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Castability of a Commercial Castable Glass Ceramics

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This study was carried out to determine the design and thickness of the cervical margin of a castable ceramic restoration from the point of view of its castability. Castability of castable ceramics was lower compared to Ag-Pd-Au and Co-Cr alloy with the use of the mesh pattern and rod patten test ($p<0.05$). It was more dependent on the pattern thickness than alloys ($p<0.05$), and perfect reproducibility with non-measurable variability could be estimated to reach 1.0 mm thickness of the original pattern ($p<0.001$). Marginal shape was certainly more reproducible in a right angle shoulder than in 30, or 45 degree bevels ($p<0.05$). From these results, it is suggested that a right angle shoulder margin with 1.0 mm thickness is more suitable to castable glass ceramic restoration than any other design.

Key words : Castability, Glass ceramics, Marginal shape

INTRODUCTION

There has been a tendency to greatly expect the use of castable glass ceramics for dental restorations, not only because of its esthetic appearance but also its biocompatibility compared with metal allergy. The greatest advantage of the castable glass ceramics is that it is possible to fabricate restorations by the lost wax casting method. There is thus no requirement of the skill needed for the building and firing of conventional porcelain techniques[1]. Castable glass ceramics which produce two crystals such as mica and β-spogumene[2], or crystalline appatite and magnesium titanate[3] by heat treatment of crystalization have some merits concerning the increase of mechanical properties such as tensile strength, bending strength, and fracture toughness to be twice that of conventional porcelain.

However, the castability of glass had been estimated to be inferior to casting alloys because of the mold temperature being much lower than the melting temperature and their light specific gravity. A few studies have investigated the castability of castable glass ceramics[4]. The purpose of this study was to evaluate the castability of glass ceramics by comparing them with known standard dental casting alloys and to clarify the cervical marginal thickness of the wax pattern which can be reproduced completely by casting for clinical applications.

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MATERIALS AND METHODS

Three test patterns were used to evaluate the castability of castable glass ceramics (Olympus Castable Ceramics (OCC), Olympus Optical Co., Ltd. Tokyo, Japan)and to compare with known casting alloys, Ag-Pd-Au (Castwell M.C., GC Corporation, Tokyo, Japan) and Co-Cr alloy (Levo-Chrome, Heraeus Kulzer GmbH & Co., Dormagen, Germany):

1. Round hole test pattern:
A wax mesh sheet 29 × 35 × 1 mm with retention holes 2 mm in diameter (Wax Retention Hole, Shofu Inc., Kyoto, Japan), which was used for fabricating a cast for a partial denture, was prepared as an indicator for getting an outline of the melting liquid flow. It contained one hundred complete round holes. Two pieces of wax sheeting were stationed symmetrically at an interval of 10 mm on a runner bar 3 mm in diameter. The runner bar was attached to the main spur. Casting was repeated twice for each material.

The outline of castability of the castable glass ceramics and two casting alloys were determined by the total number of complete round holes in the four casts from each material.

2. Rod test pattern:
Two nylon lines, 0.3 and 0.5 mm in diameter, and ready casting waxes of rods 0.7 and 1.0 mm in diameter were used as the test pattern for the casting. These rods in four different diameters were cut flat at one end by a razor, then they were projected perpendicularly at intervals of about 4 mm onto a runner bar 3 mm in diameter. The length of each rod was approximately 5 mm. Four runner bars were set parallel at intervals of 3 mm and they were connected to the main spur.

