Original Article

# The Effect of Casting Ring Liner Length and Prewetting on the Marginal Adaptation and Dimensional Accuracy of Full Crown Castings

*Satheesh B. Haralur, Osama A. Hamdi, Abdulaziz A. Al-Shahrani, Sultan Alhasaniah*

Department of Prosthodontics, College of Dentistry, King Khalid University, Abha, Saudi Arabia

ABSTRACT

**Aim:** To evaluate the effect of varying cellulose casting ring liner length and its prewetting on the marginal adaptation and dimensional accuracy of full veneer metal castings.

**Materials and Methods:** The master die was milled in stainless steel to fabricate the wax pattern. Sixty wax patterns were fabricated with a uniform thickness of 1.5 mm at an occlusal surface and 1 mm axial surface, cervical width at 13.5 mm, and 10 mm cuspal height. The samples were divided into six groups ($n$ = 10). Groups I and II samples had the full-length cellulose prewet and dry ring liner, respectively. The groups III and IV had 2 mm short prewet and dry cellulose ring liner, respectively, whereas groups V and VI were invested in 6 mm short ring liner. The wax patterns were immediately invested in phosphate bonded investment, and casting procedure was completed with nickel-chrome alloy. The castings were cleaned and mean score of measurements at four reference points for marginal adaption, casting height, and cervical width was calculated. The marginal adaption was calculated with Imaje J software, whereas the casting height and cervical width was determined using a digital scale. The data was subjected to one-way analysis of varaince and Tukey *post hoc* statistical analysis with Statistical Package for the Social Sciences version 20 software.

**Results:** The group II had the best marginal adaption with a gap of 63.786 µm followed by group I (65.185 µm), group IV (87.740 µm), and group III (101.455 µm). A large marginal gap was observed in group V at 188.871 µm. Cuspal height was more accurate with group V (10.428 mm), group VI (10.421 mm), and group II (10.488 mm). The cervical width was approximately similar in group I, group III, and group V. Statistically significant difference was observed in Tukey *post hoc* analysis between group V and group VI with all the other groups with regards to marginal adaptation.

**Conclusion:** The dry cellulose ring liners provided better marginal adaptation in comparison to prewet cellulose ring liners. Accurate cuspal height was obtained with shorter ring liner in comparison to full-length cellulose ring liners.

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## INTRODUCTION

Indirect restorations constitute a major part of dental restoration. This includes the inlay, onlay, crown, bridges, ceramic restorations, and implant prosthesis. Accurate contour, proximal contact, compatible occlusion, and good marginal adaptation are critical for the long-term durability of indirect restorations.[1] Poor marginal adaptation of crown and bridge leads to multiple deleterious consequences such as secondary caries, discoloration, and periodontal breakdown.[2] Solidification shrinkage of metal during casting procedure is a well-documented phenomenon.[3] Accurate and adequate expansion of the investment mold is employed to compensate for alloy shrinkage during cooling. Expansion of the mould is achieved with the combined effect of setting behaviors, thermal expansion, and seldom by hygroscopic expansion. The setting expansion of the investment is the collective effect of different factors. These include the length, position, and number of ring liner, thickness, softness, and position of wax pattern, water/powder ration of investment.

The influx of scientific evidence on the potential health hazard of asbestos led to its discontinuation as casting ring liner.[4] Cellulose and ceramic ring liners are routinely used by dental laboratories. The ring liner on the inner surface of the casting ring acts as a cushion to provide room for

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***Address for correspondence:***
Dr. Satheesh B. Haralur, E-mail: hb_satheesh@yahoo.com



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thermal and setting expansion. The cellulose material burns out during the casting procedure, and hence, it is advised to keep the ring liner short at both ends of the casting ring to retain the investment within the casting ring.[5] This also restrains the diametrical and axial expansion of the mold. A prewetted liner is reported to increase setting expansion.[6] Utilizing the prewet ring liner for better marginal adaptation is still controversial in dental literature. Phosphate-bonded investment is regularly used for the casting of base-metal and high melting noble metal alloys. Previous authors have investigated the influence of absence of ring liner and wetness of ring liners on the dimensional behavior of the phosphate-bonded investment with conflicting conclusions. The effect of ring liner length within the casting ring and its prewetting on the resultant metal castings accuracy and margin adaptation needs further evaluation. Hence, this *in-vitro* study was designed to evaluate the effect of varying cellulose acetate casting ring liner length and its prewetting on the marginal adaptation and dimensional accuracy of the subsequent full veneer metal castings.

