The effect of four sprue shapes on the quality of cobalt-chromium cast removable partial denture frameworks

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Abstract

Statement of Problem: Sprue design is a factor that controls the velocity and adequate supply of metal to the mould. Currently various manufacturers recommend different shapes of sprue, which have not been advocated in textbooks and literature is lacking for their routine applications. Purpose: This in vitro study was carried out to determine the efficacy of four sprue shapes in producing complete, void free cobalt-chrome removable partial denture frameworks. Materials and Methods: A brass metal die with a Kennedy class III, modification 1, partially edentulous arch was used and four sprue shapes (Group A-Ribbon, Group B-Square, Group C-Round and Group D- Round with reservoir) were evaluated. 40 refractory casts were made, 10 wax patterns for each sprue design were waxed up, invested with phosphate bonded investment material and castings done with induction casting machine by the same operator under standardized protocols. The cast frameworks were evaluated for 1. The defects observed visually before finishing and polishing procedures, 2. Fit on the master die as seen with naked eye and 3. Defects on radiographic evaluation. Data were tabulated and statistically analyzed with 1-way ANOVA followed by Student ‘t’ test. Results: The results differed significantly \(P < 0.0001\) between the Groups with maximum defects in the castings of Group A followed in decreasing order by Group B, Group C and Group D. When comparing between the Groups \(P < 0.05\), the defects in Groups C and D was significantly lower than Group A and Group B. Conclusions: Round sprues with reservoir produced most satisfactory fit of castings with minimum number of internal and external defects.

Keywords: Casting defects, cobalt-chromium, sprue

Introduction

Removable cast partial denture is an effective treatment modality to restore form and function. Cobalt-chromium (Co-Cr) alloys have been used to fabricate cast removable partial denture frameworks since 1933. Many technical difficulties were initially encountered and their use in dentistry was limited. However, improved alloys and techniques have been developed that resulted in greater use of these alloys. Despite these advances, failures are often encountered in the form of various internal and external defects. Structural faults in dental castings can result from any combination of problems related to spraying, investing, wax elimination, alloy melting, casting, and solidification of alloy. Understandably, confusion remains in the minds of dental laboratory technicians as to which technique will produce dense and defect free castings most consistently. This is partly due to the fact that various manufacturers and distributors of dental casting devices and alloys advocate different techniques to produce satisfactory dental castings.

The selection of sprue shape is a variable of crucial importance, which affects the castability of dental alloys and the porosity in cast removable partial denture framework. The purpose of a sprue is to provide a channel through which molten alloy can reach the mould after the wax has been eliminated. Sprue former is a wax, plastic or metal pattern used to form the channel or channels allowing molten metal to flow into a mould to make a castin. The sprue also acts as a reservoir from where the casting may draw molten alloy during solidification, thus avoiding porosity due to shrinkage. The factors responsible for shrink spot porosity include the size, number, length and configuration of the sprues and the location and mode of attachment of the sprues to the wax pattern.

Various sprue shapes and designs have been reported. These include cylindrical shape sprues with and without reservoirs, conical shape sprues, straight, flared, abrupt constriction, and gradual constriction at the point of attachment, tree, ball and circular shapes, and top and bottom spruing. Cylindrical shape of sprue is advocated in books and used most commonly. Some manufacturers recommend different shapes of sprues, which have not been advocated in textbooks. These include ribbon and square type of sprues. There have been no studies on these designs and information as to their suitability for regular use is not
available. In view of the above, it was deemed appropriate to conduct a laboratory study to evaluate the effect on the quality of Co-Cr removable partial denture frameworks cast with these types of sprues.

Materials and Methods

An in-vitro study was undertaken to determine the ability of four sprue shapes (Group A: Ribbon type, Group B: Square type, Group C: Round type and Group D: Round type with reservoir) to produce complete, void free cast removable partial denture frameworks. Forty Co-Cr cast removable partial denture frameworks (10 for each sprue shape) were fabricated. Macroscopic (visual) and radiographic evaluation was carried out to detect external and internal flaws. All materials and equipment’s used for the fabrication of cast removable partial denture frameworks were of BEGO, Bremer Goldschlägerei Wilh. Herbst GmbH Co. KG, Germany except the Cobalt Chromium alloy, Remanium GM 380 from Dentaurum GmbH Co. KG, Germany.

