To Evaluate the Effect of Different Margin Designs on Marginal Accuracy and Fracture Resistance of Zirconia Core Restorations

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ABSTRACT

Introduction: The strength of all-ceramic restoration depends not only on the fracture resistance of the material but also on a suitable preparation design that provides adequate material thickness.

Objective: The purpose of the study was to evaluate the property of fracture resistance and marginal accuracy of zirconia core restorations with two different margin designs.

Methods: Two stainless steel dies, with deep chamfer and shoulder margin designs were fabricated. Impressions of the dies were made in polyvinylsiloxane material and poured in die stone followed by fabrication of zirconia copings using CAD/CAM technology. A stereomicroscope was used to evaluate the marginal accuracy before and after cementation. For testing fracture resistance, a universal testing machine was used.

Results: Comparison of mean values of marginal accuracy before cementation for deep chamfer $11.41 \pm 4.61\mu\text{m}$ and shoulder margin group $51.9 \pm 13.1\mu\text{m}$ and after cementation for deep chamfer $40.38 \pm 9.47\mu\text{m}$ and shoulder margin groups $77.4 \pm 14.3\mu\text{m}$ were calculated. The data for both the groups was statistically analyzed $P < 0.0001$. The mean value of fracture resistance for deep chamfer $1874 \pm 723\text{N}$ and shoulder margin $1069 \pm 288\text{N}$ was calculated, $P < 0.005$.

Conclusion: Hence within the limitations of the study, deep chamfer margin showed better marginal accuracy and fracture resistance than shoulder margin for zirconia copings.

Key Words: Dental ceramics, Deep chamfer, Fracture resistance, Marginal accuracy, Shoulder margin, Zirconia

INTRODUCTION

The demand for tooth-coloured restorations has surged by multitudes in the last decade.¹ Although a 94% success rate has been attributed to metal-ceramic restorations² due to their conservative preparation and satisfactory aesthetics, concerns have been raised regarding their biocompatibility and optical properties.³ On the other hand, properties like biocompatibility, light absorption, light scattering behaviour and relative affordability present a significant rationale for the use of all ceramics in dentistry.⁴ These materials can be defined by their inherent properties that form hard, stiff and brittle materials due to the nature of their inter-atomic bonding which is ionic and covalent.⁵

The all-ceramic restorations that were initially indicated exclusively in the aesthetic zone, are now also being used in

the posterior regions owing to advancements in the material science & fabrication methodology of dental ceramics. Longitudinal clinical studies evaluating glass-ceramic crowns^{6,7} and those with a densely sintered alumina core⁸ have shown similar results when compared to metal-ceramic crowns, but have shown higher failure rates in the posterior region, where these restorations are prone to brittle fracture.⁹ However, the use of toughened ceramics such as yttria-stabilized zirconia offers a more fracture-resistant application of all-ceramic crowns in the posterior region without compromising aesthetic qualities.¹⁰ Zirconia is a crystalline dioxide of zirconium. Its mechanical properties are very similar to those of metals and its colour is like tooth colour.¹¹

Zirconia ceramics have physical properties that can achieve twice the flexural strength and fracture toughness of densely sintered high purity alumina ceramics.^{11,12} The tetragonal

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crystals in the yttria-stabilized zirconium oxide ceramics are metastable and can be transformed into larger monoclinic crystals with the application of stress from cracks or flaws.¹³ This phenomenon is beneficial in hindering the crack growth and increasing fracture toughness; hence, it is referred to as transformation toughening.¹⁴

All-ceramic restorations must ensure requirements of fracture strength and precision for marginal accuracy to ensure their clinical success. Increased marginal discrepancies expose the luting agent to the oral environment leading to cement dissolution and microleakage.¹⁵ A weak cement seal permits the percolation of bacteria and causes inflammation of the vital pulp.¹⁶ *In-Vivo* studies have correlated a large marginal discrepancy with a higher plaque index and compromised periodontal health.¹⁷⁻²⁰

Since the preparation & fabrication of all-ceramic restorations are far more critical & technique sensitive as compared to metal-based restorations, adequate preparation guidelines are of paramount importance to ensure their success. The strength of an all-ceramic restoration depends not only on the fracture resistance of the material but also on a suitable preparation design that provides adequate material thickness.²¹ The most commonly used margin designs for all-ceramic restorations include chamfer, deep chamfer, chamfer with collar, round end shoulder & shoulder. The purpose of this study was to comparatively evaluate the effect of two margin designs deep chamfer and shoulder on the marginal accuracy & fracture resistance of zirconia core restorations.