## Materials and Methods

In this study, 60 nickel–chromium full veneer castings were fabricated from wax patterns obtained from the stainless steel master die. The metal castings were divided into six groups of 10 each according to the length of the cellulose ring liner and prewetting during their casting process.[7]

- Group I: Prewet–full length (up to the casting ring edge) cellulose ring liner in the metal casting ring
- Group II: Dry–full length (up to the casting ring edge) cellulose ring liner in the metal casting ring
- Group III: Prewet–3 mm short cellulose ring liner within the casting ring from both ends
- Group IV: Dry–3 mm short cellulose ring liner within casting ring from both ends
- Group V: Prewet–6 mm short cellulose ring liner within casting ring from both ends
- Group VI: Dry–6 mm short cellulose ring liner within casting ring from both ends.

**Figure 1:** Stainless steel master die used in the study

### Master die assembly

The master die assembly was milled in stainless steel and was used for the fabrication of uniform wax patterns [Figure 1]. The stainless steel master die was machined to simulate molar tooth preparation for a full veneer crown. The master die had 6.0 mm diameter on the occlusal surface, and 6-degree taper (cervical–occlusal). The master die assembly used in the study had three components. The master die, removable gingival spacer, and detachable occlusal section [Figure 2]. The V-shaped groove was milled in the occlusal surface of the die to enable the exact reorientation of the finished metal casting during the measurements. The removable gingival spacer of 2-mm thickness was milled to fit accurately at the cervical finish line. During the measurement for margin adaptation, it was removed to enable easier measurement. The detachable occlusal section included two separable sleeves. It allowed easy removal of wax pattern without distortion after its fabrication. Space between the master die and occlusal sleeves was 1.5 mm at an occlusal surface and 1 mm at the axial surface. The top part of the occlusal section had a 3-mm diameter hole at the midpoint between the two sleeves. It helped in escape of excess molten wax during fabrication as well as to standardize the sprue position during the investment procedure.

### Preparation of wax patterns

All the wax pattern fabrication and investment were accomplished at a controlled temperature of 21 ± 1°C and 55 ± 5% humidity. The inlay casting wax was molten with the electrically heated wax bath at 185–195°F. The Die lubricant (Isocera, BEGO GmbH, Bremen, Germany) was applied to both the master die and occlusal sleeves. The molten wax was poured into the master die assembly and sleeves were placed back. Excess wax was extruded through the vent. Pressure during the solidification of wax pattern was also standardized by maintaining the occlusal sleeves throughout the cooling period. Hardened wax pattern was removed by dissembling the occlusal sleeves without distortion. Excess or deficient margin of the wax pattern was evaluated and corrected before investment. Wax patterns were invested immediately to avoid any distortion.

### Investing and casting

A wax sprue of 3 mm diameter and 6 mm length was attached at the centre. Wax patterns were invested individually in separate metal casting ring. During wax pattern attachment to the sprue, due care was observed to maintain 6 mm space

**Figure 2:** Dissembled stainless steel master die

between the wax pattern and casting ring. The wax patterns were sprayed with a surfactant (Picosilk, Renfert, Germany) to improve the wettability. The cellulose ring liner was adapted inside the casting ring, and its dimension was maintained according to the group. The groups I, III, and V casting ring were immersed into water for 15–20 seconds and shaken five times to remove excess water. Groups III and IV had a ring liner adopted 3 mm short at each end of the casting ring, whereas group V and VI had a 6 mm short ring liner. The ring liner was overlapped by 2 mm at the joint. The phosphate-bonded investment (Bellavest, BEGO GmbH, Bremen, Germany) was vacuum mixed (Easy Mix, BEGO GmbH, Bremen, Germany) for 90 s and then poured into the metal ring on a vibrator. The investment was kept for bench set for 30 min.

