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EVALUATION OF EFFECT OF VARIOUS COOLING PROCEDURES ON DIMENSIONAL ACCURACY AND FLEXURAL STRENGTH OF HEAT CURE DENTURE BASE RESINS: AN IN VITRO STUDY

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ABSTRACT
Purpose:- Heat activated PMMA resins remains the most preferred material for fabrication of denture prosthesis. However, dimensional changes are unavoidable as it undergoes processing shrinkage. Denture bases undergo repeated stress during mastication over time and may crack intraorally while in use because of fatigue, therefore, a high flexural strength is required for the success of a denture. Besides the curing cycle of the denture, the cooling regimen that follows is of significance to determine the properties of heat cure denture base resin. The aim of this study is to investigate the effect of various cooling procedures on dimensional accuracy and flexural strength of heat cure denture base resins. **Materials and Method:**- A total of 96 samples were fabricated which were divided into two groups with 48 samples each. Group A: dimensional accuracy and Group B: flexural strength. Each group were further subdivided into three groups according to the different cooling procedures- Subgroup 1: bench cool for 30 min and then immersed in cool tap water for 15 min, Subgroup 2: cooled under running water for 20 min and Subgroup 3: flask cooled overnight in water bath. The subgroups were again divided into 2 groups each for the two materials used- conventional (TREVALON) and high impact (TREVALON HI). Dimensional accuracy was checked using an Electron microscope by measuring the distance between the grooves. Flexural strength was measured by using Universal testing machine. **Results:** Highest dimensional change was seen in samples cooled directly under running water for 20 min and least changes were seen in samples that were cooled overnight in water bath. Samples cooled in water bath for overnight showed highest flexural strength. **Conclusion:** Fast cooling should be discouraged as it has shown to result in significant dimensional change. Cooling procedures does have a significant effect on the flexural strength of heat cure denture base resin where slow cooling resulted in a higher flexural strength in comparison with the fast cooling method.

KEYWORDS: Heat cure denture base resin, Cooling procedures, Dimensional accuracy, Flexural strength.

INTRODUCTION
Ever since the introduction of acrylic resin in dentistry, it has been a useful material in the fabrication of denture prosthesis.[1-10] In spite of development of several new materials, PMMA remains the most preferred material for rehabilitation of totally and partially edentulous patients as it is easy to process and repair, economical, light weight and has excellent aesthetic properties.[9-18]

Denture base resins used in dentistry are polymerized by heat, chemicals, visible light, and microwave energy.[19-21] Heat activated acrylic resin is still the most widely accepted material and is the principal choice when it comes to denture base.[4,9,22-25] However, dimensional changes due to polymerization shrinkage are inevitable in heat processed Polymethacrylate (PMMA) denture base, materials.[4,7,9,22-25] In addition to polymerization shrinkage there is also thermal shrinkage as the processed denture cools in the flask.[6,25] These changes are compensated to some extent by water sorption. The final adaptation of the denture thus, is affected by several factors as: 1) Type of acrylic resin; 2) Flask cooling procedures and 3) Water uptake.[25,26] Denture undergoes volumetric and linear shrinkage initially, primarily linear shrinkage occurs due to thermal changes resulting in significant effects upon the adaptation of denture base and cuspal inter-digitation.[23,26]

Denture bases undergo repeated flexing during mastication over several years and may fracture or crack intraorally due to fatigue failure.[13-17] A high flexural strength is required to prevent catastrophic failure under load, which is paramount for the success of a denture.[14,17] Many factors influences flexural fatigue strength, some of them being frenum notches, surface irregularities, and foreign body inclusions.[13,16,17,27]

Porosities and residual monomer content have been shown as important factors influencing the flexural fatigue strength.[13,16,27] The processing technique used to polymerize the denture base resin has been found to be an important factor, which can induce stress into the denture base during processing and finally lead to fatigue failure.[10,13,16,27]

Besides the curing cycle of the denture it's the cooling regimen followed which is of significance to determine the linear dimensional changes.[25,26,28] Numerous studies have been conducted on the effect of long and short curing cycles on dimensional stability of dentures and generally the longer cycles have produced the most dimensionally stable denture.[1,25,26,29] However, comparatively little work has been done on the effect of different cooling regimens on the dimensional accuracy and flexural strength of heat cure PMMA dentures.

