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ORIGINAL ARTICLE

Influence of convergence angle and cement space on adaptation of zirconium dioxide ceramic copings

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Abstract

Objective. The purpose of the present study was to evaluate the influence of total convergence angle and cement space on internal and marginal adaptation of posterior zirconium dioxide (zirconia) ceramic copings. ***Material and methods.*** Seventy-two standardized mandibular first molar zirconia copings were fabricated with nine parameters: three different total convergence angles (6°, 12°, and 20°) with three different computer-fixed cement spaces (10, 30, and 60 μm). Marginal adaptation was assessed to measure vertical discrepancy between the coping and abutment by direct viewing. Internal adaptation was evaluated using the cement replica technique with a laser microscope. The Kruskal-Wallis test and Wilcoxon rank-sum test were performed to test for differences in internal space and marginal discrepancy values ($a = 0.05$). ***Results.*** The median of mean internal spaces/marginal discrepancies ranged from 54.0/27.4 to 128.1/77.8 μm. Statistically significant differences in the internal spaces were found between groups with 6° and 20° convergence angle, regardless of cement space. The different cement spaces did not have any significant influence on the 12° and 20° convergence angle groups. The 60-μm cement space group exhibited statistically smaller marginal discrepancies than the 10-μm cement space group in all the different convergence angles. ***Conclusions.*** Within the limitations of the present study, the internal spaces of zirconia ceramic copings may decrease as the convergence angles of abutments increase. The computer-fixed cement space might influence the marginal adaptation of zirconia ceramic copings. The internal and marginal adaptation of zirconia ceramic copings obtained was within the range of clinical acceptance.

Key Words: *Adaptation, cement space, convergence angle, zirconium dioxide*

Introduction

With the development of ceramic materials in the past decade, all these materials for fixed restorations are more and more commonly being used in the posterior and anterior regions. The advent of CAD/CAM technology has facilitated the use of zirconium dioxide (zirconia) ceramics for posterior fixed restorations. Zirconia, a high-strength ceramics, exhibits several advantages, including high flexural strength (>1 GPa) or fracture toughness ($K_{IC} = 9$–$10\ MN/m^{3/2}$) [1], biocompatibility, and acceptable optical properties. Clinical studies on zirconia ceramic restorations have shown a high success rate over a relatively short evaluation period [2,3].

Excellent adaptation is essential for successful all-ceramic restoration in terms of longevity. Poor internal adaptation can reduce the resistance to fracture of all-ceramic restorations. Previous studies have suggested that internal spaces between 50 and 100 μm were advocated as standard with regard to the performance of resin cements [4,5]. A large marginal opening allows more plaque accumulation, gingival crevicular fluid flow, and bone loss, resulting in microleakage, recurrent caries, and periodontal disease. Most researchers agree that the clinically acceptable range of marginal discrepancy is from 50 μm to 120 μm in terms of longevity of the restoration [6–8]. The adaptation of zirconia ceramic restorations fabricated with CAD/CAM has been evaluated in several investigations [9–12]. In a clinical study, the mean marginal discrepancy for zirconia ceramic restorations was 65 μm, whereas mean internal

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spaces of 39 to 105 μm have been reported [12]. In laboratory studies, the reported mean marginal discrepancies ranged from 22 to 42 μm [10,11] and the internal spaces were 41–192 μm for single zirconia restorations [9–11]. Some *in vitro* studies [13–15] on the internal or marginal adaptation of all-ceramic restorations have evaluated the influence of convergence angles and cement spaces which affect adaptation of the fixed restorations. These studies reported conflicting and high variable results [13–15]. To date, however, there is little information on the integrity of zirconia ceramic restorations with different convergence angles and cement spaces of posterior abutments.

The purpose of the present study was to evaluate the influence of different convergence angle and cement space on internal and marginal adaptation of posterior zirconia ceramic copings fabricated with CAD/CAM technology.

Material and methods

Twenty-four steel dies (SUS303) were designed to simulate all-ceramic full-coverage crown preparation for a mandibular first molar. Three different total convergence angle designs were prepared 6°, 12°, and 20° (Figure 1). Each steel die was machined 4 mm in height with a rounded shoulder preparation. A lateral notch was placed cervical to the finish line for exact positioning of the ceramic copings during measurement. An impression of each steel die was made with a hydrophilic vinyl impression (Take1; Kerr USA, Romulus, Mich., USA) using a custom-made impression tray (Tray Resin; Shofu, Kyoto, Japan). Impressions were poured with vacuum-mixed Type IV dental stone (New Fuji Rock; GC, Tokyo, Japan).