Wax burnout process followed two stages; the mold temperature was raised to a rate of 50°C/min to 2500°C and held for 30 min. Subsequently, the temperature was raised to 9500°C at a rate of 70°C and maintained for 1 hour. The induction casting machine (Fornax, BEGO GmbH, Bremen, Germany) was utilized to complete the casting using nickel–chromium alloy (Wiron 99, BEGO GmbH, Bremen, Germany). The casted mold was allowed to cool until room temperature. The castings were divested and sandblasted with 250 µm alumina to remove investment debris. Castings were then steam cleaned and subsequently subjected to ultrasonic cleaning for 10 min. The intaglios of the casting were examined to evaluate the presence of nodules.

## Sample testing for margin adaptation and dimension

Marginal adaptation was measured with the help of ImageJ [Figure 3] analytical software (National Institutes of Health, Maryland, U.S.A). Casting samples were reoriented back to the master die without a gingival sleeve. The margin adaption was measured by addition of 2 mm width of the gingival sleeve. Color photograph of the master die along with the seated casting on all four side was obtained with a standardized clinical close-up photography method. Nikon

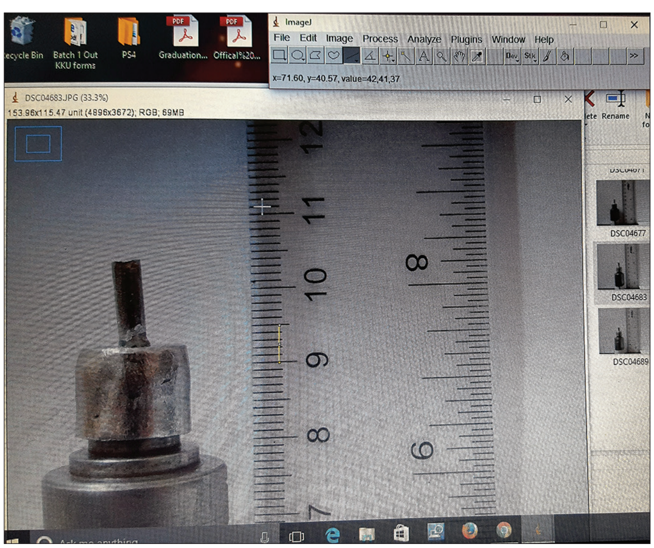


**Figure 3:** MArginal adapation measurement using Image J software

digital single-lens reflex camera with 15 megapixels and 50 mm camera body in nonreflective background was used to standardize the photographs. Camera lens axis was maintained at the level of the master die with the help of a camera mount. An opaque ruler was placed next to the master die during the photograph. The ruler in the photograph was used for calibration of scale in ImageJ analytical software.

Cuspal height and cervical width were measured using a digital calliper (Mitutoyo. Illinois, USA) to analyze the dimensional accuracy. The reference points were marked on the stainless steel die as an orientation point for measurement of all samples. The mean of recording from four sides was calculated, and was assigned as a marginal gap for each sample. Similar method was adapted to determine the length and cervical width of the casting. The data was analysed with analysis of variance (ANOVA) and Tukey Student's test using the Statistical Package for the Social Sciences version 19 software (SPSS, IBM Corporation, Armonk, New York, USA).

## Results

Table 1 shows the mean marginal gap recorded in all the groups. The groups I and II had mean marginal gap of 65.18 µm and 63.786 µm, respectively. Meanwhile, groups III and IV showed marginal gap of 101.455 µm and 87.740 µm, respectively. Corresponding values for groups V and VI were 188.871 µm and 160.844 µm, respectively. All the groups utilizing the dry ring liner displayed better marginal adaptation compared to their prewet counterparts. Group II displayed the best marginal adaptation with a marginal gap of 63.786 µm.

The dimensional accuracy of the castings was assessed by evaluating the accuracy in casting length and cervical width. The length of the casting was measured from cuspal tip to the cervical margin of the casting in the premarked reference point on all four sides, and average of these four recordings was calculated to determine the mean length. Table 1 depicts the mean casting height for all the samples, and also depicts the mean casting height for all the samples. The total height of the casting, including the spacer for cuspal height, was 10 mm in the stainless steel master die. The casting height expansion was observed to be the highest in group II at 11.132 mm followed by group I at 10.757 mm. The groups III and IV had a moderate increase in vertical height at 10.448 mm and 10.625 mm, respectively. The least vertical expansion was observed in groups V and VI at 10.428 mm and 10.421 mm, respectively.