The aim of this study is to evaluate and compare the effect of various cooling procedures on dimensional accuracy and flexural strength of heat cure denture base resin.

The null hypothesis of this study is that there is no effect of cooling procedures on dimensional accuracy and flexural strength of heat cure denture base resins.

MATERIALS AND METHOD

The study comprises of 96 samples.
The samples were divided into 2 groups:

- Group A- dimensional accuracy
- Group B- flexural strength

These groups are again subdivided into 3 subgroup each according to the different cooling procedures.

- Subgroup 1- bench cooled for 30 min and then immersed in cool tap water for 15 minutes
  - a) 1a- conventional heat cure (Trevalon)
  - b) 1b- high impact heat cure (Trevalon Hi)
- Subgroup 2- cooled under running water for 20 minutes
  - a) 2a- conventional heat cure (Trevalon)
  - b) 2b- high impact heat cure (Trevalon Hi)
- Subgroup 3- cooled overnight in water bath.
  - a) 3a- conventional heat cure (Trevalon)
  - b) 3b- high impact heat cure (Trevalon Hi)

Preparation of wax pattern

a) For dimensional accuracy

A metal die of 65mm length, 10mm width and 3mm thickness was fabricated with three V shaped grooves 20mm apart from each other (fig 1A). The distance between the grooves was measured using a travelling microscope. Putty mould was made by taking impression of the metal die. Modelling wax was melted and poured into the mould and the wax patterns of desired dimension were made. These patterns were used to form mould for test samples.

b) For flexural strength

A metal die of dimensions 65mm x 10mm x 3mm in length, breath and thickness respectively was made (fig 1B). Putty mould was made by taking the impression of the metal die and wax pattern was fabricated by pouring melted wax into the mould. The patterns were then used to prepare mould for test samples.

Preparation of mould

For preparation of mould, drag portion of the flask was filled with freshly mixed dental stone, and wax patterns were placed into this mixture. Upon reaching initial set, the stone was coated with cold mould seal. The cope of the selected denture flask was positioned on top of the drag of the flask and the second mix of dental stone was poured. The cap was gently tapped into place and stone was allowed to set. Upon completion of setting, the wax was removed by immersing the flask in boiling water for 10 minutes. The flask was then removed from the water and segments of flask were separated. The softened wax was carefully removed from the surface of the mould by boiling water until all residues of wax were removed and mould left clean. Cold mould seal was then applied onto the walls of mould cavity and allowed to dry.

Packing and Curing

The powder and liquid were mixed according to the manufacturer's instruction. Packing was done in dough stage and flask assembly was placed into hydraulic press, and pressure was applied incrementally. The flash that was produced was removed using blunt instrument. The flasks were kept for bench curing for 30 minutes aknd then transferred to water bath for curing at 74˚C for 2 hrs and then increasing the temperature to 100^0C and processing for 1 hr. After completion of the curing, the different cooling procedures was employed.

Evaluation of dimensional accuracy

After employing the different cooling procedures, the samples were retrieved. The distance between the grooves was measured using travelling microscope (fig 2) and checked for any changes in the linear dimension.

Evaluation of flexural strength

After retrieval of the samples, it was finished and stored in distilled water at a temperature of $(37 \pm 1)^0$C for (50 ± 2) hrs prior to flexural testing. Flexural strength was obtained from a 3-point bend test by using a universal testing machine (fig 3). The flexural strength was calculated by using the formula $S=3FL/2BD^2$, where S- flexural strength, F- maximum load before fracture, L- length of the support arm, B- width of the specimen, D- thickness of the specimen.