Considering the location of rod affecting on castability as an error, rods with four different diameters were arranged in a random fashion on the runner bar ac-

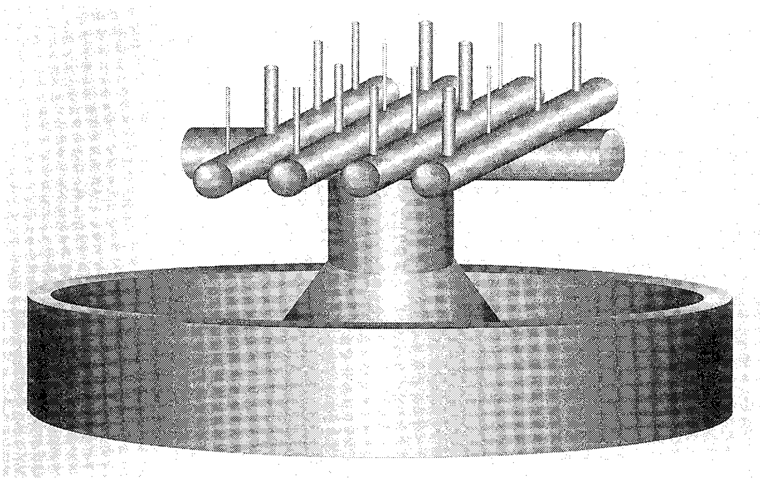

Fig. 1 The original pattern for the rod test. Rods with four different diameters were arranged according to the Latin Square design.

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cording to the Latin Square design. Sixteen test rods with four different diameters on four runner bars in one test pattern were considered as one cell with four lines and four rows. Four rods at each diameter were allocated in one line and in one row only, and not overlapping. One cast therefore had sixteen rods in total and four rods of each diameter (Fig. 1). Castings of glass were repeated six times, on the other hand, the castings of Ag-Pd-Au alloy were repeated twice and Co-Cr alloy were repeated 3 times. Each pattern was allocated a differently-designed Latin Square.

The length of each projection of test pattern and glassy cast were traced and measured with a measuring projector (Profile Projector Model 6CT2, Nippon Kogaku Co., Ltd., Tokyo, Japan) at ×20 power on paired lengths of pre-and-post casting. The criteria of castability was defined as the number of perfect cast rods, and the ratio of the length of cast rod to the original length of test pattern at each rod.

3. *Edge test pattern:*

Three types of edge were prepared by lathe cutting an edge of acrylic plate with dimensions 10 × 10 × 1 mm as shown in Fig. 2. The cross section of one was shaped into a 45 degree bevel edge, and another possessed a right angle corner and 30 degree bevel. These three edges represented, both in form and size, the finishing line of a shoulder for a porcelain jacket crown, bevel, beveled shoulder and flare for onlay or inlay. Two test patterns for each, a total number of four, were placed randomly onto a runner bar. The castings for edge test patterns were repeated 5 times. The evaluation of castability of castable glass ceramics was defined by the length of the defects at corners and/or edges, which were compared to the traced figures between pre-and-post casting as shown in Fig. 3. The test of reproduction of edges was not compared with alloys.

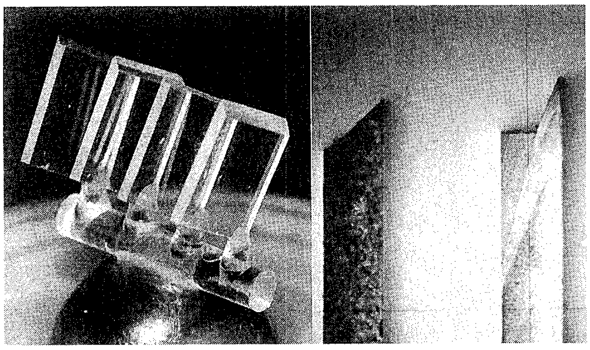

Fig. 2 Plastic plates (10 × 10 × 1 mm) for reproduction of edges. An edge of the plate was prepared by lathe (left). Cross sectional figure of two types; one is prepared with a 45° bevel cut and another is a right angle shoulder with a 30° bevel (right).

