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Determination of the Fabricating Conditions for the Preferable Marginal and Internal Adaptation of the Mica Crystal Castable Ceramic Crown

Shinichi UKON[1], Masatugu ISHIKAWA[1], Monica TOHYAMA[2] and Hironobu SATO[1]
[1]Department of Oral Rehabilitation, Division of Fixed Prosthodontics, Fukuoka Dental College, 2-15-1 Tamura, Sawara-ward, Fukuoka 814-01 Japan
[2]Private Practice, N:321Casilla, Santa Cruz, Bolivia
Corresponding author, E-mail: baronuk@college.fdcnet.ac.jp

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This study was performed to find an acceptable internal adaptation of castable ceramics containing mica and β-spodumene crystals. The influences of factors, expansion rate of phosphate-bonded investment (A), anisotropic expansion (B), die-coating (C), shrinkage during crystallization (D), and interaction (A×B), and (A×C) were tested by twice repeated experiments under block design according to $L_8(2)^7$ orthogonal array. Estimated mean ranges under the conditions combined with significant factors were judged by considering the criteria of the ideal internal gap (about 50 μm).

The ideal marginal fit of less than 50 μm and uniform cement space about 50 μm around the axial wall could be achieved by a combination of optimum levels of $A_1B_1C_2D_2$. However, the estimated mean gap at the cusp tip and central fossa of occlusal inside by this combination were about 120 μm. The near intolerable gaps could not be reduced.

Key words: Internal gap, Castable ceramics, Fabricating condition

INTRODUCTION

Castable ceramics have great merit, because they can be completed by relatively simple procedures such as the lost wax technique and crystallizing heat treatment in esthetic restoration fabrication. They avoid technical skill and difficulties. However, it is a fact that all ceramic restorations are of questionable strength and clinical longevity for clinical use because of their brittle nature[1)].

Good internal adaptation of all ceramic restorations was required for not only a marginal seal or exerting retentive force but also for strengthening ceramic restorations after cementation. However, clinical tooth preparation forms such as the degree of facio-lingual curvature of the cervical margin, the occlusal reduction form, or additional retentive features and clinical crown length had more of a tendency to affect the magnitude of the marginal opening and internal gap than a simple geometric experimental master die form[2)]. Hata *et al.* developed glass ceramic containing mica and β-spodumene crystals (OCC) (Olympus Optico Co., Tokyo, Japan) for dental use in 1988. It revealed about 0.4〜0.7% casting shrinkage and 0.8% shrinkage by subsequent crystallizing heat treatment of the OCC crown, total shrinkage was almost 1.5%. The maximum surface roughness of about 30 μm (R max.) formed at the occlusal inside where cooling of the glassy cast developed at the slowest region in the mold, and occurred bonding silica in investment and glass[3,4)]. A thinner cement layer is more desirable, however, the cement space over 30 μm for the OCC crown was required to advocate the hitting internal surface to the abutment by the maximum surface roughness and to reduce the elevation by interfering complete seating of the crown.

Phosphate-bonded investment expansion has been available to compensate for casting high melting materials, and dilution of special investment liquid with distilled water has been available to regulate mold expansion[5)]. What degree of investment expansion was adequate to compensate for OCC shrinkage of casting and crystallization and to make acceptable cement space? Uneven expansion of the investment appeared in a cast ring in a radial direction and long axis direction toward the open end of the cast ring. It might have produced a greater gap in the occlusal surface with the amount of wax, and this phenomenon might introduce a weak point to the castable ceramic crown. Was it possible to reduce the greater gap by changing the sprue placement and orientation of the wax pattern in the cast ring for this uneven expansion?

The application of die-spacer has also commonly used to achieve a loose fit with adequate cement space and reduce frictional fit. Two to eight layers of die-spacer from 20 to 40 μm covered the axial wall to the axio-cervical line angle resulting in a decrease in crown elevation and an increase in crown retention after cementation[6,7)]. Was it possible to make the preferable cement space using selective die-spacer coating instead of uneven expansion?

Therefore, the authors concluded that if the cement space could be nearer by 50 μm uniformly at the inside with less of a marginal opening, then restoration would be acceptable for clinical use and could improve the strengthening of the castable ceramic restorations.

To establish the optimum magnitude of the marginal and internal adaptation, the following factors could affect the dimensional accuracy of a castable ceramic crown; 1) adequacy of investment expansion to compensate for the shrinkage during cast and crystallization, 2) uneven expansion of investment mold in the ring, 3) the die spacer coating on axial wall for the adjusting internal cement space and 4) the degree of the shrinkage by crystallization.

The purpose of this study was to examine the effects of these factors on the internal adaptation and to determine how to control these factors while at the same time establishing the optimum condition for finding a preferable internal fit of the castable ceramic OCC crown.

MATERIALS AND METHODS

The following were considered to be the main factors which influenced internal adaptation: 1) Special liquid consistency of phosphate bonded investment to water ratio (factor-A), 2) difference between spuring directions of the wax pattern set up in a cast ring for the nonuniform expansion of the investment (factor-B), 3) die spacer coating (factor-C) and 4) heat-treatment of crystallization (factor-D). In addition, we considered there to be two-way interaction between A and B, and A and C (A×B, A×C). These factors were placed in an $L_8(2)^7$ orthogonal array column using a Linear graph[8] in order to analyze the effects of these main and interactive factors on the variation of gap at different portions of the abutment tooth. Among these factors, heat treatment was a routine procedure, however, this factor was also analyzed to clarify the extent of distortion by making a comparison between as-cast glassy and ceramic crowns before or after crystallization. Eight kinds of experiments which combined four factors with two levels according to $L_8(2)^7$ orthogonal array were performed in random order and repeated twice under blocked design (Table 1, 2 and Fig. 1). Two wax patterns were made for each die, set on both ends of a runner bar in the same way, invested in a ring at room temperature of 24(±2)℃, and then cast. A total of 32 samples were fabricated. The one with less cast defects (bubbles, flash, defects, nodes, voids) in each pair was used, so sixteen crowns were used as study samples.