MATERIALS AND METHODS

The study was carried out using two machined standard stainless-steel dies with a height of 7mm and diameter of 5mm.²² The marginal area of one machined die was prepared with a deep chamfer (Figure 1A) finish line (1mm depth) while the marginal area of the other die was prepared with a shoulder (Figure 1B) finish line (1mm depth). The convergence of the axial walls was kept at 10°. Four reference lines were scribed at the mid-point of each surface of the die (i.e. mid buccal, -distal, -lingual, -mesial) for evaluating the marginal accuracy. A custom tray for each die was fabricated for making the impression. Orientation grooves were machined on the base of the die to ensure the accurate fit of the custom tray (Figure 1C). Impression of each die was made using polyvinylsiloxane impression material (Dentsply AQ-UASIL; Monophase). An equal amount of base & catalyst paste was dispensed on a glass slab. Using a cement spatula, the two pastes were manipulated to achieve a uniform colour & consistency, after which it was carried onto the custom tray and an impression was made (Figure 1D and 1E). The impressions were poured in die stone (Kalabhai Ultrarock) following which zirconia copings (CDA ZIRCAM 5AXIS

CAD/CAM) of 0.4mm thickness with 35µm cement space²³ were fabricated on the stone dies, using CAD/CAM technology (Figure 2).

For evaluation of marginal accuracy before cementation, the fit of each coping was visually examined on the metal die before assessing the marginal accuracy. The marginal fit was evaluated by measuring the gap between the edge of the coping and the prepared steel die margin using a stereomicroscope (Wuzhou New Found Instrument Co. Ltd. China; Model: XTL 3400E) of 30X magnification Figure 3A and 3B. All the measurements were made perpendicular to the steel die axis.²⁴ At four different points (mid-buccal, mid-distal, mid-lingual, mid-mesial) the distance between the edge of the coping and the prepared steel die margin was measured using image analysis software.²⁴ Three measurements were made at each of the four positions; a total of 12 measurements per coping was performed. The mean of 12 values indicated the mean marginal accuracy value for each coping.²⁴

Before cementation, all the copings were thoroughly cleaned with distilled water and then air-dried. The copings were then luted to the master metal die with RelyX resin cement (3M ESPE) following the manufacturer's recommendation. During the cementation procedure, the crowns were placed under the constant pressure of 10N for 1 minute to ensure complete and uniform seating and polymerized with light exposure of 30 seconds per crown.²⁵ After removing the excess cement and cleaning the restoration margin, post cementation marginal gap analysis was executed in the same manner as previously described in Figure 3C and 3D.

For testing the property of fracture resistance, the cemented samples were loaded in distilled water at room temperature for 24hrs to mimic the hydrolytic effect of saliva on the ceramic.¹⁴ Mechanical testing was done using a Universal Testing Machine²⁶ (Star Testing Systems, India Make, Software Based Model no. MST5 248). The samples were clamped in the holder of the machine and loaded vertically on the occlusal surface. As the position of the applied force has a significant influence on fracture strength results, the loading piston was positioned at the center of the occlusal surface.²³ The load was applied along the long axis of each stainless-steel die with a crosshead speed of 3mm/min until fracture occurred. The fracture load data was automatically recorded using the software (Figure 4 A and B).

METHOD OF DATA ANALYSIS

Statistical analysis was done by descriptive statistics as mean, SD, etc. Comparison of groups was done by applying Student's 't' test (unpaired) and inter-group comparison by Student's t-test (paired). The level of significance (P) was calculated using SSPS Version 17.0 Software program.

