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Comparison of the marginal fit of soft-machined monolithic zirconia crowns*

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ABSTRACT

Aims: The aim of this study was to compare the marginal fit of five different soft machined monolithic zirconia materials.

Methods: A mandibular right first molar on an acrylic model was prepared with standardized dimensions using diamond burs. Fifty metal duplicates were fabricated via laser sintering with Co-Cr alloy and divided into five groups (n=10). All duplicates were scanned using a CAD/CAM system, and zirconia crowns with a 1.5mm occlusal thickness and 20µm cement space were produced. Following sintering, marginal gaps were measured using the silicone replica technique. The obtained silicone replicas were sectioned into four parts mesiodistally and buccolingually using a scalpel. The marginal gaps of the samples were examined using a stereomicroscope under 10×magnification. Marginal gap measurements were performed at four specific points where the crown margin was closest to the cemento-enamel junction: mesial, distal, buccal, and lingual. For each crown, the measurements were repeated three times, and the mean value was recorded. A total of 600 measurements were performed for 50 crowns. Statistical analysis was conducted using one-way ANOVA and Tukey's HSD test ($p<0.05$).

Results: Significant differences were found among the zirconia groups ($p<0.001$). Zenostar exhibited the highest marginal gap (92±22µm), followed by Katana (81±18µm) and Incoris TZI (66±20µm). The lowest values were recorded in the Bruxzir (46±9µm) and Prettau (48±23µm) groups. Zenostar and Katana showed significantly larger marginal gaps compared to Prettau and Bruxzir ($p<0.05$), while Incoris TZI presented intermediate values without significant differences.

Conclusion: All tested monolithic zirconia materials demonstrated clinically acceptable marginal fit. However, notable differences were observed among materials, with Bruxzir and Prettau showing superior marginal fit compared to Zenostar and Katana.

Keywords: Yttria stabilized tetragonal zirconia, dental marginal adaptation, dental crown

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INTRODUCTION

In recent years, all ceramic restorations have gained increasing importance in fixed prosthodontic treatments due to their superior aesthetic properties.[1] Among these materials, yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) have become one of the most commonly used options, owing to their high flexural strength[2], low plaque accumulation[3], and exceptional resistance to fracture.[4] The development of monolithic zirconia restorations has eliminated the need for porcelain veneering, thereby reducing complications such as chipping and delamination seen in bilayered systems and further enhancing the clinical performance of zirconia.[5]

In dentistry, there are two main milling techniques used in the production of zirconia for the fabrication of dental crowns and fixed partial dentures: soft machining and hard machining. In the soft machining technique, partially sintered zirconia blocks with lower density are milled, followed by a final sintering process to achieve full densification. In contrast, the hard machining technique involves milling fully sintered, high-density zirconia blocks.[6,7] Due to the high hardness and density of fully sintered blocks, hard machining is associated with increased tool wear, longer processing times, and the potential formation of microcracks during fabrication.[8] Soft machining, on the other hand, overcomes these challenges by offering a more efficient and cost-effective manufacturing process. Moreover, the approximate 20% shrinkage that occurs during sintering is digitally compensated during the design stage, ensuring dimensional accuracy of the final product.[9] For these reasons, soft machining has become the preferred method in the fabrication of monolithic zirconia restorations.

The clinical success and overall quality of restorations are largely determined by their fit to the prepared tooth, with

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marginal fit being one of the most critical factors affecting the long-term success of fixed prosthetic restorations.[4] The marginal gap was defined as the vertical or horizontal space between the finish line of the prepared tooth and the edge of the restoration. Inadequate marginal fit can compromise the integrity of the restoration by leading to microleakage, cement dissolution[10], bacterial infiltration[11], secondary caries[12], and periodontal inflammation.[13] According to the literature, marginal gaps up to 120µm were considered clinically acceptable; however, minimizing this gap is always preferable.[14]

The physical properties of zirconia materials can vary depending on factors such as their chemical composition[15], grain size[16], sintering protocol[17], translucency level and additive content.[18] These variations can affect the material's adaptation behavior to the prepared tooth surface. Therefore, comparing the marginal fit of different zirconia types is of great importance for clinical material selection.