The cervical width of the casting in the master die including space was 13.5 mm. The maximum expansion was observed again in group II at 14.60 mm, followed by group III and group VI with 14.149 mm and 14.234 mm, respectively. The corresponding cervical width observed for groups I, III, and V were 13.703 mm, 13.708 mm and 13.798 mm, respectively.

The statistical analysis [Table 2] by one-way ANOVA comparing the difference between the mean marginal gap, casting height, and cervical height between all the groups indicated statistically significant difference, with a $P$ value of 0.000, 0.001, and 0.000, respectively.

**Table 1: Mean measurements for marginal gap (µm), casting height (mm), and cervical width (mm) for all groups**

| | Full length wet (G I) | Full length dry (G II) | 2 mm short Wet (G III) | 2 mm short Dry (G IV) | 6 mm short wet (G V) | 6 mm short Dry (G VI) |
|---|---|---|---|---|---|---|
| Marginal gap | 65.185 | 63.786 | 101.455 | 87.740 | 188.871 | 160.844 |
| Casting height | 10.757 | 11.132 | 10.448 | 10.625 | 10.428 | 10.421 |
| Cervical width | 13.703 | 14.600 | 13.708 | 14.149 | 13.798 | 14.234 |

**Table 2: ANOVA analysis of all groups for marginal gap. Casting height and cervical width**

| Parameter | ANOVA score | | | | |
|---|---|---|---|---|---|
| | Sum of Squares | df | Mean square | *F* | Sig. |
| Marginal gap | | | | | |
| Between Groups | 135080.096 | 5 | 27016.019 | 27.036 | 0.000* |
| Within Groups | 53960.543 | 54 | 999.269 | | |
| Total | 189040.639 | 59 | | | |
| Casting Height | | | | | |
| Between Groups | 3.854 | 5 | 0.771 | 5.159 | 0.001* |
| Within Groups | 8.067 | 54 | 0.149 | | |
| Total | 11.921 | 59 | | | |
| Cervical width | | | | | |
| Between Groups | 6.449 | 5 | 1.290 | 8.349 | .000* |
| Within Groups | 8.343 | 54 | 0.154 | | |
| Total | 14.792 | 59 | | | |

*The mean difference is significant at the 0.05 level

Table 3 displays the *P* values for each group after Tukey post-hoc analysis. The Tukey post-hoc test for marginal gap showed that the 6-mm short prewet (group V) and dry (group VI) differed significantly at $P < .05$ with all the tested groups. The post-hoc analysis for casting height indicated the full-length dry liner (group II) had statistically significant difference between group III ($P = 0.003$), group V ($P = 0.002$), and group VI ($P = 0.002$). The cervical width of group II samples also displayed the difference between group I, group III, and group V with $P < .05$.

## Discussion

Indirect restorations share the major part of restorative dentistry; lost wax process for casting metal is predominantly used to fabricate the indirect restorations. Dental laboratory techniques are upgraded constantly to fabricate accurate casting from last wax technique.[8,9] A precise cervical margin adaptation is critical for biological, aesthetic, and physical requirement of the restorations. Open margins are known to accentuate periodontal diseases and secondary caries.[10] The phosphate-bonded investment materials are commonly used investment material for casting base metal alloys because of the adequate investment expansion, ability to obtain nonporous castings, and easy retrieving of casting. The nickel-chromium metal alloy was used in the study because it is most commonly used alloy for the fabrication of fixed partial prosthesis. Nickel–chromium alloys are preferred due to high yield strength, modulus of elasticity, resistance to sag deformation, and better bonding to the porcelain.[11]