All stone dies were scanned with a non-contact laser in the CAD machine (Cercon Art; DeguDent, Hanau, Germany). Next, the ceramic copings were designed using Cercon Art software (DeguDent): the copings were standardized with 0.5-mm thickness and three different cement spaces (10, 30, and 60 μm). The data designed were transferred to the CAM unit and 72 copings were milled out from partially sintered zirconia ceramic blanks (Cercon Base; DeguDent). Subsequently, all machine-milled copings were final-sintered in a special furnace (Cercon Heat; DeguDent) at 1300°C and finalized.

Internal adaptation of the copings was evaluated by measuring the internal space width using the cement space replica technique [12,13,16,17]. White silicone paste (Fit Checker; GC) was applied to the inner surface of each coping and then the coping was seated on the corresponding steel die with a force of 30 N. When the white silicone paste had polymerized, the coping, along with the paste, was carefully removed from the steel die. The thin silicone film in the coping was stabilized by injecting a black silicone paste (Bite-Checker; GC). After polymerization of the black silicone paste, a lump of the two silicone pastes adhered was removed from the coping. This lump was used as a cement space replica. For measuring points of internal adaptation, the replicas were segmented in the labio-lingual direction with a scalpel (Stainless Surgical Blade #11; Feather Safety Razor, Osaka, Japan) and seven standardized sliced surfaces on cross section were used (Figure 2). The width of white silicone was measured as the perpendicular distance at five points in each of the seven sections using a laser microscope (1LM21W; Lasertec Inc., Yokohama, Japan). Measurements were performed by viewing the specimens at ×250 magnification using software (SALT; Mitani Corp., Fukui, Japan) of a high-resolution image processing analysis system. The mean of 35 points was defined as the internal space width of a specimen.

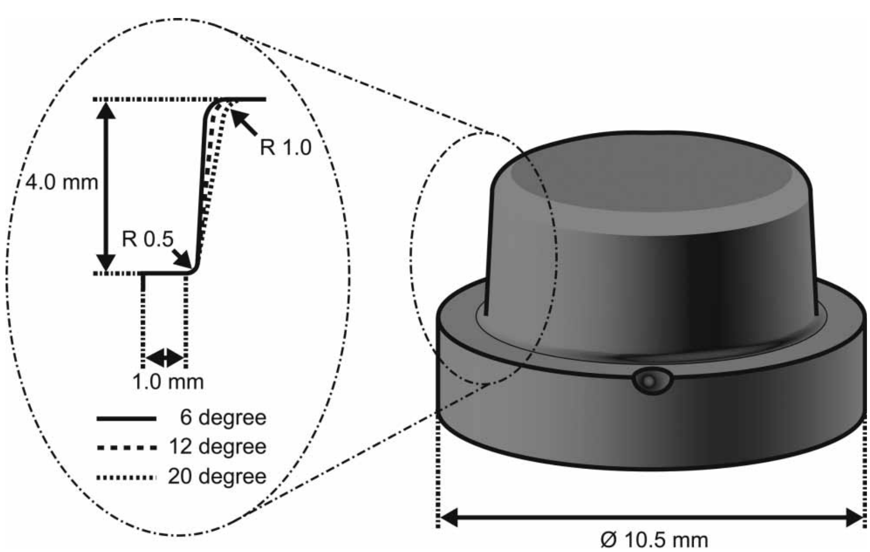

Figure 1. Illustration of steel dies with three different total convergence angles.

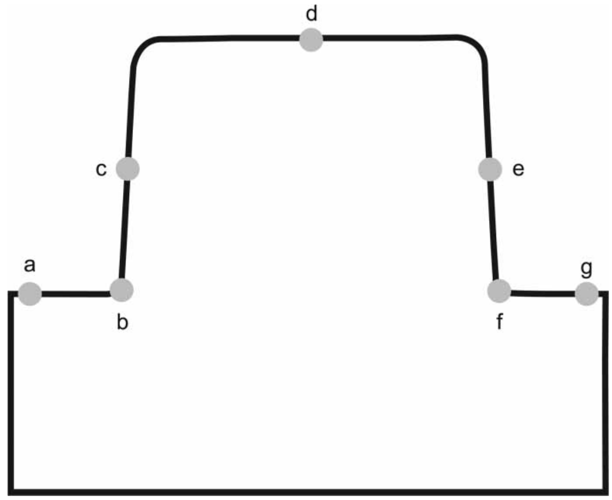

Figure 2. Locations in which internal space width was measured. (a, g), Marginal area (300 μm internal from the restoration margin); (b, f), finish line angle; (c, e), mid-axial area; (d), occlusal area.