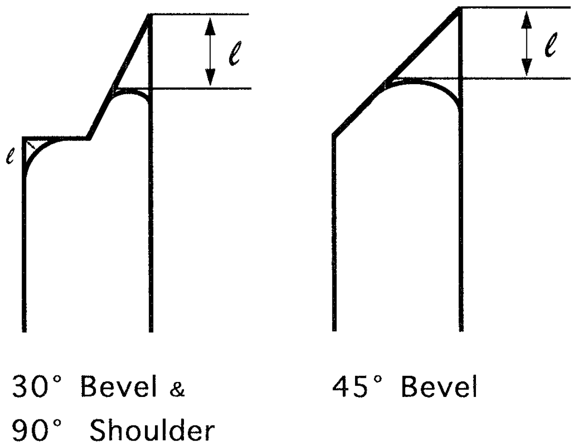

Fig. 3 Evaluation of castability of beveled edges and a right angle shoulder compared with original pattern. l= defect length.

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The patterns of glass ceramics were invested in phosphate-bonded investment (Maizoudon, Tokuyama Co., Ltd., Tokuyama, Japan), each pattern to be cast in Ag-Pd-Au alloy was invested in cristobalite investment (Cristobalite, GC Corporation, Tokyo, Japan), and the pattern for Co-Cr alloy were also invested in phosphate bonded investment (Snow White, Shofu Inc., Kyoto, Japan). Water and/or a special liquid/powder ratio, and the burnout schedule of each material was carried out according to the manufacture's instructions. The glass was melted (1450℃) and cast at 1250℃ (mold temperature holding at 550℃) with a computer controlled casting machine (Chuta, Olympus Optical Co., Ltd., Tokyo), the Ag-Pd-Au alloy was prepared with a gas-oxygen torch and a centrifugal casting machine by three turns of spring force (Centriferico, Kerr Manufacturing Co., Romulus, USA), and the Co-Cr alloy with a high frequency centrifugal casting machine (Acetron Automatic AA-2000, Sankin, Osaka, Japan). Castable glass ceramics was cast with about 10~11 g in weight for each test pattern, while the Ag-Pd-Au and Co-Cr alloys used about 26 g in weight for each casting. After bench cooling, a lump of investments were pulled out from the ring, then they were cut and removed carefully by a girth of the cast by using forceps. Divestment was accomplished by using glass bead blasting (50 μm glass beads, Heraeus Kulzer GmbH & Co., Dormagen, Germany) at 2 air pressures (Micro Sand Blaster, Comco Inc., Burbank, USA) to prevent chipping or reducing the edge of the cast during removing the investment.

RESULTS

The results of the three tests regarding castability were as follows. It was easy to judge the completeness of cast for the round hole test pattern, and more so in the rod test pattern for both groups (alloys and glass). If the cast rod was flat at the open ends it showed complete cast, and if it was round-ended due to surface tension, it showed an incomplete cast. In addition, a sharp shiny glassy surface of the castable ceramics meant a fracture of the rod at divestment.

In the test with round holes, the number and percentage of complete round holes in all four casts for each material is presented in Table 1. The flow of OCC was highly inferior to the casting alloys, as shown in Figure 4. The complete cast percentage of Ag-Pd-Au alloy was 100%, and even the Co-Cr alloy achieved almost 100%. On the other hand, the OCC cast had few perfect round holes, only sixteen of 400 holes (4 %).

In the rod test pattern, the results regarding completeness of cast for each mate-

Table 1 The number of complete round holes in the cast for each material (total number was 400 holes for each material)

