Fractured specimens from each group were examined under a scanning electron microscope (SEM) to evaluate the mode of failure and surface morphology.

RESULTS

The mean fracture strength values across all tested subgroups are presented in **Table 1**. Monolithic zirconia crowns exhibited significantly higher fracture strength than bilayered crowns, regardless of the cement used. The AR (monolithic with resin cement) and AG (monolithic with GIC) groups recorded mean values of **2541 ± 349 N** and **2578 ± 339 N**, respectively. In contrast, the BR (bilayered with resin cement) and BG (bilayered with GIC) groups showed lower strength values of **1557 ± 418 N** and **1691 ± 526 N**, respectively (Table 1).

The **one-way ANOVA** test revealed statistically significant differences among the four groups ($F(3,28) = 13.69$, $p < 0.001$), confirming that the type of crown had a significant influence on fracture strength, while the cement type did not had any significant effect (Table 2).

Further **post hoc Tukey's multiple comparison** test confirmed significant differences between:

- AR vs BR (mean difference = 984.0 N, **p = 0.0003**),
- AG vs BR (mean difference = 1022.0 N, **p = 0.0002**),
- AR vs BG (mean difference = 849.1 N, **p = 0.0018**), and
- AG vs BG (mean difference = 886.9 N, **p = 0.0011**).

However, there was **no statistically significant difference** between AR and AG (**p = 0.9978**) or between BR and BG (**p = 0.9148**) as shown in **Table 3**.

Scanning electron microscopic (SEM) analysis revealed that all monolithic crowns fractured in a catastrophic manner, exhibiting complete separation across the structure. Conversely, bilayered crowns primarily demonstrated chipping and delamination of the veneering ceramic without core fracture, indicating a different failure pattern (Table 4).

These results indicate that the **monolithic crowns** provide superior fracture strength performance compared to **bilayered crowns**, and the choice between **resin cement and glass ionomer cement** had no significant influence on the outcomes within each crown type (Table 5).

Table 1. Descriptive Statistics of Fracture Strength Values (N = 8 per subgroup)

Subgroup	Crown Type	Cement Type	Mean Fracture Strength (N)	Standard Deviation (±SD)
AR	Monolithic Zirconia	Adhesive Resin Cement	2541	349
AG	Monolithic Zirconia	Glass Ionomer Cement	2578	339
BR	Bilayered Zirconia	Adhesive Resin Cement	1557	418
BG	Bilayered Zirconia	Glass Ionomer Cement	1691	526

Table 2. One-Way ANOVA Summary for Fracture Strength Comparison

Source of Variation	SS	df	MS	F (3, 28)	P value
Between Groups (Treatment)	7,078,423	3	2,359,474	13.69	<0.001***
Within Groups (Residual)	4,824,923	28	172,319		
Total	11,903,346	31			

Table 3. Tukey's Multiple Comparison Post Hoc Test

Comparison	Mean Difference (N)	95% CI of Difference	Significance	Adjusted P Value
AR vs AG	-37.7	-604.4 to 529.0	ns	0.9978
AR vs BR	984.0	417.3 to 1551	***	0.0003
AR vs BG	849.1	282.4 to 1416	**	0.0018
AG vs BR	1022.0	455.0 to 1588	***	0.0002
AG vs BG	886.9	320.2 to 1454	**	0.0011
BR vs BG	-134.8	-701.5 to 431.9	ns	0.9148

Legend:
ns = not significant, ** = significant at $p \leq 0.01$, *** = significant at $p \leq 0.001$

Table 4. Summary of Fracture Mode Observed Under SEM

Group	Crown Type	Observed Failure Mode
A	Monolithic Zirconia	Catastrophic complete fracture
B	Bilayered Zirconia	Chipping and delamination of veneer