RESULTS

Dimensional changes in group A- conventional heat cure resin (TREVALON) and group B- high impact resin (TREVALON HI) after employing the different cooling procedures are shown in figure 4. The mean of dimensional changes in samples of group A: subgroup 1 (bench cool for 30 min + immersed in water for 15 min) was A-B- 0.24 and B-C- 0.242 , for subgroup 2(running water for 20 min) A-B- 0.321and B-C- 0.317 and for subgroup 3 (overnight cooling in water bath) A-B- 0.122 and B-C- 0.123. The mean of dimensional changes in samples of group B: subgroup 1 (bench cool for 30 min + immersed in water for 15 min) was A-B- 0.246 and B-C- 0.258, for subgroup 2(running water for 20 min) A-B- 0.326 and B-C- 0.326 and for subgroup 3 (overnight cooling in water bath) A-B- 0.123 and B-C- 0.13. For both the groups maximum changes are seen in subgroup 2 followed by subgroup 1 and subgroup 2. One-way ANOVA test indicated that there was significant difference. Tukey's post hoc test was applied for comparison of dimensional changes between the subgroups which showed significant difference ($p<0.001$). Unpaired t test was applied to compare the dimensional changes between group A and B and no significant difference was found ($P>0.05$).

Mean flexural strength of group A (Conventional heat cure- TREVALON) and group B after employing the cooling procedures are shown in figure 5 and 6 respectively. The mean of flexural strength of samples for group A: subgroup 1 (bench cool for 30 min + immersed in water for 15 min) 221.15 MPa, for subgroup 2 (running water for 20 min) 212.71MPa and for subgroup 3(overnight cooling in water bath) was 233.35 MPa. The mean of flexural strength of samples for group B: subgroup 1 (bench cool for 30 min + immersed in water for 15 min) 278.39 MPa, for subgroup 2(running water for 20 min) 264.81 MPa and for subgroup 3(overnight cooling in water bath) was 291.08 MPa. For both the groups samples in subgroup 3 showed highest flexural strength followed by subgroup 1 and 2 respectively. One way ANOVA indicated that there was highly significant difference ($P<0.001$). Tukey's post hoc test was applied for comparison between the subgroups which showed significant differences ($P<0.001$). Unpaired t test was applied to compare the flexural strength between group A and B which showed significant difference ($P<0.001$).

DISCUSSION

The dimensional changes of dentures have been examined using a variety of shapes and methods.[4,25] In this study, rectangular specimens with dimensions 65 x 10 x 3 mm was used as dimensional changes of specimens made with acrylic resins are affected by the shape of the specimen. Therefore, it is important to examine the dimensional changes of acrylic resins using a specimen with a simple shape to permit examination of the dimensional change of the acrylic resin itself.[4,25]

In this study, the samples were processed at 74^0C for approximately 2 hr and increasing the temperature of the water bath to 100^0C and maintaining it for 1 hr. The temperature is maintained at 100^0C for 1 hr to reduce the content of residual monomer.[20] After completion of curing cycle different cooling methods were employed.

Savirmath et al.[24] and Duymus et al.[23] have used travelling microscope to determine dimensional changes in various kinds of acrylic denture base specimens in their respective studies. The same was used in the present study as well. The precision of the travelling microscope used was 0.001mm.

According to the results, maximum dimensional changes were seen in samples cooled directly under running water for 20 mins followed by the samples which were benched cooled and least changes were seen in samples which underwent overnight cooling. The results were in agreement with the studies done by Savirmath et al.,[25] Kobayashi et al.,[24] Kimito et al.,[5] Ibrahim et al.,[28] khalaf et al.,[7] where they have found more dimensional changes with fast cooling methods and recommended slow cooling methods for more accurate denture bases.