	OCC	Ag-Pd-Au	Co-Cr
complete	16	400	394
percentage	4	100	98.5

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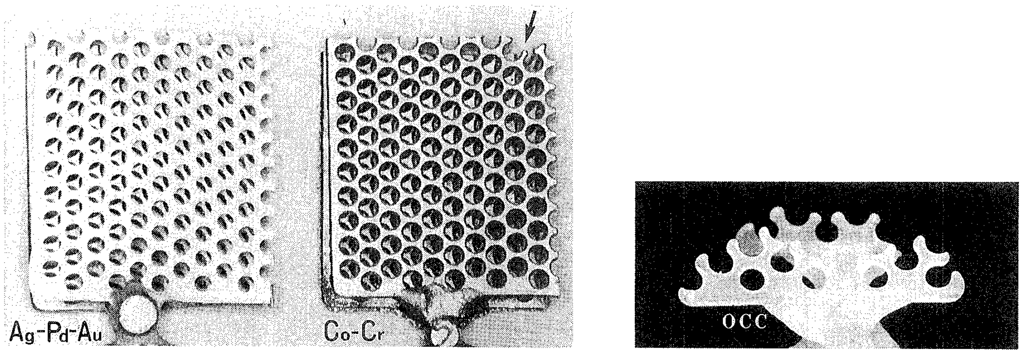

Fig. 4 Examples of casts of round hole test pattern.

Table 2 Completeness of cast (%) at each diameter for each material

diameter (mm)	OCC (n=24 at each diameter)	Ag-Pd-Au (n=8 at each diameter)	Co-Cr (n=12 at each diameter)
1.0	100	100	100
0.7	0	100	92
0.5	0	88	67
0.3	0	0	33

Result of Mantel-Haenszel test
OCC vs Co-Cr: $|MH| = 6.50 > z(0.025) = 1.96$
Co-Cr vs Ag-Pd-Au: $|MH| = 1.6 < z(0.025)$

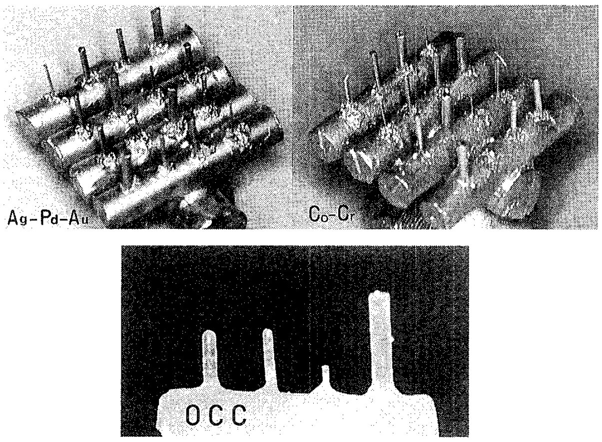

Fig. 5 Examples of casts of rod test pattern.

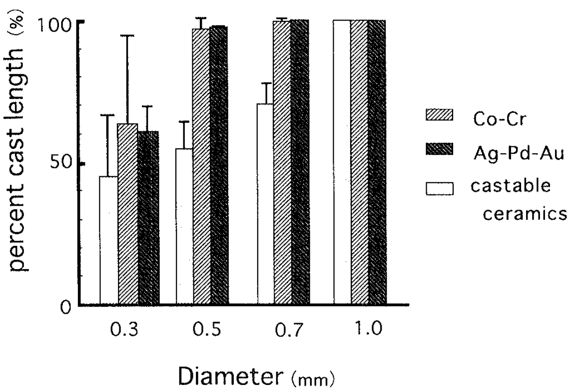

Fig. 6 Average (± 1 S.D.) of percent cast length at each diameter for each material.

rial at each diameter are shown in Table 2. The nonparametric Mantel-Haenszel test was used to compare the completeness of casts between the glass ceramic and the two casting alloys from the data in Table 2. It was found that both alloys reproduced significantly better castability than castable ceramics ($p < 0.05$).

The mean percentage and standard deviation of cast length in relation to diameter for each material is shown in the bar graph (Figs. 5 and 6). Two-way ANOVA

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was applied to determine which material had the better reproducibility of length over all diameters among the three materials. It was shown that a significant difference existed among materials and diameters ($p<0.05$). The test of the difference between means of materials illustrated that two alloys had significantly superior reproducibility to castable ceramics ($p<0.05$) (Table 3).

