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Comparative Evaluation of the Marginal Adaptation of Zirconia and Nickel–Chromium Copings: An in Vitro Study

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Abstract

Introduction: Marginal adaptation is a critical determinant of the biological, mechanical, and clinical success of fixed dental restorations.

Material and Methedology: The present in vitro study compared the marginal adaptation of zirconia copings fabricated using computer-aided design and computer-aided manufacturing (CAD/CAM) technology with that of nickel–chromium (Ni–Cr) copings fabricated using the conventional lost-wax casting technique.

Thirty copings were fabricated on a standardized stainless-steel master die: 15 Ni–Cr copings and 15 zirconia copings. The marginal discrepancy was measured at four locations—mid-mesial, mid-distal, mid-buccal, and mid-palatal—using scanning electron microscopy.

Result: A total of 120 measurements were obtained. The overall mean marginal discrepancy was 157.262±43.856 µm for the Ni–Cr group and 92.575±52.884 µm for the zirconia group. The difference was statistically significant according to the Mann–Whitney U test (U=45.000, p=0.005).

Conclusion: Within the limitations of this study, CAD/CAM-fabricated zirconia copings demonstrated significantly better marginal adaptation than conventionally cast Ni–Cr copings.

Keywords: marginal adaptation, marginal discrepancy, zirconia, nickel–chromium, CAD/CAM, lost-wax technique, scanning electron microscopy, fixed prosthodontics.

Introduction

Fixed prosthodontic treatment aims to restore the function, comfort, phonetics, and appearance of teeth that have been damaged or lost. Complete-coverage crowns and fixed dental prostheses remain widely used because they can rehabilitate compromised dentitions while preserving or improving oral function and aesthetics. However, the long-term success of these restorations depends not only on the strength and appearance of the restorative material but also on the accuracy with which the restoration adapts to the prepared tooth[1,2].

Marginal adaptation refers to the degree of proximity between the restoration margin and the finish line of the tooth preparation. Although a completely gap-free interface is not clinically achievable, the marginal discrepancy should be minimized to reduce the amount of exposed luting cement. The cement layer at the tooth–restoration interface is vulnerable to dissolution in the oral environment. As the cement deteriorates, marginal leakage, bacterial penetration, plaque retention, and recurrent caries may occur. Excessive marginal discrepancy may also contribute to gingival inflammation and compromise periodontal health[3,9,10].

The marginal fit of a restoration is influenced by several factors, including tooth-preparation design, impression accuracy, die fabrication, restorative material, fabrication technique, cementation, thermal processing, and laboratory finishing procedures. Conventional metal restorations are commonly fabricated using the lost-wax technique. Although this technique has been used successfully for decades, it is sensitive to multiple variables, including wax distortion, investment expansion, casting shrinkage, incomplete casting, and finishing errors[3,4].

The development of CAD/CAM technology has introduced more standardized and digitally controlled approaches to the fabrication of dental restorations. In a typical digital workflow, the prepared die is scanned, the coping is designed using specialized software, and the design is transferred to a milling unit. Zirconia copings are generally milled in an enlarged form and subsequently sintered to compensate for material shrinkage. This process may reduce several operator-dependent variables associated with conventional casting[6,10].

Zirconia has become an important restorative material because of its favourable mechanical properties, biocompatibility, corrosion resistance, and aesthetic potential. It does not contain a metallic substructure and may therefore be advantageous in cases where soft-tissue aesthetics, translucency, or metal sensitivity is a concern[14,15]. Nevertheless, the clinical performance of zirconia restorations depends substantially on the accuracy of scanning, digital design, milling, sintering, and final adaptation.

Because marginal fit is directly related to the longevity and biological safety of fixed restorations, the present

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study was undertaken to compare the marginal adaptation of CAD/CAM-fabricated zirconia copings and conventionally cast Ni–Cr copings. The study used scanning electron microscopy to provide quantitative measurements of the marginal discrepancy at standardized locations.

Materials and Methods

Study Design

The study was designed as an in vitro comparative investigation. Two groups of copings were fabricated using different materials and manufacturing methods:

- **Group I:** Nickel–chromium copings fabricated using the conventional lost-wax casting technique.
- **Group II:** Zirconia copings fabricated using a CAD/CAM milling workflow.

Each group consisted of 15 copings, resulting in a total sample size of 30 copings. Four marginal measurements were obtained from each specimen, producing a total of 120 readings.