RESULTS

The following values were obtained for Marginal accuracy (deep chamfer and shoulder) using Image analysis software and fracture resistance (deep chamfer and shoulder) using a Universal testing machine as shown in Table 1 and 2.

For marginal accuracy before cementation, the mean $\pm$ SD was $11.41 \pm 4.61\mu\text{m}$ (deep chamfer) and $51.9 \pm 13.1\mu\text{m}$ (shoulder margin) as shown in Table 3. The marginal accuracy was better in the deep chamfer group as compared to the shoulder group.

The mean $\pm$ SD of marginal accuracy after cementation were $40.38 \pm 9.47\mu\text{m}$ (deep chamfer) and $77.4 \pm 14.3\mu\text{m}$ (shoulder margin) as shown in Table 4. The data were analysed for both the groups using a student t-test which showed a statistically significant difference ($P < 0.0001$). The marginal accuracy was better in the deep chamfer group as compared to the shoulder group.

The comparison of marginal accuracy gap before and after cementation in deep chamfer and shoulder group is shown in Figures 5A and 5B. The marginal gap increased in both groups post cementation.

Similarly, fracture resistance for deep chamfer the mean $\pm$ SD was $1874 \pm 723\text{N}$ and for shoulder margin, the mean $\pm$ SD was $1069 \pm 288\text{N}$. The data was analysed using the student's t-test which showed a statistically significant difference ($P < 0.005$) as shown in Table 5. Chamfer margins showed a better fracture resistance as compared to shoulder margins.

DISCUSSION

Marginal fit & fracture strength are two important criteria for the clinical success & longevity of all-ceramic restorations. During a systematic review of clinical complications in fixed prosthodontics,²⁷ all-ceramic crowns showed an 8% incidence of complications, with crown fractures being the most common. A decrease in strength after thermal and/or mechanical fatigue has been reported for various ceramic materials. Ceramic materials are particularly vulnerable to tensile stresses, and mechanical resistance is also additionally influenced by the presence of superficial flaws and internal voids. Such defects may represent the sites of crack initiation.²⁶ This phenomenon could also be influenced by various factors, like marginal design and thickness of the restoration, residual processing stress, magnitude direction and frequency of the applied load, modulus of elasticity of restoration components, restoration cement interfacial defects and oral environmental effects.²⁸

It is desirable to possess close marginal adaptation to scale back the width of cement lines. Open marginal configurations encourage microleakage of bacteria and their by-prod-

ucts due to the dissolution of the luting agents. This will cause severe effects on the health of pulpal tissues. The connection between margin adaptation and periodontal health has been confirmed in experimental animals and humans.²⁹ Inaccurate margin adaptations also affect the fracture strength of the ceramic restoration. Hence, there's a continuing quest to determine the best way to minimize the width of the cement line within accepted technique constraints & increase the fracture strength of all-ceramic restorations.

This study aimed to comparatively evaluate the influence of two margin designs namely- deep chamfer and shoulder on the marginal accuracy and fracture resistance of zirconia core restorations. The metal dies utilized in this study, although not replicating the elastic modulus of teeth, were homogeneous in composition and provided even, void-free support for the ceramic restorations.²⁸ It has been previously stated that since metal dies are obtained by milling processes, they permit for more uniform measurements along any preparation^{30,31} compared to natural teeth³² or acrylic resin dies.³³ The non-uniform nature of the preparations within the natural teeth and acrylic resins incorporate other variables during discrepancy measurements. Thus, the utilization of metal dies aided in the standardisation of the study. In the present study, zirconia copings were tested without any veneering material, this is because studies have indicated that marginal gaps of zirconia crowns are within clinically acceptable limits after porcelain veneering³⁴ and that neither the veneering porcelain nor the thickness of the veneering porcelain had a significant effect on the compressive load to failure of bi-layered crowns.²⁸