The maxillary part of a Typodont (Columbia Dentoform Corporation, USA) was converted into a Kennedy class III mod I edentulous situation, duplicated with reversible hydrocolloid (Castogel, BEGO, Bremer Goldschlägerei Wilh. Herbst GmbH Co. KG, Germany), poured with die stone (BEGO, Bremer Goldschlägerei Wilh. Herbst GmbH Co. KG, Germany) and the master cast retrieved. This cast was surveyed, designed and necessary tooth preparation was carried out. A palatal strap maxillary major connector with circumferential clasps and rest seats next to edentulous spaces (Quadrilateral design) was designed. Beading was performed to delineate the anteroposterior extension and to standardize the dimensions of palatal strap maxillary major connector. This stone cast was duplicated into a brass metal die, which served as master die. The master die was surveyed again and undesirable undercuts blocked out with block out wax (BEGO, Bremer Goldschlägerei Wilh. Herbst GmbH Co. KG, Germany) [Figure 1]. The saddles were relieved with 0.5 mm preparation wax (BEGO, Bremer Goldschlägerei Wilh. Herbst GmbH Co. KG, Germany). The ledges were made for retentive and reciprocal arms with block out wax. Indentations were made on the wax ledges to mark the termination of the clasp arms. Simultaneously, the abutment teeth were also indented at the occlusal third of buccal and lingual surfaces to help in verifying the completeness of clasp arms after the castings were made.

Fabrication of refractory casts

The duplication of the master die was done with reversible hydrocolloid (Castogel, BEGO, Bremer Goldschlägerei Wilh. Herbst GmbH Co. KG, Germany) in the duplicating unit (Gelovit MP, BEGO, Bremer Goldschlägerei Wilh. Herbst GmbH Co. KG, Germany) following the manufacturer’s instructions. The master die was carefully detached from the gel mould and removed. The refractory casts were made with phosphate bonded investment material (Wirovest, BEGO, Bremer Goldschlägerei Wilh. Herbst GmbH Co. KG, Germany) following manufacturer’s recommendations. Forty such refractory casts were made (10 for each sprue type) for this study.

Wax-up and spruing

Refractory casts were dried in a drying oven at 250°C for about 60 min and then dipped in hardener solution (Durol dipping hardener, BEGO, Bremer Goldschlägerei Wilh. Herbst GmbH Co. KG, Germany) for 5-8 s. The casts were removed from the hardener, excess liquid was allowed to drain and placed back in the preheated oven in a vertical standing position for 10 min so that excess liquid could evaporate. All the partial denture frameworks were fabricated using a uniform standardized technique. The refractory casts were divided into 04 groups of 10 each. The wax patterns for the frameworks were made from prefabricated wax forms (BEGO, Bremer Goldschlägerei Wilh. Herbst GmbH Co. KG, Germany) to get uniform thickness of various components. The planned design was transferred to the refractory cast before wax-up. All wax forms were adapted lightly to the refractory cast and sealed. Though there was difference in shape and size of the sprues, an attempt was made to standardize the amount of alloy which will flow through per unit length of each sprue type by keeping the cross sectional areas of all types of sprues almost equal at 13 mm² approx. Ten waxed-up refractory casts were sprued with each of the sprue shape [Figures 2-5]. Each sprue design consisted of two main feeder sprues attached to thickest parts of the wax-up (junction of the saddle and major connector) and one round accessory sprue of 1 mm diameter attached to each occlusal rest area. The funnel former was positioned in the center of the wax framework 10 mm above the arch of the teeth and carefully waxed to the sprues.