Table 5. Summary of Key Findings

Outcome	Observation
Highest fracture strength	Monolithic crowns (AG: 2578 N, AR: 2541 N)
Lowest fracture strength	Bilayered crowns (BR: 1557 N, BG: 1691 N)
Influence of cement type	No significant difference within same crown type (AR vs AG, BR vs BG)
Statistically significant differences	Between monolithic and bilayered crowns regardless of cement type
SEM Failure Mode	Monolithic: complete fracture; Bilayered: cohesive and adhesive veneer loss

DISCUSSION

Because they look good, are safe for the body and are more resistant to wear, zirconia crowns are popular option over traditional metal-ceramic alternatives [1]. We attempted to examine and contrast the fracture resistance of monolithic and bilayered zirconia crowns placed on teeth using adhesive resin cement or regular glass ionomer cement. It was found that monolithic zirconia crowns demonstrated much greater strength compared to bilayered crowns, no matter which cement was used.

The high structural strength of monolithic crowns is partly due to eliminating the weak spot between the core and the veneer that occurs in bilayered crowns [2,3]. The majority of design experts say this interface commonly fails, usually by chipping or delamination, especially when the restoration is being used [4]. Cracks in yttria-stabilized tetragonal zirconia are harder to spread because of the toughness brought by transformation toughening under stress.

As previous literature has found, all types of crowns applied in this study could withstand loads higher than both the average masticatory force and the strongest bite force typically measured [7,8]. This proves that either restorations can be used satisfactorily for strengthening molars.

Even though bilayered zirconia crowns showed less resistance to fracture than some other types, they are valuable when looking for a crown that can be customized in layers. In addition, the findings show that there is a risk of veneer failure, mainly if non-anatomical copings are used since they may not be strong enough to hold the veneer (9). According to research, the success of bilayered systems depends on suitable core shapes, constant veneering thickness and maintained temperatures between the core and veneering materials 10,11.

The current research found no statistically meaningful difference between adhesive resin cement and glass ionomer cement in every crown group considered. Both cements gave similar mechanical support for zirconia crowns, when tested in laboratory conditions. Rosentritt et al. [12] also found that the fracture strength of zirconia monolithic crowns was similar regardless of the cement type used.

However, a number of researchers have preferred adhesive resin cements that include MDP (10-Methacryloyloxydecyl dihydrogen phosphate) as a functional monomer for its better bonding with treated zirconia surfaces, obtained by sandblasting and using a primer. At the same time, conventional cements are easier to manage but depend on small-scale bonding that might not last over time in certain clinical circumstances [15].

Thermocycling was used in this investigation to create the different temperature fluctuations found in the mouth. This type of test has been found to result in lower temperature damage for zirconia which may affect its mechanical characteristics (16). Notwithstanding this, the values for fracture strength exceeded what is required in the clinic, showing zirconia to be reliable for restoration even as samples aged artificially.

Regarding failure modes, groups showed different ways of failing. The majority of monolithic crowns showed complete failure, implying that they broke only once the material was severely overloaded. Conversely, in bilayered crowns, chipping and separation of the porcelain veneer which is weakest in layered crowns, was observed, as documented in other scientific studies.

In general, the results support previous studies that show monolithic zirconia crowns perform better mechanically. They also show that adhesive techniques and conventional cementation methods can be safely and successfully used with zirconia restorations. Even so, you should consider that bilayered crowns have certain mechanical drawbacks because of their attractive appearance.

CONCLUSION

No matter what cement was used, monolithic zirconia crowns were shown to be much stronger against fracture than bilayered zirconia crowns. The fracture resistance of zirconia restorations cemented with adhesive resin and glass ionomer cement was acceptable, so either can be trusted for this treatment. Its strong structure and resistance to failures make monolithic zirconia preferred for posterior crowns.

DECLARATIONS

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Consent for publication

Informed consent was obtained from every participant for documentation and examination.

Competing interests

The authors declare no competing interests.

Ethical approval

Ethical approval was granted by the Institutional Human Ethical Committee

Informed patient consent

All patients' clinical records were obtained with informed consent.

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