Although various measurement methods have been used by researchers to evaluate marginal fit, the silicone replica technique is widely preferred due to its ease of application and high reproducibility. This method uses low- and high-viscosity silicone materials to create a negative mold of the gap between the crown and the prepared tooth.[19] This allows for indirect but highly precise measurements of marginal fit without damaging the restoration, making it an ideal technique for both in vitro and clinical studies.[20]

The aim of this in vitro study was to compare the marginal fit of five different soft machined monolithic zirconia materials Bruxzir, Katana, Prettau, Zenostar, and InCoris TZI. The null hypothesis of the study was that there would be no significant difference in the marginal fit among the different zirconia materials.

METHODS

This study did not require ethical approval as it did not involve any human subjects or animal experiments. The research was carried out in accordance with the ethical standards applicable to in vitro studies. In this study, the preparation of the mandibular right first molar on an acrylic jaw model (Ivoclar-Vivadent, Schaan, Liechtenstein) was performed using diamond burs (229-014XC Torpedo, Romidan, Kiryat-Ono, Israel) with a rotary instrument. The occlusal surface was reduced by 2 mm, and all other surfaces by 1.5 mm. The prepared tooth had a chamfer finish line with a thickness of 1mm, a 6°taper, a height of 4 mm, a mesiodistal dimension of 8mm, and a buccolingual dimension of 6 mm. Based on the prepared acrylic tooth, a total of 50 duplicates were fabricated via laser sintering using a Co-Cr alloy (Dentorium, New York, USA), with ten specimens produced for each experimental group. The metal duplicates were scanned using a CAD/CAM system (Yenamak D40, Yenadent, İstanbul, Turkiye), and zirconia crowns with a 1.5 mm occlusal thickness and a cement space of 20 µm were fabricated. Subsequently, all crowns underwent a sintering process. The compositions of the zirconia materials used in the study and the sintering temperatures applied were presented in Table 1. The marginal gap measurements were evaluated using the silicone replica technique. A low-viscosity silicone impression material (Elite HD+, Zhermack, Italy) was applied to the internal surface of each crown, which was then seated onto the prepared tooth under standardized manual pressure for five minutes. After setting, the crowns containing the light-body material were carefully removed, and a high-viscosity silicone material (Elite HD+, Zhermack, Italy) was poured into the crown to support the thin replica layer. The obtained silicone replicas were sectioned into four parts mesiodistally and buccolingually using a scalpel. The marginal gaps of the samples were examined using a stereomicroscope (ZEISS Stemi 2000-C, Oberkochen, Germany) under 10×magnification. Marginal gap measurements were performed at four specific points where the crown margin was closest to the cemento-enamel junction: mesial, distal, buccal, and lingual. For each crown, the measurements were repeated three times, and the mean value was recorded. A total of 600 measurements were performed for 50 crowns. The marginal gap of all crowns, with 10 crowns in each group, was evaluated by the same operator. The analyses were conducted using the commercial software IBM SPSS Statistics version 19 (IBM Inc., Somers NY, USA). One-way ANOVA followed by Tukey's HSD post hoc test was used for statistical analysis. All data were presented as mean±standard deviation (SD). A p-value of <0.05 was considered statistically significant.

RESULTS

The mean marginal gap values of the tested monolithic zirconia groups were presented in Table 2. Statistically significant differences were observed among the groups ($p<0.001$). The Zenostar group showed the highest mean marginal gap value (92±22 µm), followed by Katana (81±18 µm) and Incoris TZI (66±20 µm). The lowest values were observed in the Bruxzir (46±9 µm) and Prettau (48±23 µm) groups. According to the results of the Tukey HSD post hoc test, the marginal gap values of Katana and Zenostar were significantly higher than those of Prettau and Bruxzir ($p<0.05$). While Incoris TZI did not show a statistically significant difference compared to the other groups, Prettau differed significantly from Katana and Zenostar. However, there was no statistically significant difference between Prettau and BruxZir, or between Katana and Zenostar. Despite these statistical differences, all tested zirconia materials showed marginal gaps below the clinically acceptable threshold of 120µm.