Investing and casting

All refractory casts with wax patterns were invested within an hour using the phosphate bonded investment
material (Wirovest, BEGO, Bremer Goldschlägerei Wilh. Herbst GmbH Co. KG, Germany) in accordance with the manufacturer’s instructions. The mould former was removed after 10 minutes and the investment mould was allowed to set for 30 min before preheating. Prior to burn out procedure the mould along with crucible and the required amount of alloy, approximately five ingots of Co-Cr alloy (Remanium GM 380, Dentaurum, Germany) was carefully balanced and adjusted in the centrifugal arm of induction-casting machine (Fornax G, BEGO, Bremer Goldschlägerei Wilh. Herbst GmbH Co. KG, Germany. The mould was then placed in burn out
Contemporary Clinical Dentistry | Apr-Jun 2013 | Vol 4 | Issue 2

Viswambaran and Agarwal: The effect of four sprue shapes on Co – Cr Cast RPD frameworks

The preheated crucible containing ingots was removed from the furnace and casting procedures carried out in an Induction casting machine following manufacturer’s instructions. The mould was allowed to bench cool to room temperature. Divesting was then carried out with a light hammer. The investment material still adhering to the casting was removed by sandblasting with 250 µ alumina (BEGO, Bremer Goldschlägerei Wilh. Herbst GmbH Co. KG, Germany). Sprues were cut-off with high-speed grinder using the high speed cutoff discs (BEGO, Bremer Goldschlägerei Wilh. Herbst GmbH Co. KG, Germany).

All the castings were examined visually under magnification by using the hand-held magnifier lens (×2.5 Power MG 82015-L, China) under proper illumination for any surface irregularities, nodules, porosities or incompleteness. Number of defects in each casting and location of the defects were noted [Table 1].

The fitting surfaces of the clasps and the frameworks were not polished. The frameworks were then cleaned with steam-cleaning unit (Triton SLA, BEGO, Bremer Goldschlägerei Wilh. Herbst GmbH Co. KG, Germany).

Table 1: Number of defects visualized for all castings before finishing and polishing

| Sample no | Group A | Group B | Group C | Group D |
|-----------|---------|---------|---------|---------|
| 1         | 2       | 2       | 3       | 1       |
| 2         | 4       | 4       | 0       | 2       |
| 3         | 4       | 3       | 4       | 1       |
| 4         | 1       | 4       | 2       | 1       |
| 5         | 2       | 2       | 3       | 2       |
| 6         | 4       | 3       | 2       | 1       |
| 7         | 4       | 2       | 2       | 0       |
| 8         | 3       | 2       | 4       | 1       |
| 9         | 4       | 4       | 2       | 2       |
| 10        | 4       | 2       | 1       | 1       |
| Mean      | 3.2     | 2.8     | 2.3     | 1.2     |

Table 2: Percentage of satisfactory fit for all castings

| Sample no | Number and percentage of satisfactory fit sites |
|-----------|-----------------------------------------------|
| Group A   | Group B | Group C | Group D |
| 1         | 7       | 53.85   | 6       | 46.15   | 9       | 69.23   | 9       | 69.23   |
| 2         | 6       | 46.15   | 7       | 53.85   | 8       | 61.54   | 8       | 61.54   |
| 3         | 5       | 38.46   | 8       | 61.54   | 10      | 76.92   | 7       | 53.85   |
| 4         | 7       | 53.85   | 6       | 46.15   | 7       | 53.85   | 9       | 69.23   |
| 5         | 4       | 30.77   | 5       | 38.46   | 6       | 46.15   | 8       | 61.54   |
| 6         | 6       | 46.15   | 7       | 53.85   | 6       | 46.15   | 6       | 46.15   |
| 7         | 8       | 61.54   | 8       | 61.54   | 8       | 61.54   | 8       | 61.54   |
| 8         | 4       | 30.77   | 6       | 46.15   | 8       | 61.54   | 9       | 69.23   |
| 9         | 7       | 53.85   | 3       | 23.08   | 7       | 53.85   | 8       | 61.54   |
| 10        | 6       | 46.15   | 4       | 30.77   | 9       | 69.23   | 7       | 53.85   |
| Mean      | 46.15   | 46.15   | 60      | 60.77   |

Evaluation of fit on the master die
All 40 frameworks [Figure 6] were evaluated for satisfactory fit on the master die at the following sites: Four retentive arms, four reciprocal arms, four occlusal rests, and one major connector [Figure 7]. Average satisfactory fit of each
group was determined based on the number of sites found satisfactory out of the total of 13 sites for each framework and the results were reflected in a table form [Table 2].