1. Dies

A right second premolar epoxy resin tooth (Nisshin, Osaka, Japan) was prepared as recommended by preparation design for all ceramic crowns[9]. It included an approximately 1.2 mm flat shoulder along the crown-root junction with a moderate bucco-lingial cervical curve. It was also prepared with approximately 8 degrees of total convergence of the axial

Table 1 Experimental conditions

Factor	level 1	level 2
A: Consistency of special liquid to water ratio	30%	0%
B: Direction of wax pattern	Vertical	Horizontal
C: Coating of axial wall	non-Coating	Coating
D: Crystallization	non-Treatment	Treatment

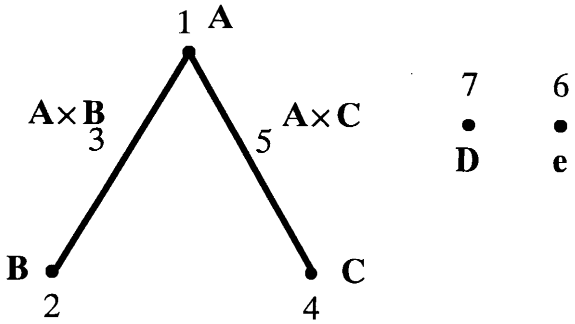


Fig. 1 Designing factors to the $L_8(2)^7$ orthogonal array column using a linear graph. The number shown in the linear graph is the array column number.

Table 2 $L_8(2)^7$ orthogonal array and combination of levels

Factor	A	B	A×B	C	A×C	e	D	Combination of Level
#Experiment \ Column / Level	1	2	3	4	5	6	7	
1	1	1	1	1	1	1	1	$A_1B_1C_1D_1$
2	1	1	1	2	2	2	2	$A_1B_1C_2D_2$
3	1	2	2	1	1	2	2	$A_1B_2C_1D_2$
4	1	2	2	2	2	1	1	$A_1B_2C_2D_1$
5	2	1	2	1	2	1	2	$A_2B_1C_1D_2$
6	2	1	2	2	1	2	1	$A_2B_1C_2D_1$
7	2	2	1	1	2	2	1	$A_2B_2C_1D_1$
8	2	2	1	2	1	1	2	$A_2B_2C_2D_2$

wall and 1.5 to 2.0 mm occlusal reduction. The metal mold was made from this master die, and then sixteen working dies were made from epoxy resin.

2. Die spacer application

Die spacer (Nice fit, Shofu, Kyoto, Japan) was applied onto the axial wall of the die except at the shoulder and occlusal surface as shown in Figure 2. Silver and gold colored spacers were painted alternately after a layer coating dried. Selective coating was performed in the following manner: first of all, a layer of die spacer was painted around the cervical third, then different colored spacer was over-coated to half of the axial wall, and finally two layers were applied to all of the axial wall. As a result, the cervical third of the axial wall was coated by four layers, the cervical-half by three layers and the occlusal third was painted by two layers of die spacer (Fig. 2).

The first level of the die spacer coating factor was designed by non-coating (C_1) and the second level was the coating application (C_2).

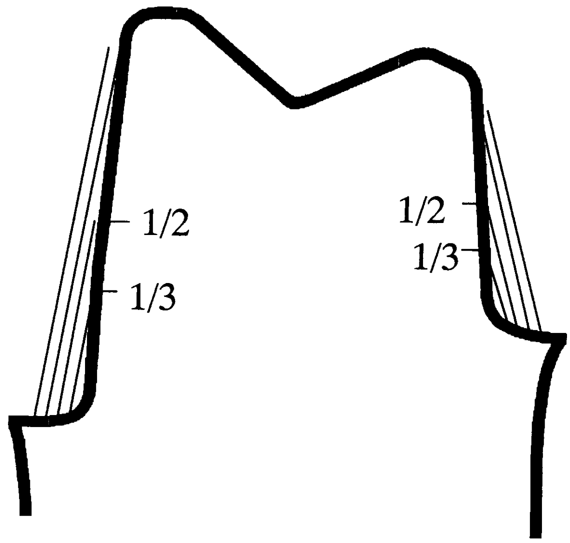


Fig. 2 Selective die spacer coating method on the axial wall.

3. Preparation of wax pattern fabrication

Complete wax patterns were fabricated on the dies directly (coating and non-coating). A split silicone putty mold was formed (Labo silicone, Heraus Kulzer GmbH, Wehrkein, Germany) using an abutment tooth overimpression before preparation in order to regulate the standardized outline form of complete wax crown for the die (Fig. 3). After dipping the die in molten soft wax (Inner wax, GC, Tokyo, Japan), the working die was seated into a split mold and molten hard wax (Gray inlay wax medium, GC, Tokyo, Japan) was poured into the gap. The silicone mold was compressed by finger pressure and held in place with a rubber band until cooling, then removed from the mold. After leaving it for two hours at least, the cervical margin was corrected by the dual wax technique with finger pressure and a warm beaver-tail burnisher to adjust open and over wax margins microscopically, then polished with cotton wool soaked in soapy water. The complete wax crown was put buck again in the silicone mold, then a very thin line was drawn by needle on the buccal and lingual surface of the crown along the juncture of the mold representing the center of the medio-distal plane. Two small dimples by a #1 steel round bar on the buccal surface and a same dimple or wax knob on the lingual site were made on the center line. A tapered sprue about 2 mm in length and a 1.5 mm diameter tip with 3.2 mm casting wax was attached to near the buccal cusp and coil vent with 1.0 mm casting wax to the opposite side near the cervical margin on the lingual surface. Both sprue and vent were also on the mid line. The dimples, knob, sprue and vent-sprue were available as guides of cutting direction (Fig. 4).