DISCUSSION

Monolithic zirconia restorations have gained increasing popularity in fixed prosthodontics due to their enhanced mechanical strength, high fracture resistance, and reduced risk of chipping compared to veneered zirconia systems.[21,22] In addition to their structural advantages, their monolithic nature allows for simplified fabrication workflows and the elimination of layering ceramics, which are typically associated with technical complications. Furthermore, their low surface roughness and favorable biocompatibility make them a viable option for long-term clinical success.[3]

In addition to high fracture resistance, low surface roughness, and favorable biocompatibility, marginal fit plays a crucial role among the key parameters influencing the clinical longevity

Table 1. The materials used with brand name, manufacturer, material composition, sintering temperature and grain size

Brand name	Manufacturer	Material composition	Sintering temperature (°C)	Dwell time	Grain size
Incoris TZI	Sirona	-ZrO_2+HfO_2+Y_2O_3:≥99.0% -Y_2O_3: 5.6% (Σ Y_2O_3+Er_2O_3) -Al_2O_3:≤0.35% -Other oxides (excluding Er_2O_3):≤0.2%	1510°C	2h	0.4µm
Prettau anterior	Zirkonzahn	-ZrO2+Y_2O_3+HfO_2 ≥ 99.0% -Y_2 O_3>4.5 to≤6.0, HfO_2≤5% -Al_2O ≤ 0.5% -Other oxides≤0.5%.	1600°C	2h	0.58µm
Katana UTML	Kuraray noritake	-ZrO_2+HfO_2+Y_2O_3>99.0% -Yttrium oxide (Y_2O_3)>4.5 -Hafnium oxide (HfO_2)≤6.0% -Other oxides≤5.0% -Fully stabilized zirconia≤1.0%	1550°C	2h	Unknown
Zenostar translucent	Ivoclar	-ZrO_2 -Y_2O_3: 4–6% -Al_2O_3<1% -SiO_2<0.02% -Fe_2O_3<0.01% -Na_2O<0.04%	1450°C	2h	0.3µm
Bruxzir zirconia	Glidewell	-ZrO_2 -Yttria	1580°C	2h	0.3–0.7µm

Table 2. Mean and SD of marginal gaps between the zirconia crowns

Groups	n	Marginal gap (µm)
		Mean±SD
Incoris TZI	10	66±20 (ab)
Prettau	10	48±23 (b)
Katana	10	81±18 (a)
Zenostar	10	92±22 (a)
Bruxzir	10	46±9 (b)
		p<0.001

SD: Standard deviation, *Different letters indicate statistically significant difference between groups (p<0.05)

of fixed prosthetic restorations. An insufficient marginal fit may lead to complications such as microleakage, cement dissolution, secondary caries, and periodontal inflammation, potentially compromising both the restoration and the supporting tooth structure.[23,24] Thus, evaluating the marginal fit of zirconia materials remains a relevant and valuable pursuit in prosthetic dentistry.

This study aimed to provide evidence-based guidance for clinicians in optimizing restoration fit and longevity by simultaneously evaluating the marginal fit of five popular soft machined monolithic zirconia brands.

In the present in vitro study, the marginal fit of monolithic zirconia materials was evaluated using the silicone replica technique. Statistical analysis showed a significant difference between the groups. In our study, the marginal gap measurements of monolithic zirconia crowns were determined as follows: 46±9 µm for BruxZir, 48±23 µm for Prettau, 66±20 µm for InCoris TZI, 81±18 µm for Katana, and 92±22 µm for Zenostar. This indicates that the type of zirconia material can influence marginal fit. Therefore, the null hypothesis of the study was rejected.

McLean and von Fraunhofer evaluated the marginal fit of 1000 fixed prosthetic restorations over a five-year period and reported that marginal discrepancies less than 80 µm are difficult to detect under clinical conditions.[14] Therefore, they proposed a clinically acceptable marginal gap threshold of 120 µm. Although statistically significant differences were observed among the materials, all values obtained in the present study were below 120 µm, demonstrating marginal fit within the clinically acceptable limits defined by McLean and von Fraunhofer.[14]