**Radiographic examination**
The radiographs of the 40 frameworks were taken using 200 kV X-ray machine (Siemens AG, Germany). Occlusal films (Kodak Company, USA) were exposed at 86 kV and 10 mA for 0.5 s. The source-object distance was kept at 30 cm for all the specimens [Figure 8]. All films were developed for 3 min and fixed for 5 min using X-ray developer and fixer (Kodak Company, USA). After drying, the radiographs were examined for internal defects [Figure 9]. All the radiographs were viewed independently in a semi dark room with a high intensity illuminator and magnifier. To differentiate a radiolucent area in the casting due to the presence of internal defects from that resulting from excessive thinning of the metal framework, a metal gauge was used. The number of internal defects in each radiograph and the average number of defects in each group were recorded [Table 3]. The sites of these defects were also noted.

**Results**
The cast frameworks were evaluated for the defects observed visually before finishing and polishing procedures, fit on the master die after finishing and polishing as seen with the naked eye and defects on radiographic evaluation. The results obtained were tabulated and statistically analyzed using one-way analysis of variance (ANOVA) and Student ‘t’ test. On visual examination, it was observed that maximum defects were present in the castings of Group A [Table 1] followed in decreasing order by Group B, Group C, and Group D which had minimum number of defects and this difference was statistically significant (*P* < 0.0001) [Table 4]. When comparing between the groups there was no significant difference between Groups A and B as well as Groups A and C. However, there was a significant difference between Groups A and D. There was no significant difference between Groups B and C, but there was a significant difference between Groups B and D and Groups C and D (*P* < 0.05).

The fit of the cast frameworks on the master die also showed that the frameworks of Group D had most satisfactory fit (*P* < 0.0001) [Table 5]. Group C also had comparative satisfactory fit. However, the percentage of satisfactory fit in Groups A and B was significantly lower than Group C and Group D (*P* < 0.05).

Results of radiographic evaluation showed that Group-A had the maximum number of internal defects followed by Group B and Group C, where-as Group D had the minimum number of internal defects [Table 3]. On statistical analysis with ANOVA [Table 6], it was found that the average number of internal defects differed significantly between four groups (*P* < 0.0001). Subsequent analysis with Student ‘t’ test revealed that Group A had significantly higher number of internal defects than the other three groups (*P* < 0.05). Average number of defects in Group B was higher than Group D and the difference was statistically significant. There was no significant difference between Group B and Group C and as well as Group C and Group D.

| Table 3: Number of defects for all castings on radiographic evaluation |
|------------------|-----|-----|-----|-----|
| Sample           | Group A | Group B | Group C | Group D |
| 1                | 2     | 2     | 2     | 0     |
| 2                | 4     | 3     | 1     | 1     |
| 3                | 2     | 4     | 1     | 2     |
| 4                | 3     | 2     | 2     | 3     |
| 5                | 4     | 3     | 4     | 1     |
| 6                | 6     | 2     | 3     | 2     |
| 7                | 4     | 1     | 2     | 0     |
| 8                | 5     | 2     | 1     | 2     |
| 9                | 6     | 4     | 0     | 1     |
| 10               | 4     | 1     | 1     | 1     |
| Mean             | 4     | 2.4   | 1.7   | 1.3   |

| Table 4: Comparison of average number of defects visualized before finishing and polishing by ANOVA |
|--------|-----|-------|-----|
| Group  | Mean | SD    | *P* |
| A      | 3.2  | 1.135292 | <0.0001 |
| B      | 2.8  | 0.918937  | <0.0001 |
| C      | 2.3  | 1.251166  | <0.0001 |
| D      | 1.2  | 0.632456  | <0.0001 |

ANOVA: Analysis of variance; SD: Standard deviation

| Table 5: Comparison of percentage of satisfactory fit after finishing and polishing by ANOVA |
|--------|-----|-------|-----|
| Group  | Mean | SD    | *P* |
| A      | 46.15| 10.26  | <0.0001 |
| B      | 46.15| 12.56  | <0.0001 |
| C      | 60   | 10.13  | <0.0001 |
| D      | 60.77| 7.65   | <0.0001 |