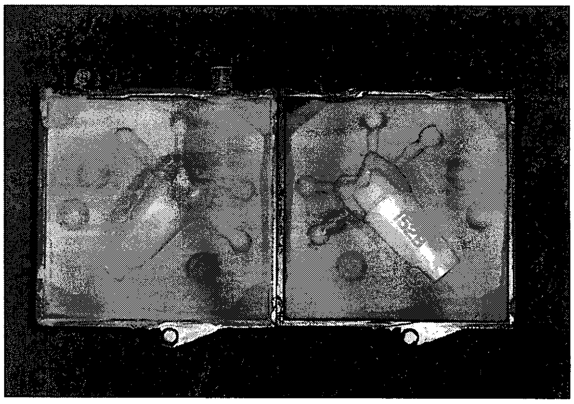


Fig. 3 Prepared abutment tooth and the silicone mold for wax crown fabrication.

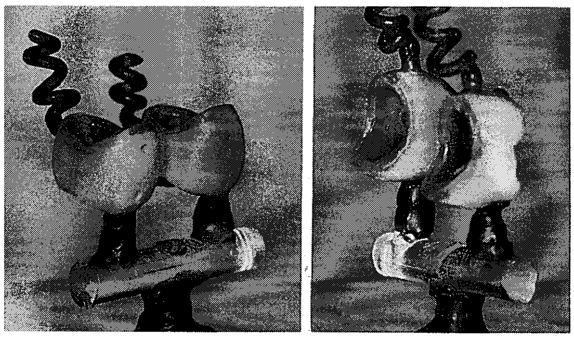


Fig. 4 Complete wax crown and spuring direction. Left picture shows vertical direction (B_1) set up and right is horizontal (B_2). The dimples, wax knob, sprue and vent were on the center of the mdio-distal plane and used the guides for the sectional plane.

Table 3 Manufacture's report on expansion at various dilution conditions of special investment liquid (liquid 17 cc/powder 100 g)

Dilution with water / Expansion	Liquid to water ratio			
	1 : 0	4 : 1	2 : 1	1 : 1
Setting	1.1	1.0	0.9	0.8
Thermal	1.2	1.2	1.1	1.0

4. Orientation of wax pattern in the ring

Two spurring methods were compared in order to consider the influence of anisotropic expansion of the investment as a factor. One was the vertical placement of the long axis of the crown-directed parallel (B_1), and another was at about a right angle to a sprue (B_2) in the ring as shown in Figure 4.

5. Investment

To adjust the mold expansion of the phosphate-bonded investment (Univest free, Shofu, Kyoto, Japan) to adequately compensate for casting and crystallizing shrinkage, two consistencies of the special liquid to distilled water ratio were designed, with 30% (A_1) water contained and undiluted special liquid (A_2), but the overall liquid/powder ratio remained constant (24 cc/140g). The relation between liquid/powder proportion and expansion (setting and thermal) in this study is listed in Table 3 with the manufacturers' report.

The wax pattern was painted vacuum mixed investment (Vacuum Mixer, Morita Corp., Osaka, Japan) with a small brush to prevent trapped air bubbles, then investment was poured into the ring. A ring liner of 1.0 mm thickness (Kaoliner, GC Co Ltd, Tokyo, Japan) coated with white Vaseline was placed inside of a stainless steel cast ring (43 mm in diameter and 60 mm in height).

6. Casting and divestment

After being bench set overnight, the rings were heated to 800℃ 20℃/min during the burnout process, kept at this temperature for a hour, then cooled down to 480℃ 10℃/min, and held for a half an hour at this temperature. Melting and casting of castable glass materials of OCC, composed of Li_2O, MgO, ZnO, TiO_2, Na_2SiF_6, Al_2O_3, SiO_2 and trace metal oxides as stain[2], was done automatically by a computer controlled motor-driven casting machine (Chuta, Olympus, Tokyo, Japan). Casting rings moved into a 480℃ furnace again immediately and held for five minutes for annealing, then allowed to cool on a bench.

The ring was divested and the cast glass crowns were blasted by 50 μm glass beads under two to three air pressures. Any internal minute bubbles of glass in the cast crown and excess marginal flash if would be present, they were removed by a #2 round carbide bar and fine carborundum bar with special care microscopically, then they were ultrasonically cleaned in distilled water for ten minutes (Ultra Sonic Cleaner, Shofu, Kyoto, Japan). One group of cast crowns (eight crowns) was subjected to the crystallizing process (D_2) and another remained as cast glassy crowns (eight crowns, D_1).

7. Measurement of the marginal and internal adaptation

Each cast glass crown and ceramic crown after the crystallizing process were placed onto their original dies individually and fixed by cyanoacrylate cement (Dental Cyanon, Koatsu Gas Kogyo Co. Osaka, Japan) while being hold with finger pressure. They were embedded in a translucent pored resin (Pala Press, Heraus Kulzer GmbH, Wehrkein, Germany) and sectioned in the central medio-distal plane by a rotational cutting machine (Isomet, Buehler, Illinois, USA) along guides. All longitudinal sections were adjusted to the cutting surface to including the previous described guiding points, and wet polished sequentially to #800 using emery paper.

The marginal and internal gaps at 9 selected points on the polished sections were measured using a digital high definition microscope (Digital Microscope, VH-7000, Keyence, Osaka, Japan) under 100× magnification. The 9 selected points were as following:

1 and 9: Vertical marginal gap from buccal and lingual finish line to 0.2 mm internally on the shoulder.
2 and 8: Internal gap at both axio-cervical line angle
3 and 7: Internal gap at the mid-point of both axial walls
4 and 6: Internal gap at the buccal and lingual cusp tips
5 : Internal gap at the central fossa

The measurements were repeated three times for each point on every crown, and measured values at both sites were averaged and used as combined data at each portion (Fig. 5).