Regression analysis between percent cast length and all diameters of rods of OCC demonstrated a high significant linear relation. The coefficient of correlation of castable ceramics was $\gamma=0.93$ ($p<0.001$) as shown in Fig. 7. The result meant that the castability of castable ceramics strongly depended on diameter. From the regression equation, it could be estimated that a 100% complete cast for OCC would require at least 1.0 mm thickness in the wax pattern.

Table 3 Summary of two-way ANOVA of the factors affecting on castability and the table of the test of the differences between materials

Summary of Two-Way ANOVA

Factor	SS	df	MS	F-value	P
A. Material	1293.9	2	647.0	5.86	0.039*
B. Diameter	3018.9	3	1006.3	9.11	0.012*
error	662.4	6	110.4		
Total	4975.2	11			

Test of the differences between materials

factor A Category 1	Category 2	mean 1	mean 2	difference
OCC	Co-Cr	68.1	89.9	−21.8*
OCC	Ag-Pd-Au	68.1	90.3	−22.2*
Co-Cr	Ag-Pd-Au	89.9	90.3	0.4

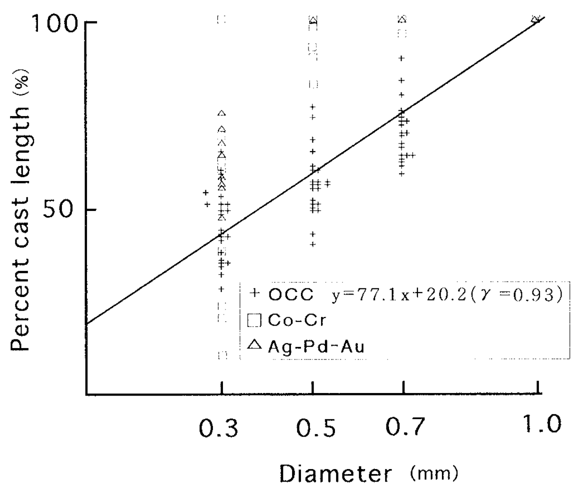

Fig. 7 Correlation between percent cast length and rod diameter.

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Table 4 Lack of length of the cast at corner and edge on each finishing line

Defect length	$\ell \leqq 50\mu m$	$50\mu m \leqq \ell \leqq 100\mu m$	$100\mu m \leqq \ell \leqq 250\mu m$	Total
30° Bevel	2	2	6	10
45° Bevel	2	4	4	10
right angle Shoulder	7	3	0	10

Result of a 2 × 3 contigency table
Shoulder vs 45° Bevel: $\chi^2_2=6.29>\chi^2_2(0.05)=5.99$
30° vs 45° Bevel : $\chi^2_2=1.06<\chi^2_2(0.05)$

In the edge test pattern, the cast projections were classified as follows: (1) no defect of length over $50\mu m$, (2) defects ranged from $50\mu m$ to $100\mu m$ and (3) less than or equal to $250\mu m$. The results of edge reproduction are shown in Table 4. Complete casts were few except shoulder edges, and most of the defects in the two bevels were between 100 and $200\mu m$. However no defect existed with length over $250\mu m$. A chi-square test by using a 2 × 3 contingency table was applied using the data of Table 4 to test the significant difference on the defect length of marginal shape among three types of edges. It was shown that there was no significant difference between a 30 and a 45 degree bevels, however, significant difference was confirmed between right angle shoulder and the two bevel margins ($p<0.05$). This result shows that the right angle shoulder had significantly higher perfect cast than the other designs.

DISCUSSION

It is expected of cast restorations that they cover all prepared tooth surfaces completely and fit perfectly to the finish line. This depends on the castability which can fill a thin section. Many factors affecting castability have been proposed such as casting force, placement, shape and temperature of mold etc. for the casting conditions, and flow of molten materials, specific gravity, surface tension force, wettability, etc. for the material properties. The melting temperature is 1450 degree Celsius, and specific gravity is 2.8 g/cm^3 in castable glass ceramics. These variables are higher and lighter than those of non-precious alloys (Levo-chrome; 1400℃, 8.0 g/cm^3), and more semi-precious alloys (12% Castwell M.C.; 960℃, 11.5 g/cm^3). It seems from these variables that this material is difficult to cast completely.