ANOVA: Analysis of variance; SD: Standard deviation

| Table 6: Comparison of average no of defects on radiographic evaluation by ANOVA |
|--------|-----|-------|-----|
| Group  | Mean | SD    | *P* |
| A      | 4    | 1.41214 | <0.0001 |
| B      | 2.4  | 1.074968 | <0.0001 |
| C      | 1.7  | 1.159502 | <0.0001 |
| D      | 1.3  | 0.948683 | <0.0001 |

ANOVA: Analysis of variance; SD: Standard deviation
Viswambaran and Agarwal: The effect of four sprue shapes on Co–Cr Cast RPD frameworks

Discussion

Clinical experience tells us that a cast metal framework seldom fits the mouth accurately without the need for some adjustments. This misfit reflects the dimensional inaccuracies that are incorporated during various clinical and laboratory stages of framework fabrication. Structural faults in a dental casting can result due to several factors including the design and method of attachment of the sprues. Although the cast partial dentures are being fabricated since long, there are very few studies, which investigated the effects of various sprue shapes on the quality of a casting. Various manufacturers and distributors recommend different sprue shapes and techniques leading to confusion. This in-vitro study was carried out to determine the efficacy of four sprue shapes in producing complete, void free cobalt-chrome removable partial denture frameworks. Some manufacturers advocate ribbon shape of sprues for casting maxillary frameworks (BEGO, Germany), whereas others advocate square shape of sprues (Yeti Dental, Japan) for achieving accurate results in fixed partial dentures. Round sprues with and without reservoirs are advocated in most of the books and practiced all over the world. Most of the studies available have used round sprues with various designs and mode of attachment to the pattern. However, there are no studies available to support the use of ribbon and square shape sprues being advocated by the manufacturers. In this study, an attempt was made to standardize most of the variables affecting the quality of a casting as far as possible. The metal die was preferred for verifying the fit of the castings because it was more resistant to abrasion on repeated insertion and removal of metal frameworks. All the laboratory procedures were carried out by the same operator following standardized protocols.

The design of wax framework has a great influence on the quality of the casting. Abrupt changes in the dimensions and sharp angles in the wax frameworks lead to external and internal defects and stress concentrations. Therefore, it was ensured that there were no sharp angles or abrupt changes in dimensions of the wax frameworks. It is well-established that the sprue should be thicker than the thickest portion of the frameworks for sufficient availability and proper flow of the molten alloy. In this study, therefore, sprues with sufficient thickness were used. Various investigators have come out with conflicting results with regard to the quality of castings produced with different sprue shapes, mode of attachment and sprue design. Rieger et al. achieved better results with conical sprue as compared to the round sprues. Mesmar et al. concluded that addition of a ball reservoir to a round sprue improved the quality of titanium castings. Compagni et al. recommended that the constriction of the sprue at the point of attachment to the wax pattern should be avoided whereas Peregrina and Schorr advocated constricted or tapered sprue design, which produced better castings as compared to cylindrical design with a flare at the point of attachment or a cylindrical sprue with a reservoir. At the same time, Wight et al. used rectangular sprues and found that venting improved the results when the sprue width was more than 2 mm. In their study, all the non-vented samples irrespective of the size had extensive porosity. No literature is available regarding the use of ribbon shape and square shape of sprues. Chan et al. found that two sprues attached to a full crown wax pattern resulted in relatively smoother titanium casting as compared to a single sprue whereas Collett concluded that only one sprue was sufficient for small castings, but advocated multiple sprues for large and complicated castings made with base metal alloys. In the present study, only two main sprues were used for all the frameworks, but accessory round sprues of 1 mm diameter were attached to all the occlusal rests to provide adequate molten alloy.