8. Statistical analysis

The linear model whereby the mean response at the levels of A, B, C, and D was considered the following;

$$Y=\mu+\mu R+\mu A+\mu B+\mu AB+\mu C+\mu AC+\mu D+e+e(ABCD)$$

(Y: experimental data; μ: grand mean; μA, μB, μC, μD: main effect of A, B, C, D; μAB, μAC: interaction effect of A×B, A×C; μR: main effect of block (repeat); e: primary error; e(ABCD): secondary error)

The variance of primary error (experimental error) was estimated in the 6th column of orthogonal array (Fig. 1 and Table 1, 2) and secondary error

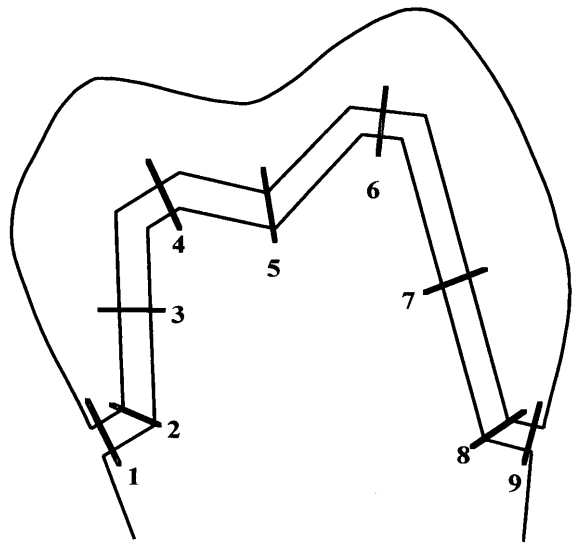


Fig. 5 Schematic drawing of measuring points to evaluate internal gap.

(variance within class of measurement error) was also calculated by being twice replicated. If no difference existed between the first and secondary error, they were pooled, and used as overall error.

Analysis of variance (ANOVA) was performed to find which main and interactive factors affected internal adaptation statistically between variables with a significance level of $p=0.05$, and an additional associated significantce level of $p=0.10$. The estimation of the gap at each portion was computed by the combination of significant factors at the two levels. The optimum condition was judged where these factors combinations would range within ideal criteria.

RESULTS

The following results were obtained from ANOVA. The Figure 6 (a~e) represents the estimation of effects of significant factors and the Figure 7 (a~d) shows the estimated mean of combined significant factors at each portion.

1. At the margin

The variance of marginal opening attributed to the crystallizing process (D; p=0.023, ρ=23.0%: D_1=24 ($\pm$8) μm, D_2=37($\pm$8) μm), and two-way interaction between degree of distilled water ratio and spuring direction (A×B; p=0.017, ρ=24.9%: A_1B_1=24($\pm$11) μm, A_1B_2=32($\pm$11) μm, A_2B_1=43($\pm$11) μm, A_2B_2=23 ($\pm$11) μm). In addition, the coating on axial surface acted as an associated significant factor (C; p=0.081, ρ=9.3%). The coating (C_2) had a tendency of reduce marginal gap. The estimated mean was 26($\pm$8) μm compared with 35 μm for non-coating (C_1). The other main and interaction factors were not significant (A: p=0.32; B: p=0.30; A×C: p=0.68; R: p=0.72). The less the gap of ceramic crown after the crystallization, the more desirable this portion, therefore the optimum condition could be determined to combine the least factors-level (Fig. 6-a).

As a result, the marginal opening showed the least under the condition of $A_1B_1C_2D_2$ (almost same $A_2B_2C_2D_2$). The mean of the optimum combination of $A_1B_1C_2D_2$ was estimated at 25($\pm$13) μm, that of $A_2B_2C_2D_2$ was 25($\pm$13) μm (Fig. 7-a).

2. At the axio-cervical line angle

The ANOVA results indicated that C-factor of the die coating (p=0.010 and ρ=17%: C_1=46($\pm$14) μm, C_2=74($\pm$14) μm) and D-factor of the crystallizing process (p=0.0004 and ρ=53%: D_1=85($\pm$14) μm, D_2=35($\pm$14) μm) influenced the internal gap at the base of the axial wall. The other main and interaction were no significant (A: p=0.16; B: p=0.11; A×B: p=0.68; A×C: p=0.36; R: p=0.29). The difference of internal gap (D_1-D_2) by shrinkage during the crystallizing process was estimated 50($\pm$20) μm. And the difference by coating (C_2-C_1) was 29($\pm$20) μm (Fig. 6-b).

The mean of the combination of the significant factor-level of C_1D_2, and C_2D_2 were estimated 21($\pm$17) μm and 49($\pm$17) μm, respectively. However, the criteria of the optimum gap was decided to be 30 to 50 μm, the combination of C_1D_2 that it was possible to hit inside. The die coating could be a closer optimum value (Fig. 7-b).