The vertical discrepancy between the external edge of the coping and preparation limit of the abutment was defined as the standard for marginal adaptation. The copings were fixed to own steel dies with a tiny amount of temporary dental cement (Temporary Pack; GC). After the specimens were placed on a jig to fix them parallel, each specimen was measured perpendicular to the abutment axis in 60 points of all the circumferences [17,18] using a laser microscope (1LM21W; Lasertec Inc.). The mean value of marginal discrepancy was calculated for each specimen, and this was used to determine the median marginal discrepancy of each group.

The Kruskal-Wallis test and the Wilcoxon rank-sum test were performed to identify differences in internal space width or marginal discrepancy values between all groups. The global significance level of 0.05 was achieved by correcting the p-values according to the Bonferroni-Holm method.

Results

The descriptive statistics of the internal spaces and marginal discrepancies in all groups are presented in Table I.

The median of mean internal spaces ranged from 54.0 to 128.1 μm. The median internal space values in the group with 6° convergence angle – 10-μm cement space (6–10 group) were high compared with the other groups. Statistically significant differences in the internal spaces were found between groups with 6° and 20° convergence angle regardless of the computer-fixed cement space ($p < 0.01$). There were no significant differences in the different cement spaces for the 12° ($p = 0.07$) and 20° ($p = 0.39$) convergence angle groups.

In all groups, the median of marginal discrepancies varied from 27.4 to 77.8 μm, and the median marginal discrepancies of the 6–10 group were the highest. The 60-μm cement space group exhibited statistically smaller marginal discrepancies than the 10 μm cement space group in all different convergence angles ($p < 0.01$ or $p = 0.01$). The marginal discrepancies of the 60-μm cement space group were significantly smaller than those of the 30-μm cement space group ($p < 0.01$), except in the 6°convergence angle specimens ($p = 0.19$). For the effect of convergence angle, there was no significant difference in the 30-μm cement space groups ($p = 0.51$). However, significant differences were determined in all angles of the 60-μm cement space groups ($p < 0.01$).

Discussion

Data on clinical adaptation would be indicative of the clinical quality of fixed restorations. In the present *in vitro* study, marginal and internal adaptation of posterior zirconia ceramic copings was evaluated with different convergence angles and cement spaces fixed by computer. The adaptation of the copings in the present study was assessed without porcelain veneering because the copings principally define the overall adaptation of veneered crowns [17,19]. Consequently, the present study focused on the differences of the abutment forms, particularly convergence angle and computer-fixed cement space.

In the present study, the internal adaptation of the 20° convergence angle group exhibited statistically smaller internal spaces compared with that of the 6° convergence angle group, regardless of the computer-fixed cement space. In addition, significant differences between the 6° and 12° convergence angles were shown in the internal adaptation, except for the group with 30-μm cement space. Such results may affect the scanning accuracy of the abutments with the laser. The scanning accuracy of abutments could have been enhanced with a larger convergence angle of abutment in the present study, since the increase in convergence angles makes the scanning more precise. These findings would indicate that the internal spaces reduce as the convergence angles of abutments increase. However, fracture resistance of the all-ceramic restoration can be related to the convergence angles of abutments [20,21]. Therefore, clinically appropriate convergence angles of the abutments should be determined in terms of both adaptation and fracture resistance. Some researchers have shown a positive relationship between convergence angles of the abutments and internal spaces of all-ceramic restorations fabricated using the CAD/CAM system [13,14]. The findings of the present study are in contrast to those of the previous studies. This may be due to the differences in scanning methods between the previous studies and the present study. A method of optical impression was employed for scanning the abutments in the previous

Table I. Descriptive statistics of the internal space and marginal discrepancy values of the zirconia ceramic copings assessed