Though there is a lot of controversy regarding the mode of attachment of sprues to the pattern, we followed the well-recognized and advocated method of attachment by flaring at the junction and the sprue was attached at the thickest portion of the pattern. Thomas Wight et al. advocated a flared attachment rather than constricted mode of attachment to the wax pattern. The length of all the sprues was also kept equal. Since, the sprues were different in shape, their cross-sectional areas were also standardized (13 mm²) so that the amount of molten alloy flowing through unit area of all the sprues remains the same, which otherwise could have been a source of variation. Investigators have used various types of X-ray machines with different combinations of kV, mA and time for detection of porosities in castings. Elarbi et al. recommended 90 kV, 15 mA and 36 impulses, Wise and Kaiser used 90 kV, 15 mA and 30 impulses and Lewis advocated 90 kV, 4 mA and 70 s. Pascoe and Wimmer advised 150 kV, 5 mA and 30 s, whereas Wang and Boyle produced good contrast with 90 kV, 25 mA and 30 s. Sunder Dharmar utilized 80 kV, 6 mA and 90 s. In this study, a 200 kV Siemens radiographic machine was used and several exposures were made with different settings of kV, mA and time to achieve the best results. It was found that 86 kV, 10 mA and 0.5 s exposure time produced the best contrast to show the internal defects in castings and the same was used as a standard for all the castings evaluated. On visual examination, it was observed that maximum defects were present in the castings of Group A followed in decreasing order by Group B, Group C and Group D, which had minimum number of defects and this difference was statistically significant (P < 0.0001). When comparing between the groups there was no significant difference between Groups A and B as well as Groups A and C. However, there was a significant difference between Groups A and D. There was no significant difference between Groups B and C, but there was a significant difference between Groups B and D and Groups C and D (P < 0.05).

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is used, there are spaces at the corners of the square sprue, might cause backpressure porosity. When the square sprue inside the mould to escape through the other end only which sprue gets completely filled up with the alloy forcing the air flows in the shape of a ball when cast centrifugally. The round sprues of rectangular type of sprues explain that the molten alloy flow of the molten alloy to maximum areas. The protagonists as compared to round sprues and therefore will help in faster this configuration allows metal to flow through a wider area and constant supply of molten alloy. This suggests that the accessory sprues of 1 mm diameter were attached at the occlusal rest and minor connector areas, which may be associated with the greater bulk of the metal in these parts. Though accessory sprues of 1 mm diameter were attached at the occlusal rest areas, they might not have been able to provide enough and constant supply of molten alloy. This suggests that the accessory sprues also should have sufficient thickness in order to produce defect free castings. These findings are in agreement with Lewis[11] and Dharmar[9] who also reported similar findings. It is presumed that advocates of ribbon sprues might be supporting this shape on the premise that this configuration allows metal to flow through a wider area as compared to round sprues and therefore will help in faster flow of the molten alloy to maximum areas. The protagonists of rectangular type of sprues explain that the molten alloy flows in the shape of a ball when cast centrifugally. The round sprue gets completely filled up with the alloy forcing the air inside the mould to escape through the other end only which might cause backpressure porosity. When the square sprue is used, there are spaces at the corners of the square sprue, which act as vent spaces for the escape of gases from inside the mould when molten alloy enters in a ball shape.

However, our study does not support their claim because the poorest results were obtained with ribbon type of sprues followed by square shape of sprues. Maximum internal and external defects observed in the castings with ribbon shape sprue can be explained because the thickness of these sprues was just 2 mm though the width of this sprue was more (6.5 mm). This might have caused resistance to the flushing of molten alloy inside the sprues leading to turbulence, which produced more defects. The Standard deviation in both these groups was also more as compared to the round sprue groups, which confirms that the results obtained with the round sprues were more consistent than the other two groups.

Conclusions

On analyzing the results and observations made, it was concluded that the round sprues produced more consistent and defect free castings as compared to square and ribbon shape of sprues. Addition of the reservoir to the round sprues improved the quality of castings. Within the limitations of this study, it was found that ribbon shape of sprue produced maximum defects followed by square shape of sprues. Though there was no statistically significant difference between these two groups when compared visually for the fit on the master die, there was a significant difference on radiographic examination. From this, we can infer that on visual evaluation, ribbon shape of sprues were comparable to square shape of the sprues, but the radiographic evaluation showed maximum internal porosities with ribbon shape, which may lead to failures during the service. This study recommends the use of round sprues with reservoir for more consistent and defect free castings.

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How to cite this article: Viswambaran M, Agarwal SK. The effect of four sprue shapes on the quality of cobalt-chromium cast removable partial denture frameworks. Contemp Clin Dent 2013;4:132-9.

Source of Support: Nil. Conflict of Interest: None declared.