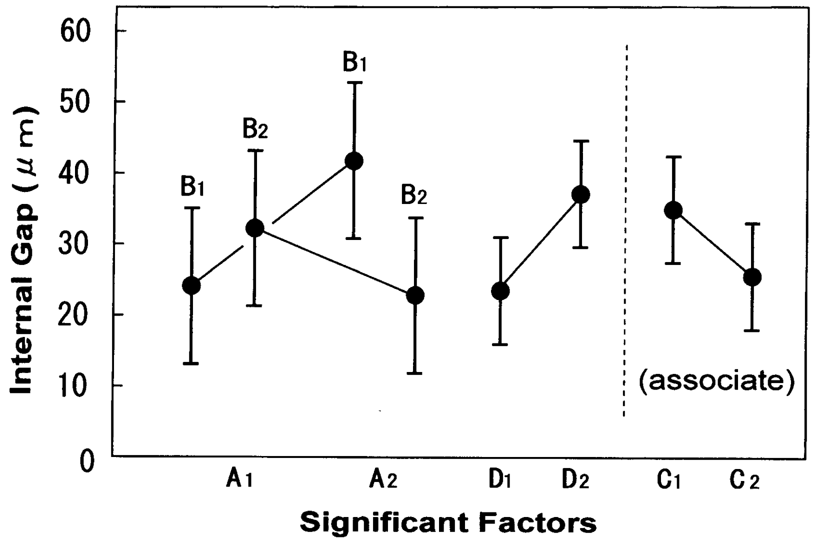
3. At the mid points of the axial wall

The factors which influenced the internal gap at the cervical half of the axial wall were D-factor (p=0.0002 and ρ=59%: D_1=120($\pm$15) μm, D_2=60 ($\pm$15) μm), C-factor (p=0.009 and ρ=15.4%: C_1=74 ($\pm$15) μm, C_2=106($\pm$15) μm), and B-factor of the spuring direction was associated (p=0.054 and ρ=6.0%: B_1=79($\pm$15) μm, B_2=101($\pm$15) μm). The other main and interactive factors were not significant (A: p=0.45; A×B: p=0.44; A×C: p=0.30; R: p=0.76). Concerning the estimated internal gap difference between the levels at each significant factor, crystallization (D_1-D_2) was 61($\pm$22) μm, the coating (C_2-C_1) was 32($\pm$22) μm and the investment direction (B_2-B_1) was 22($\pm$22) μm (Fig. 6-c).

After the crystallization process, the estimated mean of the combinations of the significant factor-levels increased as follows:

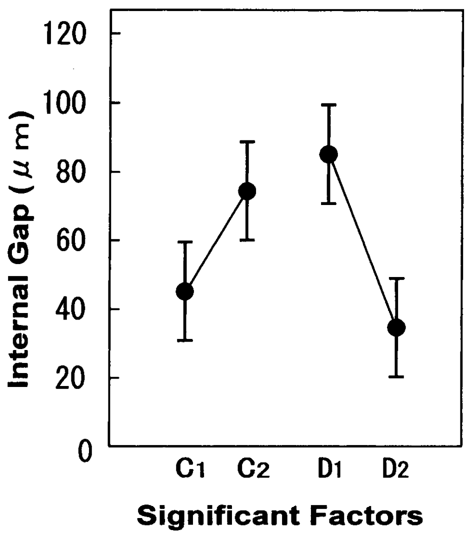
$$\mu(B_1C_1D_2)=33(\pm 22)\,\mu m < \mu(B_2C_1D_2)=54(\pm 22)\,\mu m$$
$$\fallingdotseq \mu(B_1C_2D_2)=65\pm(22)\,\mu m < \mu(B_2C_2D_2)=86\pm(22)\,\mu m$$

From this result, the combination of $B_1C_1D_2$ was the least gap, ranging from 11 to 55 μm, however, this value indicated the tendency for interference of the seating crown. The combination of $B_2C_2D_2$ was also greater than the ideal criteria. The combination of $B_2C_1D_2$ or $B_1C_2D_2$ fit the criteria, varying by 32~

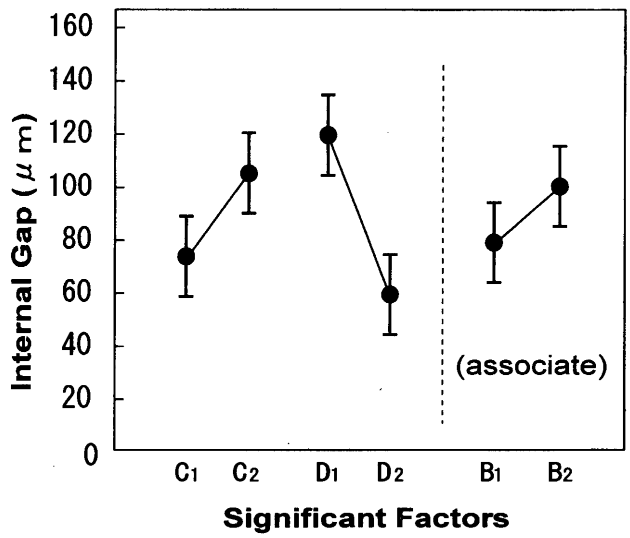


(a)

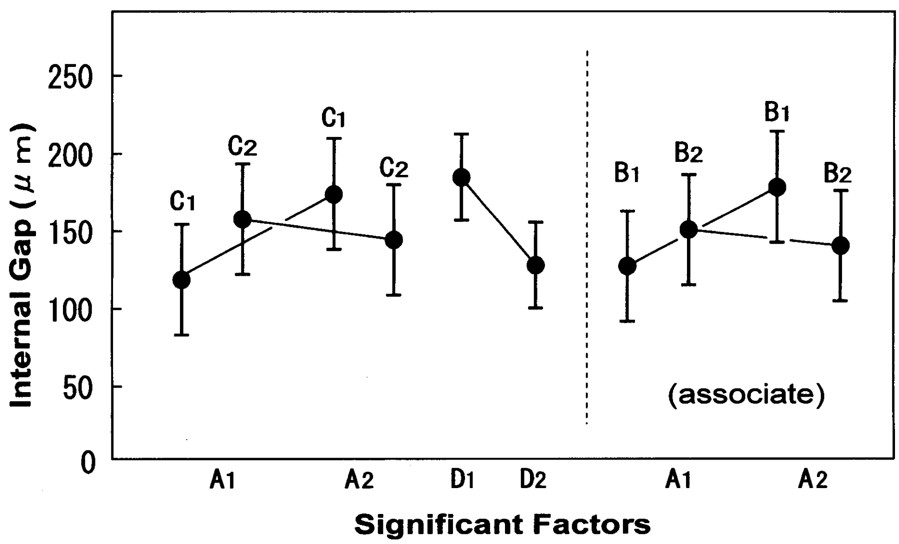
Fig. 6 Estimation of the effect of the significant factors on the marginal and the internal gap, (a) at the margin, (b) at the axio-cervical line angle, (c) at the mid point of the axial wall, (d) at the cusp tip and (e) at the central fossa. Vertical bars represent 95% confidence intervals.