The marginal accuracy was better with deep chamfer preparation as compared to the shoulder group; with a mean of $11.41\mu\text{m}$ & $51.9\mu\text{m}$ for deep chamfer & shoulder respectively, before cementation and $40.38\mu\text{m}$ & $77.4\mu\text{m}$ for deep chamfer & shoulder margins, after cementation, respectively. These results were in concurrence with the studies by Jalian et al., 2011²⁶ Pera et al., 1994³⁵, Att et al., 2009³⁶, Bindl et al., 2005³⁷ and contrary to the results obtained by Edson et al., 2004³⁸ and Souza et al., 2012³⁹

Gavelis et al., 1981⁴⁰ gave an insight into how the finish lines can affect cementation. The author stated that when the crown is cemented, the axial wall of the preparation approaches the axial wall of the interior crown surface. The escape path for the cement decreases causing the hydrostatic pressure within the crown to increase until it matches the patient's biting pressure. At this point, the crown fails to seat further. If the cement does not set, it will continue to escape until the particles at the axial walls prevent further seating.⁴⁰ Certain finish lines like deep chamfer used in this study, apparently facilitated the escape of cement early in the cementation process & thus offered a better seal with decreased width of the cement line.

The student's t-test revealed a significant difference in the fracture resistance between the two groups, with a deep chamfer margin showing a mean fracture resistance of 1874 N & shoulder margin of 1069 N respectively.

These results are in concurrence with the study carried out by Jalalian et al., 2011^{22,26} wherein the authors suggested that the chamfer margin showed better fracture strength than the shoulder margin because the marginal fit was superior in the former. They suggested that this could be because of a curve in the chamfer finish line that causes a better spread in the load. However, such a condition does not exist in a 90° shoulder margin that has sharp endings. According to their studies, shoulder margin had the worst marginal fit for all-ceramic restorations.

However, the fracture resistance of the two groups is more than biting forces & the marginal gap is within acceptable limits (120 µm). Resin cement is indicated for cementation of all-ceramic crowns; hence we have a strong marginal adaptation of the crowns that enhances the fracture strength. But a statistically significant difference exists between the two groups that revealed the deep chamfer margin has better fracture resistance than the shoulder margin.

CONCLUSION

The deep chamfer margin showed better marginal accuracy than the shoulder margin for zirconia coping restoration. Deep chamfer margin shows better fracture resistance than shoulder margin for zirconia copings. Both the margin designs showed clinically acceptable values for marginal accuracy ($\leq 120\mu\text{m}$). Within the limitations of this study, it can be concluded that preparation margin design influences the marginal accuracy and fracture resistance of all-ceramic restorations.

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Table 1: Values obtained for Marginal accuracy (deep chamfer) using Image analysis software and fracture resistance using Universal testing machine

Sample No.	Marginal Accuracy Before Cementation (µm)				Mean (µm)	Marginal Accuracy After Cementation (µm)				Mean (µm)	Fracture Resistance (N)
	MB	ML	MM	MD		MB	ML	MM	MD		
1	25.6	33.4	18.2	32.5	21.07	40.5	63.2	38.6	68.9	47.20	3384.8
	21.3	22.3	14.9	21.3		38.0	58.9	28.9	64.3		
	18.2	21.5	11.2	12.5		30.4	45.3	30.9	58.6		
2	17.9	0.0	25.1	14.3	12.34	23.7	15.0	46.6	32.5	28.16	1017.24
	21.5	0.0	26.3	0.0		32.3	13.9	53.8	12.5		
	14.3	0.0	28.7	0.0		25.1	19.2	49.8	13.6		
3	17.9	10.8	0.0	25.1	11.07	50.2	64.5	63.8	56.9	61.12	2068.78
	14.3	14.3	0.0	21.8		53.8	71.7	66.2	50.3		
	7.2	3.6	0.0	17.9		60.4	71.8	70.1	53.8		
4	7.2	33	14.3	11.3	17.55	46.7	67.9	79.0	45.6	53.77	1911.0
	3.6	35.8	14.3	8.0		53.8	58.4	68.4	34.9		
	7.2	35.8	21.8	18.3		57.3	48.7	46.7	37.9		
5	13.1	7.2	7.2	0.0	5.61	33.6	26.7	33.3	25.8	32.62	1044.68
	7.2	14.3	0.0	0.0		28.9	45.9	24.6	32.6		
	14.8	3.6	0.0	0.0		45.7	37.8	31.9	24.7		