Predominantly, mold expansion is employed to compensate for solidification shrinkage of metal.[12] Casting ring liner length and width are among the multiple factors that influence the setting and thermal expansion of the mold.[13] The ring liner provides a controlled space for unhindered expansion of mold within the metal casting ring. The recommended minimum thickness of the ring liner is 1 mm. The influence of length and prewetting of the ring liner on the marginal fit and dimensional accuracy of the casting was evaluated in this study. The results of the study showed that the castings made with a dry ring liner had better marginal adaptation across all the groups in comparison to water saturated ring liner. Groups II, IV, and VI had better marginal adaption in comparison to their prewet ring liner counterparts. Group II had the best marginal adaption with 63.786 µm gap, in contrast to group I with 65.185 µm. Similar results were observed in groups III, IV, V, and VI with 101.455 µm, 87.740 µm, 188.871 µm, and 160.844 µm respectively. Several dental researchers have reportedd that the clinically acceptable marginal gap for cast restorations is less than 160 µm.[14,15] Larger marginal gap leads to dissolution of luting cement and subsequent periodontal and caries disease activities. The results of this study are in agreement with the findings of Davis *et al*.[17] and Keyf *et al*.[18]

Results of cervical width accuracy among groups was in contrast to marginal adaptations; prewet ring liners groups showed better accuracy than the dry ring liners groups. Groups I, II, and III resulted in casting width of 13.703 mm, 13.708 mm, and 13.798 mm, whereas the groups II, IV, and VI had casting width of 14.60 mm, 14.149 mm, and 14.234 mm.

Compensation for solidification shrinkage of the metal during casting process is complex, and it is a combined outcome of setting and thermal expansion of the investment.[19,20] According to Morey,[19] investment with high thermal expansion and low setting expansion is more suitable to overcome wax distortion during investment setting and compensate for casting shrinkage of the metal.

Properties of ring lines such as water saturation, compressibility, and semi-hygroscopic expansion due to water release are known to play important roles in mold expansion and casting accuracy. The prewet technique was first reported by Taylor *et al*. in 1930.[21] Previously commonly used ring liner was prewetted asbestos paper. The practice of using prewet asbestos liner was to prevent water absorption from an unset investment mix. Wet ring liners are expected to improve the setting expansion by inducing the semi-hygroscopic expansion as water is drawn to investment during setting reaction.[6] Consequently, the liquid/powder ratio within the investment is increased, leading to decreased thermal expansion.

**Table 3: Tukey HSD multiple comparisons (*P* values)**

| Gr | Marginal gap | | | | | | Casting height | | | | | | Cervical width | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI | I | II | III | IV | V | VI | I | II | III | IV | V | VI |
| I | | 1.00 | 0.124 | 0.605 | 0.000 | 0.000 | | 0.269 | 0.483 | 0.972 | 0.412 | 0.388 | | 0.000 | 1.00 | 0.133 | 0.994 | 0.043 |
| II | 1.00 | | 0.100 | 0.541 | 0.000 | 0.000 | 0.269 | | 0.003 | 0.053 | 0.002 | 0.483 | 0.000 | | 0.000 | 0.122 | 0.000 | 0.309 |
| III | 0.124 | 0.100 | | 0.925 | 0.000 | 0.001 | 0.483 | 0.003 | | 0.908 | 1.00 | 1.00 | 1.00 | 0.000 | | 0.140 | 0.995 | 0.046 |
| IV | 0.605 | 0.541 | 0.925 | | 0.000 | 0.000 | 0.972 | 0.053 | 0.908 | | 0.863 | 0.844 | 0.133 | 0.122 | 0.140 | | 0.360 | 0.997 |
| V | 0.000 | 0.000 | 0.000 | 0.000 | | 0.366 | 0.412 | 0.002 | 1.00 | 0.863 | | 1.00 | 0.994 | 0.000 | 0.995 | 0.360 | | 0.150 |
| VI | 0.000 | 0.000 | 0.001 | 0.000 | 0.366 | | 0.388 | 0.002 | 1.00 | 0.844 | 1.00 | | 0.043 | 0.309 | 0.046 | 0.997 | 0.150 | |