	10 μm cement space					30 μm cement space					60 μm cement space				
Total convergence angle	min	25%	median	75%	max	min	25%	median	75%	max	min	25%	median	75%	max
Internal space															
6 degree	117.6	121.7	128.1	142.1	165.4	59.3	60.2	62.3[a]	64.1	67.7	63.1	67.9	70.0	72.2	74.9
12 degree	50.3	54.2	56.2[b,c]	61.1	63.5	52.6	56.6	59.9[a,b,d]	65.1	68.3	58.0	61.1	62.8[b,e]	64.5	64.8
20 degree	49.1	53.0	55.5[c,f]	57.2	59.9	42.9	48.5	54.0[d,f]	56.6	60.8	52.6	53.5	55.1[e,f]	59.7	64.2
Marginal discrepancy															
6 degree	63.1	72.7	77.8	82.5	102.4	33.0	36.1	40.2[g,h]	42.1	42.3	31.2	35.4	37.1[g]	38.0	39.3
12 degree	28.4	37.8	43.4[i,j]	45.7	49.7	30.8	36.1	40.9[h,i]	44.1	46.2	26.9	28.7	30.4	31.8	33.8
20 degree	29.4	39.0	42.5[j,k]	45.6	49.3	28.0	33.0	36.1[h,k]	39.5	45.1	20.7	25.4	27.4	28.2	30.2

Identical superscript letters indicate that the median values are not significantly different ($p > 0.05$).

studies, while the abutments were scanned with a laser in the present study.

The present study assessed the influence of computer-fixed cement spaces on the internal adaptation of zirconia copings, and the results exhibited that, when the convergence angles of abutments were 12° and 20°, there were no significant influences of three different cement spaces on the internal adaptation. In contrast to the present study, Nakamura et al. [15] reported that the internal spaces of machine-milled ceramic (ProCAD, Ivoclar-Vivadent) crowns with 15-μm computer-fixed cement spaces were significantly smaller than those of crowns with 55-μm cement spaces. The disparity in the results may be attributed to the difference arising from the different types of ceramic materials used in each study. ProCAD ceramics do not shrink in the fabrication process. However, the zirconia ceramics used in the present study logically shrink up to 20–30%, since volume changes result from the relocation of material with bulk diffusion, surface diffusion, or gas phase.

In the present study, the 60-μm cement space group exhibited smaller marginal discrepancies than the 10- and 30-μm cement space groups in all the different convergence angles. These results are consistent with those of Nakamura et al. [14]. This finding in the present study is probably related to disappearance of the premature contacts between the abutments and coping internal surfaces in the increased computer-fixed cement spaces. Basically, procedures such as scanning, designing with software, and machining, can influence adaptation of the machine-milled restorations. The influence of the manufacturing procedures on adaptation is dominated by the effect of data acquisition [22]. Owing to the finite scanning resolution of the computer system, the point clouds obtained in scanning are transformed into a smooth, continuous surface by the software. This can result in some premature contacts and internal inaccuracies at interfaces between the abutments and crown internal surfaces [23]. Furthermore, zirconia ceramic copings machine-milled in partially sintered state undergo material shrinkage (20–30%) that occurs during the final sintering stage. This phenomenon could bring about some premature contacts at the interfaces. Therefore, the cement spaces fixed by the CAD/CAM system for all ceramic restorations need to be taken into consideration if the above-mentioned issues are to be evaded. Within the results of the present study, 60-μm cement space fixed by the CAD/CAM system might be favorable from the aspect of marginal adaptation of zirconia ceramic copings.

The internal and marginal adaptation in the present study was mostly within a clinically acceptable level, 50–100 μm and 120 μm, respectively. Only the 6–10 group showed relatively higher values for the internal and marginal adaptation compared with the other groups. A misfit of the zirconia ceramic copings can possibly result from an extremely small convergence angle in part of the abutments, even if the abutment form is generally appropriate in clinical practice.

The experimental design of the present study has some limitations which make it difficult to relate the results to clinical practice. Currently, no standardized method is available for measuring the marginal and internal adaptation, although several techniques have been reported, including direct viewing, sectioning, impression taking to make replicas and explorative and visual examinations. Because of the methodology used in the present study, measuring the internal adaptation of restorations required sectioning of the specimens. In the case of sectioning, the measurements are limited to distinct points. Moreover, in the present study, the abutments were simply standardized on a prepared tooth for the application of all-ceramic full-coverage crowns on a mandibular first molar. However, in clinical practice, tooth preparations vary with natural tooth form, axial heights of the abutments, and different line angles. Thus, further investigations will be necessary to confirm the results obtained in the present study.

Within the limitations of the present *in vitro* study, it can be concluded that the internal space widths of zirconia ceramic copings may decrease with an increase in the convergence angles of the abutments. When the convergence angles of abutments were 12° and 20°, there were no significant influences of three different computer-fixed cement spaces on the internal adaptation. However, the computer-fixed cement spaces might influence the marginal adaptation of zirconia ceramic copings. The median internal space and marginal discrepancy values of zirconia ceramic copings obtained in the present study were within the range of clinical acceptance.

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