Table 1: (Continued)

6	7.2	11.3	0.0	6.0	5.66	34.6	45.6	38.5	37.5	38.7	3083.08
	8.5	10.8	0.0	8.0		56.7	38.9	45.6	34.7		
	6.8	9.4	0.0	0.0		25.7	36.7	47.2	22.7		
7	0.0	7.2	10.8	9.8	8.47	45.6	47.8	46.3	39.8	39.93	1799.28
	10.8	6.6	11.2	8.5		34.7	34.5	38.9	45.7		
	5.8	8.4	12.4	10.2		24.5	29.5	34.5	57.4		
8	10.8	14.8	10	6.5	7.97	34.6	44.8	45.7	34.6	41.79	1777.72
	6.2	14.3	0.0	8.0		26.8	57.9	56.8	45.6		
	5.4	11.8	4.0	3.9		43.5	38.5	47.9	24.8		
9	15.8	0.0	0.0	11.2	8.6	38.9	15.8	15.7	34.6	33.89	1220.1
	13.2	10.2	0.0	14.1		34.7	40.6	34.7	58.9		
	10.4	6.8	8.9	12.6		28.9	39.7	28.8	35.4		
10	6.5	0.0	20.6	17.8	12.28	29.8	12.4	59.7	34.7	34.33	1600.34
	10.4	10.2	18.9	19.4		34.7	30.2	32.7	45.6		
	11.2	0.0	11.2	21.2		29.7	18.9	45.7	37.9		
11	11.2	16.1	8.9	17.8	13.44	39.8	38.5	36.9	37.8	38.31	1850.11
	0.0	13.2	12.2	19.4		20.1	36.8	45.7	40.3		
	8.6	18.6	14.1	21.2		49.8	45.9	28.7	39.5		
12	0.0	22.6	20.1	0.0	12.75	17.8	47.6	40.2	20.0	34.69	1734.65
	11.6	24.9	18.6	9.1		24.3	38.2	37.5	33.2		
	12.8	19.2	14.1	0.0		30.5	29.6	46.8	50.6		

Table 2: Values obtained for Marginal accuracy (Shoulder margin) using Image analysis software and fracture resistance using Universal testing machine

Sample No.	Marginal Accuracy Before Cementation (μm)				Mean (μm)	Marginal Accuracy After Cementation (μm)				Mean (μm)	Fracture Resistance (N)
	MB	ML	MM	MD		MB	ML	MM	MD		
1	37.8	27.5	33.4	22.3	38.73	67.8	56.7	67.9	40.7	65.7	1024.56
	45.7	45.6	56.7	43.6		60.9	78.0	87.0	70.8		
	34.9	36.9	45.7	34.7		76.7	67.6	55.4	58.9		
2	10.8	39.4	19.3	18.6	22.15	32.3	52.4	32.3	33.1	38.23	1445.5
	14.3	46.7	17.9	22.4		32.4	49.8	28.7	36.8		
	12.6	32.3	16.8	14.8		43.0	51.2	32.3	34.5		
3	53.9	71.8	59.7	58.3	65.27	65.3	86.4	71.4	75.2	77.34	1450.78
	78.9	82.4	63.8	60.3		85.2	93.3	80.2	79.3		
	64.5	69.2	55.4	65.1		63.2	85.0	65.3	78.3		
4	71.7	53.8	61.5	64.3	57.15	90.2	69.8	80.2	80.5	78.02	1467.06
	46.6	61.0	56.2	55.1		85.6	80.2	76.5	77.6		
	60.9	50.2	53.8	50.7		62.3	70.3	73.9	89.2		
5	43.0	48.5	43.0	41.8	41.96	62.3	80.2	60.2	89.3	72.21	907.48
	28.9	44.8	35.8	39.6		50.1	71.3	70.1	86.2		
	46.7	42.6	43.0	45.9		68.3	68.5	80.3	79.8		