*The mean difference is significant at the 0.05 level

The dry ring liner is known to allow 0.4% investment expansion from compression alone. Previous studies[22] suggest that the water in investment and water in the ring liner is in continuous phase, and increases the magnitude of setting expansion by altering the investment/ring liner volume ratios. The accuracy of casting and marginal adaptation is largely dependent on the diametrical expansion in mold core. Diametrical expansion of investment core is influenced by both compressibility of the wet ring liner and wax distortion. The wax pattern in the full veneer crown has been reported to have lesser distortion of wax patterns due to its resistance to setting expansion by complete encirclement.[23] Scheu *et al*.[24] reported that the dry ring liner facilitates setting expansion due to rapid absorption of water during investment setting and improves the water/powder ratio. This leads to enhanced setting expansion of the investment in comparison to saturated investment. Closer packing of investment particles due to less water/powder has greater effect on the setting expansion than surface tension or added water.[22]

Other researchers such as Fusayama[25] and Hanari[26] have supported the use of a dry ring liner for improved marginal adaptation. The finding from this research reconfirmed the observation of Earnshaw *et al*.,[27] who reported that the investment setting in dry condition improves better marginal adaptation and less distortion.

Cellulose ring liners are burned during the wax burnout procedure, and the resultant space between the investment and metal ring leads to displacement of investment during the casting procedure. Researchers advocate keeping the ring liner shorter than the metal ring to secure investment after burnout procedure. Investment confinement at the end of a metal ring helps in reducing the setting and hygroscopic expansion in longitudinal direction. This will help in uniform expansion of mold due to prevention of unrestricted longitudinal expansion of the mold. Various authors[4] suggest different casting ring liner length, ranging from 2.00 mm to 3.25 mm short from the end of the casting metal ring. The result from this study indicates that the ring liner length significantly influences the casting height. The groups V and VI with 6-mm short ring liner had a casting height of 10.428 mm and 10.421 mm, respectively. The groups I and II showed increased casting height of 10.757 mm and 11.132 mm, respectively, indicating larger longitudinal expansion.

Because this study is an *in-vitro* study, it is difficult to replicate the clinical situations. Various methods were used for evaluating marginal gap, including direct view, explorer method, and cross-sectional view. Marginal gap in the study was evaluated with direct view method because it is more convenient, rapid, and repeatable. Marginal adaptation was evaluated without cementation in the study, whereas the clinical implication of the marginal gap is usually after the permanent cementation of the crown. Crown sectioning after cementation results in crown distortion and marginal gap, and hence, a direct method evaluation was adopted in the study. The present study investigated only phosphate bonded investment and Ni-Cr alloy, further studies are suggested to evaluate the effect of ring liner length and pre-wetting across various other investments and alloys. Further studies are also required to evaluate the effect of thickness of the casting ring liner on marginal adaption and dimensional accuracy.

## Conclusions

Within the limitations of the study, it can be concluded that the dry cellulose ring liners produce casting with better margin adaptation. The best marginal adaptation was obtained from the full-length dry cellulose ring liner (group II) with a mean marginal gap of 63.786 µm followed by group I with 65.185 µm. Group V with 6-mm short prewet cellulose ring liner had the largest mean marginal gap at 188.871 µm, whereas its dry ring liner counterpart (group VI) had 160.844 µm marginal gap. Large expansion of casting height was observed in group II with 11.132 mm, whereas better casting height dimension was observed in group V and group VI at 10.42 mm. Cervical width of full metal casting was observed to be approximately similar in groups I, III, and V at 13.703–13.790 mm.

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## Conflicts of interest

There are no conflicts of interest.

## References

1. Hickel R, Peschke A, Tyas M, Mjor I, Bayne S, Peters M, *et al*. FDI World Dental Federation: Clinical criteria for the evaluation of direct and indirect restorations-update and clinical examples. Clin Oral Investig 2010;14:349-66.
2. Neppelenbroek KH. The clinical challenge of achieving marginal adaptation in direct and indirect restorations. J Appl Oral Sci 2015;23:448-9.
3. Fredriksson H, Åkerlind U. Solidification and Cooling Shrinkage

of Metals and Alloys. In: Materials Processing during Casting. Hoboken (NJ): John Wiley and Sons, Ltd; 2006. p. 311-68.