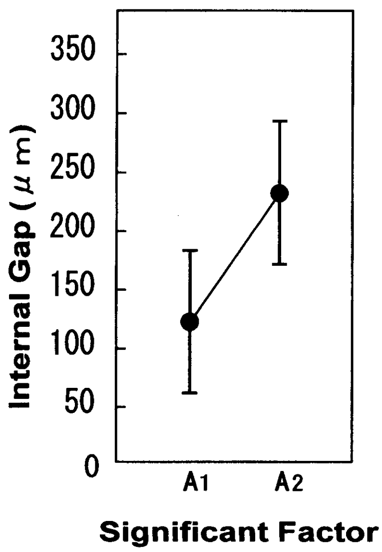
(b)



(c)



(d)



(e)

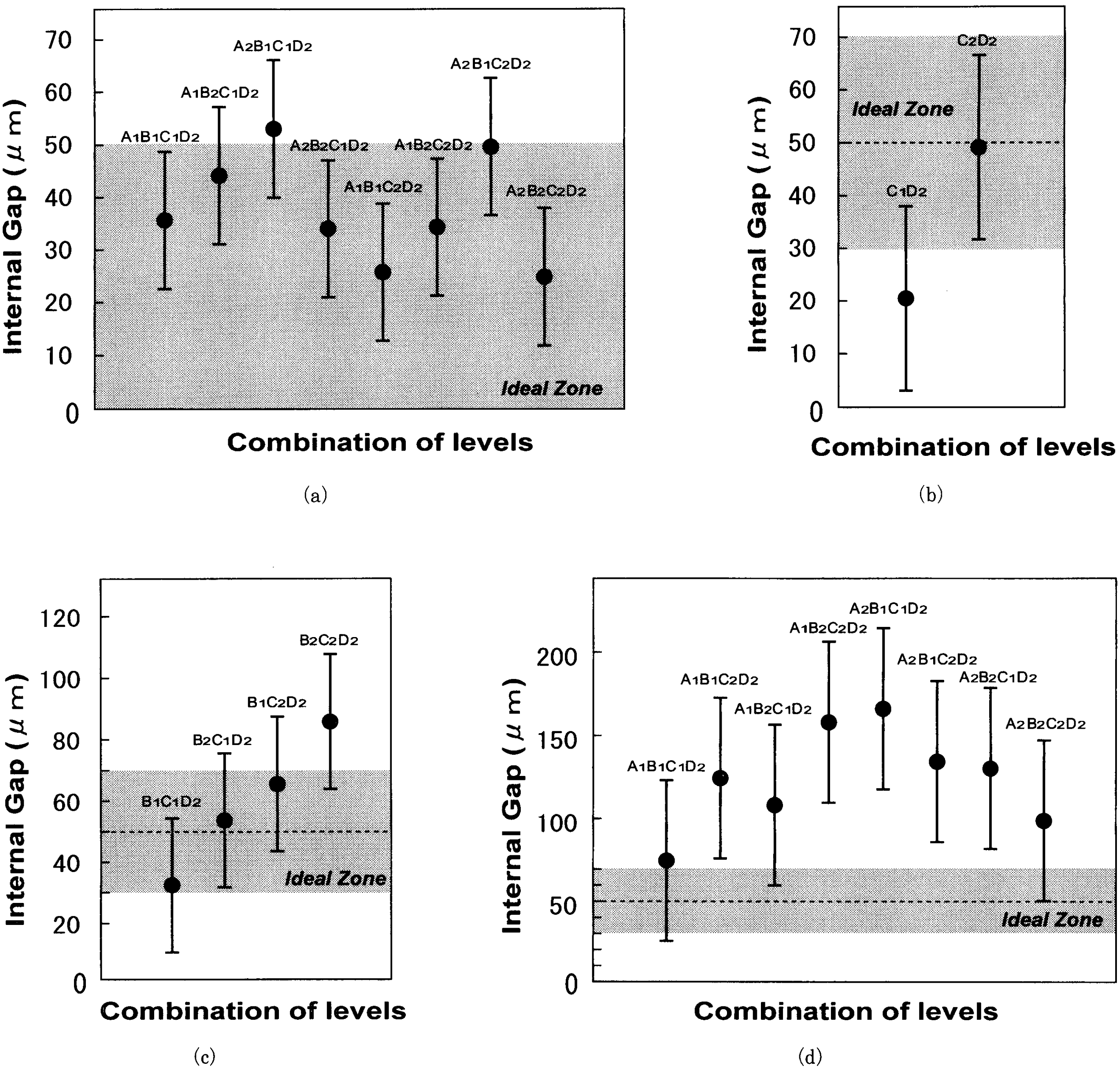


Fig. 7 Estimated mean of the combination of the significant factors, (a) at the margin, (b) at the axio-cervical line angle, (c) at the mid point of the axial wall, and (d) at the cusp tip. The vertical bars represent 95% confidence intervals.