The results showed that the castability of the castable ceramics was inferior to even base metal (Levo-chrome), which are difficult to cast in thin sections. Castable glass ceramics might have been developed to improve fluidity, and actually it seems that the fluidity is good. However, the casting temperature is set lower than the melting temperature by about 200℃, and the mold temperature is set at 550℃ to decrease the reaction to silica of the mold investment; the glass in the mold was soon cooled by this great gap of temperature. Generally, melting glass fluidity can be strongly influenced by a slight change of temperature. This may be the cause of variability among experimental results. In addition, the casting force's effects on

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castability could not be considered constant for the three materials in this study because different casting machines were used on each material. Centrifugal force was calculated using the following equation. $F=mr\omega^2=mr(2\pi n)^2$ (m=mass (kg), r=length of arm (m), ω=angular velocity, n=revolution per second, F=centrifugal force ($kg \cdot m/s^2$). It is certain that the revolution-per-minute of the casting machine for castable ceramics (Chuta: 1200 rpm and arm length 100 mm) is twice that of the two other centrifugal casting machines (Acetron AA-2000: 650 rpm and arm length 150 mm, Centriferico: 600 rpm and arm length 150 mm). The amount of melting OCC was about 10～11 g, however, a small amount of that stuck to the wall of a melting pot, so the actual amount poured into the cast ring was about 8 g. If all the cast volumes are the same, mass of castable ceramics poured into the mold would be much lighter than the two casting alloys-about one-third of the Co-Cr alloy, or one-quarter of the Ag-Pd-Au alloy-because of its lower specific gravity, and resulting in a decreased centrifugal force.

Regression analysis of glass ceramic castability between percent cast length and diameter of rod showed a tendency toward stronger correlation than casting alloys. It was found that complete casting of glass ceramics was more highly dependent on the thickness of the wax pattern. However, validity of castability of small rods were low and the coefficient of variance was also stable. The Hartley test was used to compare the variability of castable glass ceramics among all diameters except 1.0 mm. There was no significant difference among the three ($p<0.05$), and this is supposed to be the reason why that melting of the glass, timing of the cast and revolution speed are controlled automatically by the casting machine.

This study was designed to determine the thickness and marginal shape for glass ceramic restoration. Round holes and rods test patterns might be severe and not a fair for test of reproduction of crown margins, which is different from cast partial denture fabrication. The edge test pattern used in this experiment should be the most similar to a clinical model. It is suggested that the flat shoulder finishing line simulated right angle edge is the most applicable to marginal preparation design for castable ceramic restorations in clinic. Almost all of the reproductions were within 50μm. It has been said that the marginal discrepancy of a cast crown even under experimental conditions ranged from 45 to 110μm[5]. Lofstrome *et al.* reported that the marginal discrepancy of cemented well-fitting cast gold restorations clinically was 7 to 65μm by SEM observation[6]. If the marginal fit of gold crown was a permissible gap, the finishing line of glass ceramics should be the shoulder. Araki *et al.* found that at the end of chamfers, the edge shape tended to be more round than that of a gold cast, but otherwise similar to a gold cast in the shoulder. However even shoulder edges were slightly rounded after ceraming process[7]. Investigations of the strength of porcelain jacket crowns demonstrated that the shoulder preparation generated compressive stress and the lowest stress concentration at the marginal portion during function[8]. This could also provide a suitable design for the brittle nature of glass ceramics.

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CONCLUSIONS

A 1.0 mm margin thickness was required for complete casting of castable glass ceramic restoration. The shoulder or butt joint finishing line should be applicable and not prepared flared, or beveled.

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