A stainless-steel master die(fig 1) simulating a prepared maxillary first molar was fabricated using a CNC milling machine. The preparation featured:

- Approximately 6° convergence.
- A shoulder finish line.
- A finish-line width of approximately 0.5 mm.
- Four orientation markings corresponding to the mesial, distal, buccal, and palatal surfaces.

The standardized die was used to minimize variation in tooth morphology, preparation design, and measurement location.

Fabrication of Nickel–Chromium Copings

Impressions of the master die were made using polyvinyl siloxane impression material (fig 6). The impressions were poured with Type IV dental stone to obtain working dies. A layer of die spacer was applied to the axial surfaces, ending approximately 1 mm short of the preparation margin.

Wax patterns were then fabricated using inlay wax. A surface-tension-reducing agent was applied to the wax patterns before investing. Preformed wax sprues were attached while the patterns were seated on their respective dies. The wax patterns were invested in a phosphate-bonded investment material using the manufacturer's recommended powder-to-liquid ratio.

After setting, the invested patterns were placed in a furnace for burnout. The temperature was gradually increased to eliminate the wax and prepare the mould for casting. The Ni–Cr alloy was melted and cast using a centrifugal casting machine. After divesting, the castings were air-abraded and separated from their sprues using a diamond disc. Nodules or irregularities that prevented complete seating were removed using a tungsten carbide bur. Fifteen Ni–Cr copings were fabricated and seated on their respective gypsum dies.

Fabrication of Zirconia Copings

Impressions of the master die were made and scanned using an extraoral laboratory scanner(Fig 2). The digital data were imported into exocad software for coping design. The design process included identification of the preparation margin, definition of the axial walls, and incorporation of a virtual spacer of approximately 25 µm. The completed digital design was exported as an STL file to a five-axis milling machine. Enlarged zirconia copings were milled from prefabricated zirconia blocks. The enlarged dimensions compensated for the approximately 20–25% shrinkage expected during sintering. The milled copings were subsequently sintered in a high-temperature furnace according to the manufacturer's recommended cycle. Fifteen zirconia copings were fabricated and placed on their respective resin models(fig 3).

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Measurement of Marginal Discrepancy

Each coping(fig 7) was marked to ensure consistent orientation during evaluation. Measurements were obtained at four standardized sites:

- Mid-mesial.
- Mid-distal.
- Mid-buccal.
- Mid-palatal.

The specimens were examined using a scanning electron microscope (fig 4). Marginal discrepancy was measured as the distance between the margin of the coping and the corresponding finish line of the die. Four readings were recorded for each coping, resulting in 120 total observations.

Statistical Analysis

The data were analyzed using Jamovi statistical software version 2.6. Descriptive statistics included the mean, median, standard deviation, minimum value, and maximum value.

Normality was assessed using the Shapiro–Wilk test and Q–Q plots. Because the data showed significant deviation from normality, non-parametric analysis was selected. The overall marginal discrepancy between the two independent groups was compared using the Mann–Whitney U test. Statistical significance was established at $p<0.05p < 0.05p<0.05$.

Results

Sample Distribution (graph 1 n, l)

Thirty specimens were evaluated. The two study groups were equally distributed:

Marginal Discrepancy at Individual Sites (Graph 2)

Zirconia copings demonstrated lower mean marginal discrepancies than Ni–Cr copings at all four measured sites. (fig 10,11)

The greatest mean discrepancy in the Ni–Cr group was found at the mid-palatal site, measuring 174.455±76.502174.455 \pm 76.502174.455±76.502 µm. In the zirconia group, the greatest mean discrepancy was observed at the mid-buccal site, measuring 105.576±69.695105.576 \pm 69.695105.576±69.695 µm. At every corresponding site, the zirconia copings displayed lower mean values than the Ni–Cr copings.

Overall Marginal Discrepancy (graph 3)

The overall mean marginal discrepancy was calculated from measurements obtained at the four sites.

The Ni–Cr group showed a substantially higher overall marginal discrepancy than the zirconia group. The Mann–Whitney U test demonstrated a statistically significant difference between the groups:

U=45.000, p=0.005U = 45.000,\ quad p = 0.005U=45.000,p=0.005

Because the ppp-value was below 0.05, the null hypothesis of no difference between the groups was rejected. The results indicated that zirconia copings had significantly better marginal adaptation than Ni–Cr copings.

Discussion

The accurate marginal adaptation of a fixed restoration is essential for maintaining the health of the tooth, periodontium, and surrounding oral tissues. Marginal discrepancy can expose the luting cement to oral fluids, leading to cement dissolution and microleakage. These processes may promote plaque retention, secondary caries, pulpal irritation, and periodontal inflammation[3,6,9].