Ceramic manufacturers produce zirconia ceramics with different sintering temperatures and grain sizes (Table 1). To obtain aesthetically acceptable monolithic restorations from the highly white Y-TZP, certain modifications in its optical properties have been necessary. These include adjustments made during the manufacturing process, such as reducing crystal size, increasing sintering temperature, and altering yttrium content to enhance translucency and better replicate the natural tooth color.[25] Additionally, the color of zirconia can be adjusted by adding other oxides.[18] It has been shown that the material composition of zirconia affects the quality of the crown margin and, consequently, the marginal fit.[15] To promote the transformation from the tetragonal to the monoclinic phase for crack arrest and fracture toughness, while preventing undesirable phase transformation, a grain size between 0.2–1.0 µm is recommended for 3Y-TZP.[26] The grain sizes of all materials in the present study fall within this range. The polycrystalline density affects the strength of zirconia.[27] Stawarczyk et al.[7] reported that the grain size of zirconia increases with rising sintering temperatures. A decrease in the sintering temperature results in smaller grain sizes, which may lead to insufficient phase transformation and inadequate material density.[25] The desired sintering temperature for 3Y-TZP should be between 1350–1550°C. In the present study, although the sintering temperatures of the zirconia materials used were within the ideal range, Prettau and BruxZir, which had the highest sintering temperatures, exhibited the lowest marginal gap values. Katana, which had the lowest sintering temperature, was found to have the highest marginal gap. Further studies are needed to investigate the correlation between grain size and sintering temperature. However, this may be attributed to the complex production processes involved in soft machining. During sintering, approximately 20% shrinkage occurs, which must be accurately anticipated and compensated for.[28] To accommodate this shrinkage, soft-machined zirconia frameworks are over-milled prior to sintering. However, this compensation may not always be precisely predictable, potentially leading to variations in marginal fit. Therefore, the findings of our study suggest that dimensional changes due to sintering in the soft-machining process can have an impact on the marginal fit. Additionally, Schwiver et al.[15] reported that marginal defects occurred in crowns as a result of the soft machining procedure, and these defects are likely to negatively affect marginal fit. Since the ceramics evaluated in this study differ in terms of composition, sintering temperature, and grain size, it was not possible to clearly determine which specific factor influenced the marginal fit.

When examining previous studies on the marginal fit of zirconia, Shembesh et al.[29] evaluated the effect of four different impression techniques on marginal gap values and reported that Zenostar zirconia crowns exhibited marginal gaps ranging from 26.6 µm to 81.4 µm. In another study by Ji et al.,[30] the marginal fit of Prettau and Zenostar zirconia crowns produced using different CAD/CAM systems was assessed, with reported marginal gaps of 109 µm for Prettau and 84.7 µm for Zenostar. Kale et al.[31] investigated the influence of different cement space settings on the marginal fit of monolithic zirconia crowns, finding values between 53 µm and 85 µm. Kocaağaoğlu et al.[32] measured the marginal gap of monolithic zirconia crowns using three different digital scanning methods, reporting results ranging from 47.7 µm to 85.6 µm. The mean cement gap in the present study ranged from 46 µm to 92 µm, and these values were consistent with the marginal gap measurements reported in the previous studies.

Sachs and colleagues stated that the accuracy of marginal gap measurements in zirconia was also influenced by the scanning method, restoration design, milling, and sintering procedures.[33] Upon reviewing the literature, it was observed that there was no standardization for the measurement of marginal gaps. The marginal measurement methods used in the studies[34-42], the applied ceramic production techniques (e.g., CAD/CAM or casting)[34,36,39,43-45], the type of finishing line of the dental preparation[34,46,47], and variables such as the number of measurements taken per sample[45,48,49] are observed. Due to differences in the monolithic zirconia materials used, the finish line design of the preparations, marginal gap measurement methods, cement space settings, manufacturing systems, and the number of measurements taken per specimen, it is not possible to make a direct comparison with previous studies. Nevertheless, all marginal gap values obtained in the present study were found to be within the clinically acceptable range of 120 µm.

Limitations

This study has several limitations that should be acknowledged. Firstly, the investigation was limited to soft-machined monolithic zirconia crowns; fully sintered (hard-machined) zirconia restorations were not included in the comparison. Secondly, all marginal gap evaluations were conducted using a fixed cement space of 20 µm, which may not reflect the variations encountered in clinical practice. Additionally, the marginal gaps were assessed using the silicone replica technique, which, while widely used, could be complemented or validated by more advanced methods such as micro-computed tomography. Furthermore, only a single CAD/CAM system was employed; the influence of different scanning and milling systems on marginal fit remains to be explored. Lastly, the measurements were performed prior to cementation. Since the cementation process can affect the final fit of restorations, future studies should include post-cementation evaluations for a more comprehensive analysis.

CONCLUSION

All tested monolithic zirconia materials demonstrated clinically acceptable marginal fit. However, notable differences were observed among materials, with Bruxzir and Prettau showing superior marginal fit compared to Zenostar and Katana.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study did not require ethical approval as it did not involve any human subjects or animal experiments.

Informed Consent

Because the study has no study with human and human participants, no written informed consent form was obtained.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

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Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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