87 μm. However, it was easy for B_2 of the horizontal spurring direction to lead to an air bubble trap, so the $B_1C_2D_2$ combination could be judged as the optimum condition, ranging from 43 to 87 μm (Fig. 7-c).

4. At the cusp tip

The internal adaptation at the cusp tips had the largest gap, the same as at central fossa. The estimated mean of 123 μm was found after crystallization. The factors which influenced the internal gap at the cusp tip were D-factor ($p=0.006$ and $\rho=35\%$: $D_1=180(\pm 25)$ μm, $D_2=123(\pm 25)$ μm), the interaction A×C ($p=0.033$ and $\rho=16\%$: $A_1C_1=119(\pm 36)$ μm, $A_1C_2=168(\pm 36)$ μm, $A_2C_1=175(\pm 36)$ μm, $A_2C_2=144(\pm 36)$ μm). The interaction A×B ($p=0.053$ and $\rho=12\%$: $A_1B_1=127(\pm 36)$ μm, $A_1B_2=161(\pm 36)$ μm, $A_2B_1=178(\pm 36)$ μm, $A_2B_2=141(\pm 36)$ μm) acted as an associate factor. The main factors of A, B, C and R were not significant ($p=0.3$, $p=0.9$, $p=0.5$, $p=0.4$, respectively). The difference of the gap by crystallization (D_1-D_2) was $57(\pm 36)$ μm. The minimum gap of interaction A×B, A_1B_1, was $127(\pm 36)$ μm and the maximum gap was obserbed in A_2B_1, $178(\pm 36)$ μm. Also, the effect of the interaction A×C, the minimum gap, could be seen in the combination of A_1C_1 and the maximum gap in A_2C_1, being $119(\pm 36)$ μm and 174(±36) μm, respectively (Fig. 6-d).

After crystallization, the increased order of the estimated mean of the combination of significant factor-levels was as follows:

$A_1B_1C_1D_2(=74\mu m) < A_2B_2C_2D_2(=97\mu m) \fallingdotseq A_1B_2C_1D_2(=107\mu m) < A_1B_1C_2D_2(=123\mu m) \fallingdotseq A_2B_2C_1D_2(=128\mu m) \fallingdotseq A_2B_1C_2D_2(=134\mu m) < A_1B_2C_2D_2(=156\mu m) \fallingdotseq A_2B_1C_1D_2(=164\mu m)$, varying from 28 to 200 μm. The combination of $A_1B_1C_1D_2$ or $A_2B_2C_2D_2$ was the closest to the criteria. The mean gap of $A_1B_1C_1D_2$ and $A_2B_2C_2D_2$ was estimated at 74(±47) μm and 97(±47) μm, respectively (Fig. 7-d). However the condition of B_2, horizontal spuring, had a tendcy to produce a bubble trap, so it is better to avoid this technique.

5. At the central fossa

The internal adaptation at the central fossa revealed the largest gap, with an estimated grand mean of 177 μm. The ANOVA table indicated that only A-factor significantly affected gap production ($p=0.018$ and $\rho=38\%$). The other main factors of B, C, D, R and the interaction of A×B and A×C were not significant ($p=0.8$, $p=0.15$, $p=0.96$, $p=0.91$, $p=0.88$, $p=0.40$, respectively). The mean of A_1 and A_2 were estimated at 122(±61.3) μm and 232(±61.3) μm, respectively. A_1 demonstrated smaller gap, but it indicated intolerable gap value (Fig. 6-e).

DISCUSSION

1. About methods

Since different shrinkage rates of glass ceramics depending on the growth of individual crystals during crystallization were observed, many studies on the internal adaptation of developed castable ceramics have been reported[10-13]. In this study, we dealt with the fabricating methods to get optimum internal fit of the OCC castable ceramic crowns containing mica and B-spodumene crystals. Three compensating expansion factors for the casting and crystallizing shrinkage were considered to detect which factors were significant and which combination of levels gave the optimum condition compared with the criteria of the characteristic value of gap using the orthogonal array of $L_8(2)^7$. Since sixteen experiments according to the $L_8(2)^7$ orthogonal array were performed with twice replication of the block design, two levels of each factor have been given eight data. It corresponds to 32 experiments of the full model of ANOVA. However, it could not negate the fact to have demerit as this method was factorial fractional design. Only one column of error, therefore one degree of freedom of error variance is responsible for reducing the sensitivity of the test. In order to overcome this short coming, pooling of the error, and the ordinary 5% level of the significant factor and the 10% level were considered an associated factor.

It has been recognized that the dilution of special liquid by water was a very effective method for reducing the expansion rate of the phosphate-bond investment[14-16]. To analyze the effect of special liquid dilution, the mean values of the experimental data of A_1, A_2 (each eight data) and the combination of A_1D_1, A_2D_1 (each four data), allocated in the orthogonal array were compared in Table 4. It might be suggested that the undiluted condition of A_2 indicated a slightly greater tendency, but a significant difference was not detected except at the central fossa. Even the A_1 condition could give enough compensation for casting shrinkage around the axial wall, and also might allow crystallizing shrinkage, considering that their estimated mean of (D_1-D_2) was almost 50 μm. The discrepancy, 0.3%, of total expansion (setting and thermal) between A_1 and A_2 (indicated in Table 2) might be included within the error at margin and axial wall in this experiment. However, significant interaction between A and B, and A and C could be recognized at the margin and the cusp tip.