In the present study, zirconia copings consistently demonstrated lower marginal discrepancies than Ni–Cr copings at the mid-mesial, mid-distal, mid-buccal, and mid-palatal sites. The overall mean discrepancy for zirconia was approximately 92.6 µm, compared with approximately 157.3 µm for Ni–Cr. The statistically

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significant difference suggests that the CAD/CAM zirconia workflow provided more accurate marginal adaptation under the conditions of this investigation.

The superior performance of zirconia may be related primarily to the digital fabrication process rather than to the intrinsic properties of zirconia alone. In the CAD/CAM workflow, the preparation is digitally captured, the coping is designed using software, and the restoration is milled from a standardized industrially manufactured block. These steps reduce several sources of variability associated with manual waxing and conventional casting[5,6,17,21].

By contrast, the lost-wax technique involves multiple stages that may contribute to dimensional inaccuracy. Wax patterns can distort during fabrication or removal from the die. Investment expansion may not fully compensate for alloy shrinkage. Additional discrepancies may arise during burnout, casting, divesting, sprue removal, air abrasion, and manual adjustment. Even when performed carefully, the cumulative effect of these steps can increase marginal discrepancy[7,14,15,16].

The mid-palatal region recorded the highest mean marginal discrepancy in the Ni–Cr group. This may reflect localized distortion during waxing, casting, or finishing. The zirconia group showed relatively consistent values across the four sites, supporting the role of digital design and standardized milling in reducing regional variation[11,12,30].

The findings are consistent with several previous in vitro investigations that have reported lower marginal discrepancies for CAD/CAM-fabricated zirconia than for conventionally cast Ni–Cr restorations. For example, studies cited in the thesis have reported substantially smaller marginal gaps for zirconia copings compared with Ni–Cr copings when evaluated using microscopic methods. Other studies have also indicated that CAD/CAM systems can produce restorations with clinically acceptable marginal adaptation, although the actual values vary according to the manufacturing system and measurement protocol[6,12,17,,21].

However, the literature does not demonstrate that CAD/CAM systems are universally superior in every circumstance. Some investigations have reported comparable or even better adaptation with conventional techniques, particularly when highly controlled laboratory procedures were used. Differences among studies may be explained by the type of scanner, milling unit, zirconia system, die design, finish-line configuration, coping thickness, cementation procedure, and method of measurement[22,23,24].

It is also important to distinguish statistical significance from clinical significance. A statistically significant difference indicates that the observed difference was unlikely to have occurred by chance within the study sample. It does not, by itself, establish how the difference will influence long-term clinical outcomes. The clinical effect of a marginal discrepancy depends on factors such as cement type, oral hygiene, margin location, periodontal susceptibility, occlusal loading, restoration design, and the presence of parafunctional habits[33,34].

The thesis discusses commonly cited marginal-gap values ranging from approximately 50 to 200 µm as clinically acceptable in different studies. However, there is no universally accepted maximum marginal discrepancy that guarantees long-term clinical success. Consequently, the objective should be to achieve the smallest and most consistent discrepancy possible while also ensuring adequate mechanical strength, occlusal accuracy, contour, proximal contacts, and appropriate cement space.

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Clinical Implications

The results suggest that CAD/CAM-fabricated zirconia copings may be advantageous when marginal accuracy is a primary concern. A smaller marginal discrepancy may provide several potential benefits:

- Reduced exposure and dissolution of luting cement.
- Lower risk of microleakage.
- Reduced plaque retention at the restoration margin.
- Improved protection of the periodontal tissues.
- Lower potential for secondary caries.
- Greater consistency between restorations.
- Improved suitability for aesthetic areas because zirconia eliminates a visible metal substructure.

Zirconia may be particularly useful for anterior restorations, patients with high aesthetic demands, and selected implant-supported prostheses. Ni–Cr remains a mechanically reliable and economical material, especially for posterior restorations, but its conventional fabrication process may produce greater variability in marginal adaptation.[19]

The choice of material should not be based on marginal fit alone. Tooth preparation, margin placement, occlusal design, cement selection, isolation, scanning accuracy, laboratory expertise, and patient-specific factors must also be considered. A well-executed Ni–Cr restoration may perform successfully, while an improperly designed or processed zirconia restoration may still demonstrate unacceptable fit[20].