4. Rong Y, Luo X, Zhang Z, Cui X, Liu Y, Chen W. Occupational exposure to asbestos and cardiovascular related diseases: A meta-analysis. Prev Med Rep 2015;2:920-6.
5. Anusavice, KJ, Phillips, RW, Shen, C, Rawls, HR. In: Phillips' Science of Dental Materials. 12th ed. St. Louis: Elsevier/ Saunders; 2013. pp. 216.
6. J'Obrien W. Dental Materials and their selection, 3rd ed. Berlin: Quintessence Publishing Co. Inc; 2002. p. 98-9.
7. Davis DR, Kawashima SS, Nguyen JH. Effect of ring length and diameter on effective radial setting expansion. Dent Mater 1990,6:56-9.
8. da Silva LJ, Leal MB, Valente ML, de Castro DT, Pagnano VO, Dos Reis AC, *et al*. Effect of casting atmosphere on the marginal deficiency and misfit of Ni-Cr alloys with and without beryllium. J Prosthet Dent 2016 [Epub ahead of print].
9. Alex D, Shetty Y B, Miranda GA, Prabhu M B, Karkera R. Marginal accuracy of nickel chromium copings fabricated by conventional and accelerated casting procedures, produced with ringless and metal ring investment procedures: A comparative *in vitro* study. J Indian Prosthodont Soc 2015;15:58-64.
10. Al-Sinaidi A, Preethanath RS. The effect of fixed partial dentures on periodontal status of abutment teeth. Saudi J Dent Res 2014;5:104-8.
11. Anwar M, Tripathi A, Kar SK, Sekhar KC. Effect of PFM Firing Cycles on the Mechanical Properties, Phase Composition, and Microstructure of Nickel-Chromium Alloy. J Prosthodont 2015;24:634-41.
12. Kalavathi M, Sachin B, Prasanna BG, Shreeharsha TV, Praveen B, Ragher M. Marginal Accuracy of Castings Fabricated with Ringless Casting Investment System and Metal Ring Casting Investment System: A Comparative Study. J Contemp Dent Pract 2016;17:165-70.
13. Davis DR. Effect of denture wax-pattern position on radial setting expansion. Clin Mater 1993;12:83-7.
14. Fransson B, Oilo G, Gjeitanger R. The fit of metal-ceramic crowns, a clinical study. Dent Mater 1985;1:197-9.
15. Boitelle P, Mawussi B, Tapie L, Fromentin O. A systematic review of CAD/CAM fit restoration evaluations. J Oral Rehabil 2014;41:853-74.
16. Jacobs MS, Windeler AS. An investigation of dental luting cement solubility as a function of the marginal gap. Jf Prosthet Dent 1991;65:436-42.
17. Davis DR. Effect of wet and dry cellulose ring liners on setting expansion and compressive strength of a gypsum-bonded investment. J Prosthet Dent 1996;76:519-23.
18. Keyf F, Erman G. Full-Crown Castings Made with Water-Saturated and Dry Casting Ring Liners. J Biomater Appl 2000;14:399-408.
19. Morey EF. Dimensional accuracy of small gold alloy castings. Part 3. Gypsum bonded investment expansion. Aust Dent J 1992;37:43-54.
20. Hutton JE, Marshall GW. Expansion of phosphate-bonded investments: Part II-Thermal expansion. J Prosthet Dent 1995;73:127-31.
21. Taylor NO, Paffenbarger GC, Sweeney WT. Dental Inlay Casting Investments: Physical Properties and a Specification. J Am Dent Assoc 1930;17:2266-86.
22. Mahler DB, Ady AB. An explanation for the hygroscopic setting expansion of dental gypsum products. Dent Res 1960;39:578-89.
23. Mahler DB, Ady AB. The influence of various factors on the effective setting expansion of casting investments. J Prosthet Dent 1963;13:365-73.
24. Scheu CH. Controlled Hygroscopic Expansion of Investment to Compensate for Shrinkage in Inlay Casting. J Am Dent Assoc 1935;22:452-5.
25. Fusayama T. Technical procedure of precision casting. J Prosthet Dent 1959;9:1037-48.
26. Hanari M. Mold distortion by four different investing techniques. Bull Tokyo Med Dent Univ 1967;14:435-45.
27. Earnshaw R. The Effect of Casting Ring Liners on the Potential Expansion of a Gypsum-bonded Investment. J Dent Res 1988;67:1366-70.