Table 2: (Continued)

Sample No.	Marginal Accuracy Before Cementation (µm)				Mean (µm)	Marginal Accuracy After Cementation (µm)				Mean (µm)	Fracture Resistance (N)
	MB	ML	MM	MD		MB	ML	MM	MD		
6	64.5	58.9	53.8	55.6	57.45	90.2	88.2	93.3	86.2	90.67	1224.02
	60.9	61.3	43.0	51.8		79.4	91.3	96.2	89.0		
	57.3	62.4	61.0	58.9		95.3	90.6	98.2	90.2		
7	78.9	61.2	57.3	52.4	59.85	95.8	85.6	77.8	83.1	84.28	1257.73
	64.6	68.4	46.6	55.6		91.31	80.9	80.2	82.4		
	64.5	60.6	57.3	50.8		90.4	79.8	78.5	85.6		
8	39.4	41.2	57.3	51.4	43.51	78.5	80.6	90.2	90.3	79.41	833.98
	32.3	38.6	35.8	55.1		65.4	73.2	88.6	85.4		
	39.4	40.1	43.0	48.6		67.9	76.8	67.5	88.6		
9	53.9	59.6	75.3	70.5	63.88	88.6	78.6	97.5	88.5	88.67	631.12
	61.2	62.4	60.9	65.8		95.6	87.5	90.2	86.3		
	58.6	57.1	71.7	69.6		93.4	81.5	88.3	88.1		
10	69.1	63.8	65.6	67.8	66.64	98.2	88.8	90.0	85.3	89.86	830.60
	65.7	66.5	71.2	71.2		91.4	97.5	91.2	82.2		
	70.1	60.3	63.5	64.9		90.0	80.0	93.4	90.4		
11	51.2	58.2	60.1	48.9	53.50	70.5	88.9	88.5	75.5	80.71	915.0
	49.8	54.5	54.6	49.8		76.4	82.1	78.4	73.2		
	53.6	53.9	55.2	52.3		85.2	86.5	77.2	86.2		
12	52.6	49.6	51.3	53.1	52.20	70.4	88.7	89.6	90.3	83.21	842.34
	50.1	47.8	57.9	50.5		76.5	82.1	84.5	88.6		
	53.8	52.6	54.4	52.8		89.0	76.3	76.4	86.2		

Table 3. Comparison of marginal accuracy before cementation in deep chamfer and shoulder group

	Deep Chamfer (n=12)		Shoulder (n=12)		t Value	P Value
	Mean	SD	Mean	SD		
Marginal Accuracy gap	11.41	4.61	51.9	13.1	10.08	<0.0001

Table 4: Comparison of marginal accuracy after cementation in deep chamfer and shoulder group

	Deep Chamfer (n=12)		Shoulder (n=12)		t Value	P Value
	Mean	SD	Mean	SD		
Marginal Accuracy gap	40.38	9.47	77.4	14.3	7.47	<0.0001

Table 5: Comparison of fracture resistance in deep chamfer and shoulder group

	Deep Chamfer (n=12)		Shoulder (n=12)		t Value	P Value
	Mean	SD	Mean	SD		
Fracture Resistance	1874	723	1069	288	3.59	<0.005

Figure 1: A. Custom made stainless-steel die shoulder margin B. Custom made stainless-steel die deep chamfer margin C. Custom tray D. Impression made using custom tray E. AQ-UASIL MONOPHASE impression.

Figure 2: Fit of the Zirconia Coping evaluated on the stone die.

Figure 3: Marginal gap before cementation (A-DeepChamfer margin; B-Shoulder Margin) and after cementation (C-Deep Chamfer margin; D-Shoulder Margin).

Figure 4: Fracture load applied at the center of the occlusal surface at a crosshead speed of 3mm/min. A- Deep Chamfer margin; B- Shoulder Margin.

Figure 5: A. Bar diagram showing comparison of marginal accuracy gap before and after cementation in deep chamfer group B. Bar diagram showing comparison of marginal accuracy gap before and after cementation in shoulder group.