Limitations

The findings should be interpreted in light of the following limitations:

- The study was conducted in vitro under controlled laboratory conditions.
- Only 30 copings were evaluated, with 15 specimens in each group.
- The study evaluated single-unit copings rather than long- or short-span fixed dental prostheses.
- The copings were evaluated without cementation; therefore, the effect of cementation on marginal discrepancy was not assessed.
- Measurements were obtained only at selected marginal locations.
- Internal and axial discrepancies were not evaluated.
- The effect of veneering ceramic application and firing cycles was not investigated.
- Thermocycling, mechanical loading, fatigue, and long-term ageing were not incorporated.
- The study used one preparation design, one zirconia system, one Ni–Cr alloy, and specific laboratory equipment.
- The results may therefore not be generalizable to all CAD/CAM systems, alloys, preparation designs, or clinical situations.

Future research should include larger sample sizes, multiple digital systems, different preparation geometries, cemented restorations, three-dimensional measurement techniques, thermomechanical ageing, and long-term clinical follow-up. Comparison of zirconia with newer materials such as lithium disilicate, hybrid ceramics, PEEK, and additively manufactured metal frameworks may also provide clinically relevant information.

Conclusion

Within the limitations of this in vitro study, CAD/CAM-fabricated zirconia copings demonstrated significantly better marginal adaptation than conventionally cast nickel–chromium copings. Zirconia showed lower marginal discrepancies at all evaluated sites, including the mid-mesial, mid-distal, mid-buccal, and mid-palatal surfaces. The overall mean marginal discrepancy was 92.575±52.88492.575 \pm 52.88492.575±52.884 µm for

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zirconia and 157.262±43.856157.262 \pm 43.856157.262±43.856 µm for Ni–Cr. This difference was statistically significant (U=45.000, p=0.005)(U = 45.000,\ p = 0.005)(U=45.000, p=0.005). These findings support the use of CAD/CAM zirconia copings in clinical situations where precise marginal adaptation, aesthetic performance, and biological compatibility are important. Nevertheless, long-term clinical studies are required to confirm whether the improved in vitro marginal adaptation translates into superior clinical longevity and periodontal outcomes.

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Legend Figures, Tables and Graphs:



Fig 1: Stainless steel die



Fig 2: Lab scanner



Fig 3: 3 D model printer

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Fig 4: SEM



Fig 5: PVS impression of the master die

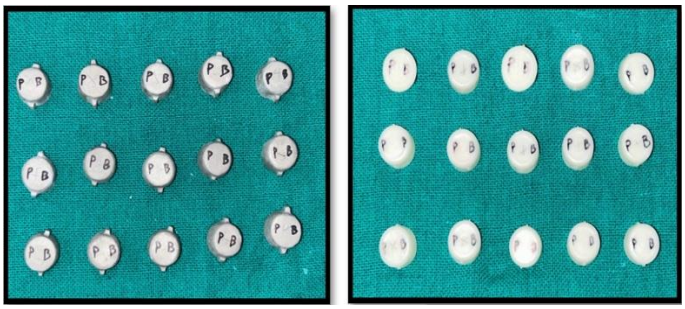


Fig 6: Ni-Cr and Zirconia copings



Fig 7: Resin model with zirconia coping



Fig 8: Gypsum model with Ni-Cr coping

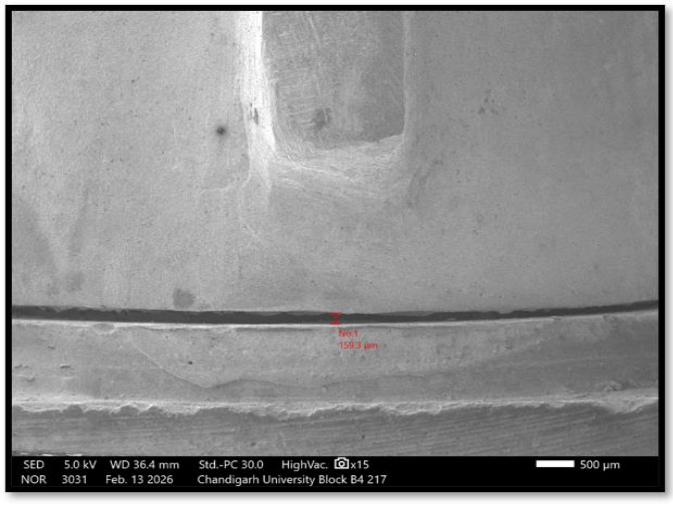


Fig 9: SEM photograph of Ni-Cr coping over gypsum model

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Fig 10: SEM photograph of Zirconia coping over resin model