Table 4 The mean gap (μm) by the effect of dilution (Factor A)

Portion \ Condition	A_1	A_2	A_1D_1	A_2D_1
Margin	28	33	19	28
Axio-cervical line angle	53	67	73	97
Mid-point of axial wall	94	86	116	123
Cusp tip	144	159	168	191
Central fossa	122	232	139	216

The internal gap increased gradually as the vertical dimension was larger from the marginal region to the occlusal surface, and the largest gaps were observed at the central fossa as well as cast metal crowns[17] or any other castable ceramic crowns[10,13]. For this reason, a selectively localized application of die spacer coating in this study might be effective to adjust the dimensional change. The thickness of die spacer applied on a polished epoxy plate in four layers was about 30 μm in this experiment, so about a 7~8 μm thickness could be adjusted directly for every one layer of coating. The reason the thicker die spacer for the second, third and fourth layers coated gradually closer to a axio-sholder line angle was to compensate for the tapered phenomenon as cast and to make up uniform cement space around the axial plane.

The influence of the anisotropic expansion was also tested by variations in the investing wax pattern direction for reducing the large gap at the occlusal inside[5,18-20]. In this study, no air bubbles on the inner surface were observed in 16 cast crowns which were set on a horizontal spuring direction, however this investment method, that the position of the pattern be mounted rectangularly on the sprue, is not recommended for clinical use because of increasing amount of trapped air bubble. It is better to avoid this technique.

2. About Results

It was agreed that a marginal gap of less than 50 μm was clinically acceptable for cast gold restoration from the viewpoint of film thickness of luting cements and the difficulty to achieve this range[21-23]. In this study, marginal discrepancy could be achieved to satisfy this agreement by using every combination. Interaction of A and B (A×B) was significant and coating factor of C was the associated factor at the cervical margin. The mean of the combined levels $A_1B_1C_2$ at the optimum condition, 26(±13.4) μm, was fully acceptable.

The die coating was a significant factor in the region of the axio-shoulder line angle where the crown hit and prevented complete seating. The mean of (C_2-C_1), about 30 μm, at the line angle and the mid-point of the axial wall was estimated to be almost the same thickness of the four coated layers. The mean of C_2D_2 was 49(±17.4) μm at the optimum condition, which fit our criteria. In other hand, noncoating of C_1D_2 varied from 3 to 38 μm at the axiocervical line angle. It has a tendency to hit the inside or to be a tight fit. The die spacer coating at the axial wall could be an effective technique to decrease the marginal opening and making loose fit.

Expansion by different spuring directions acted as an associated significant factor at the cervical half of the axial wall. Actually, this study shows that the estimated mean of B_2 was slightly larger than that of B_1 as shown in Figures 6 and 7. The discrepancy between B_2 and B_1, $\mu(B_2$-$B_1)$ might be 21 μm, similar to three layers of die spacer coating on the axial wall. The mean of the combination of $B_1C_1D_2$ was estimated to be 33(±21.9) μm, and the lower limit of mean did not fit our criteria. The estimated means of $B_2C_1D_2$ and $B_1C_2D_2$ were 54 and 65 μm, respectively. The values were closer to the criteria and in a decidedly acceptable range. The factors on expansion (coating and spuring direction) acted as interactions A×B, A×C, indicating same results at the margin and cusp tip as shown in Figures 6-a,d and 7-a,d. Given the phenomenon of $A_1C_2>A_2C_2$ and $A_1B_2>A_2B_2$ at cusp tip, it was considered that the effect of diametric expansion appeared and might have improved to loose fit at the axial wall as well as $C_1>C_2$ of the marginal gap. However, this explanation could be inadequate to explain why A_1B_1 and A_1C_1 occurred at same time and were the least among the combinations. And at the central fossa, B-factor was not significant. There may have been an effect of anisotropic casting shrinkage by the restraints of investment in the crowns. As the die coating method could compensate for different spuring directions and avoid the air bubble trap, the coating would be preferred clinically.

The cusp tip and central fossa regions in the inner occlusal surface had a large gap, with mean values were about 120 μm. The range was hardly acceptable. The factor of investment expansion influenced greatly at these regions and perhaps more dilution of special liquid with water was necessary to reduce the expansion. The use of die coating on axiocervical could also be adapted.

The ideal less marginal fit and the uniform cement space about 50 μm around the axial wall could be achieved by the combination levels of $A_1B_1C_2D_2$.

CONCLUSION

This study was performed to find the optimum condition for fabricating castable ceramic crowns with preferable internal adaptation. The influence of shrinkage factor (D) during the crystallizing process and three compensating factors for it, expansion rate of phosphate bonded investment (A), no uniform expansion by different spuring directions (B), die-coating (C) and their interaction factors (A×B), and (A×C) were tested by twice replicated experiments under block design according to $L_8(2)^7$ orthogonal array.

The following conclusion are offered:

1. Marginal fit was affected by the expansion of investment (A×B, p=0.017, ρ=25%). In addition, the die coating acted as an associate significant factor (p=0.081, ρ=9.3%). The optimum condition was $A_1B_1C_2$, and estimated mean of the combination of the optimum levels of $A_1B_1C_2D_2$ was 26(±13.4) μm.
2. A cement space at the axio-cervical line angle was influenced by coating (C: p=0.010, ρ=16.8%). Also, the coating (p=0.009, ρ=15.4%) and spuring directions (B: p=0.054, ρ=6%) was associate significant at the mid point of the axial wall. Die coating technique could adjust the cement space directly and selectively.
3. The ideal marginal fit and a uniform cement space about 50 μm around axial wall could be achieved by the combination levels of $A_1B_1C_2D_2$.
4. The estimated mean gaps under the optimum condition of $B_1C_2D_2$ revealed acceptable range of 49(±17.4) μm at the axiocevical line angle and 65(±21.9) μm at the mid point of the axial wall.
5. The estimated mean of the gap at the cusp tip and central fossa of the occlusal surface were about 120 μm. The barely acceptable gaps could not be reduced by the combinations. It is suggested that more dilution of the special liquid with water was necessary to reduce the expansion at the occlusal surface.

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