Table 1: Distribution of samples in the study groups

Group	Counts	%
Nickel-Chromium Copings	15	50.0%
Zirconia Copings	15	50.0%

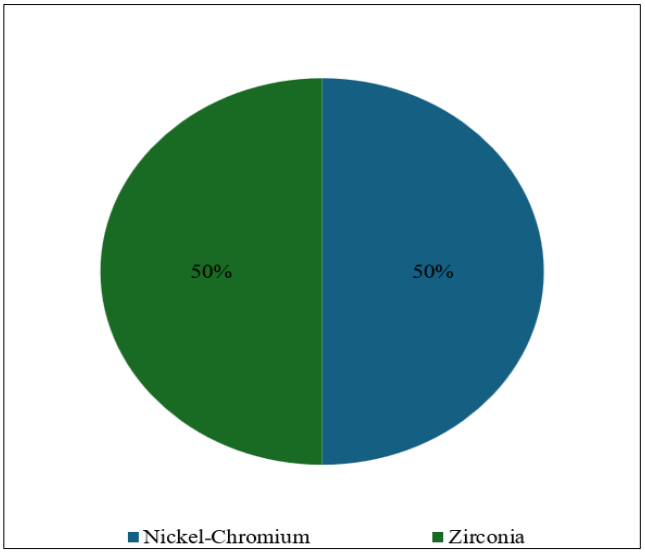
Table 2: Comparison of marginal discrepancy (µm) at various sites

	Coping	N	Mean	Median	SD	Min	Max
Mid-mesial	Ni-Cr	15	156.336	139.00	80.283	59.800	294.400
	Zr	15	88.241	72.910	62.029	26.300	189.100
Mid-distal	Ni-Cr	15	147.647	139.00	73.989	39.810	288.600
	Zr	15	84.028	77.580	62.581	19.750	249.000
Mid-palatal	Ni-Cr	15	174.455	187.00	76.502	66.800	398.000
	Zr	15	92.453	86.190	59.560	29.800	208.000
Mid-buccal	Ni-Cr	15	150.608	149.80	51.434	59.720	250.000
	Zr	15	105.576	86.180	69.695	28.300	228.000

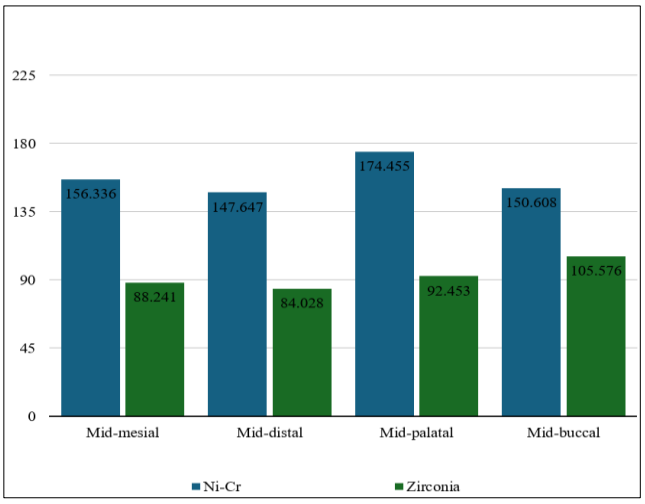
Table 3: Comparison of mean marginal discrepancy (µm) between the study groups

	Group	N	Mean	Median	SD	U	p value
Mean Marginal Discrepancy	Ni-Cr	15	157.262	141.700	43.856	45.000	0.005
	Zirconia	15	92.575	95.773	52.884		

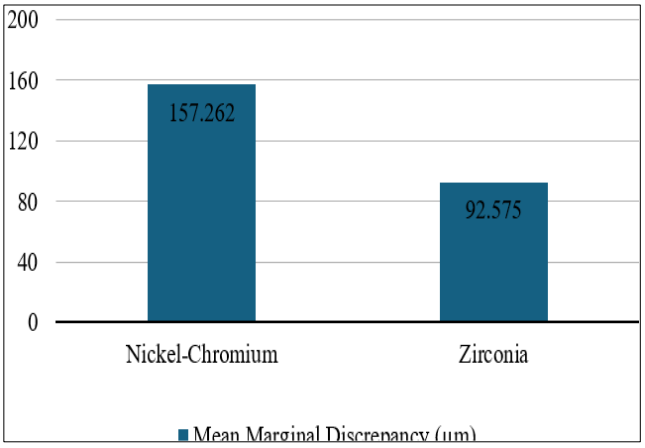
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Graph 1: Distribution of Samples in the Study Groups



Graph 2: Comparison of Marginal Discrepancy at Various Sites



Graph 3: Comparison of Mean Marginal Discrepancy between the Study Group

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