Examination of polymerization process indicates thermal shrinkage of resin is primarily responsible for the linear changes observed in heat-activated systems. During the initial stage of cooling process, the resin remains relatively soft. Consequently, the resin mass contracts at about the same rate as the surrounding dental stone. As cooling proceeds, the soft resin approaches its glass transition temperature. Cooling the denture base below the glass transition temperature yields a rigid mass. The rigid mass contracts at a different rate from the surrounding dental stone. When the denture base resin cools from glass transition temperature to room temperature, it undergoes linear shrinkage.[20]

The difference in the thermal contraction between the mould and the acrylic resin during cooling is believed to be the cause of residual stress in the processed denture and is also considered to be the main contributor to the stress release that occurs when the denture is separated from the cast.[1,7,18,25,30] The rate of cooling of the flask after processing has a definite effect on the dimensional changes of dentures, with the quenching method causing an unequal thermal contraction in various areas and thus inducing a greater amount of stress that results in greater warpage.[5,7,18,25,26] Slow cooling in water bath can be expected to result in more uniform cooling of the denture resulting in a less dimensional change.[6,7,25,28]

In this study, for the flexural strength rectangular samples were made with dimensions 65 x 10 x 3 mm. Various authors have used the similar rectangular samples for testing flexural strength.[12,13,31] Three-point flexural test is the most common technique of measuring flexural strength of denture bases. In this study, a loading force was applied to specimens at a crosshead speed of 5 mm/min based on studies by Ajaj-ALKordy et al.[14] and Agiurre et al.[17]

Increasing the polymerization temperature reduces the content of the residual monomer. The lowest content of the residual monomer (0.07%) was determined after the hot polymerization procedure at a temperature of 100°C for a period of 12 hours, which confirms the importance of the temperature and duration of the polymerization.[13,32] In this study, a polymerization protocol ending at a temperature of 100°C was applied in order to minimize the percentage of residual monomers. The conversion of monomers into polymer is an important determinant of the mechanical strength of the tested material.[13,32]

Several studies have been done to evaluate the effect of curing cycles on the flexural strength of heat cure denture base resin where they concluded that the long curing cycle proved to be better in producing denture bases with higher flexural fatigue strength as compared to the short curing cycle.[13,31,33] However, few studies were done to evaluate the effect of cooling cycles on the flexural strength of heat cure denture base resins.

PMMA is amorphous, because the pendent groups do not allow the molecules to get close to form crystalline bonds; therefore the predominant effect of the cooling rate is on shrinkage, which is associated with ill fitting dentures. This is mainly related to the conformation of the polymer chains. When fast cooling rates are used, the polymer chains are highly constrained, with reduced segmental mobility and the resultant residual stresses are high, affecting the dimensional stability and fitting of the prosthesis. Worst results have been experience by sudden temperature reduction (quenching), that creates differential shrinkage vectors and contraction at various denture areas. Quenching in water at the glassy state may induce more internal stresses and affect the mechanical properties.[22,24,26,32,34]

In a study by Polychronakis et al.[32] to evaluate the effect of cooling procedures on mechanical properties of heat cure resin by instrument indentation testing, they found that the effect cooling procedures on mechanical properties of denture base resin is different for different materials.

In our study, we have taken two materials from same manufacturer – conventional (TREVALON) and high impact (TREVALON HI). According to the results, samples that were cooled overnight in water bath showed highest flexural strength followed by the samples that were benched cooled and the samples which were directly cooled under running water for 20 min showed lowest flexural strength. After calculation of the mean flexural strength, one way ANOVA test was applied and significant difference ($p<0.001$) was found. Tukey's post hoc test was applied for comparison within the subgroups and significant difference ($p<0.001$) were found. Unpaired 't' test was applied for comparison between the two materials which showed significant difference($p<0.001$).

The standard states that acrylic resins should achieve no less than 65 MPa. The results of this study demonstrated that the mean flexural strength of the different cooling methods tested in the current work was higher than that required by ISO 1567.[35] Thus, in terms of flexural strength all three cooling methods are suitable for clinical use. However, the results of the present study shows that the cooling rates have an impact on the flexural strength of the heat cure denture base resin. Further studies need to be conducted to know the impact of cooling procedures on flexural strength using materials from different manufacturer.

The null hypothesis of this study is rejected as significant difference was found on dimensional accuracy and flexural strength of the samples after employing the cooling procedures.

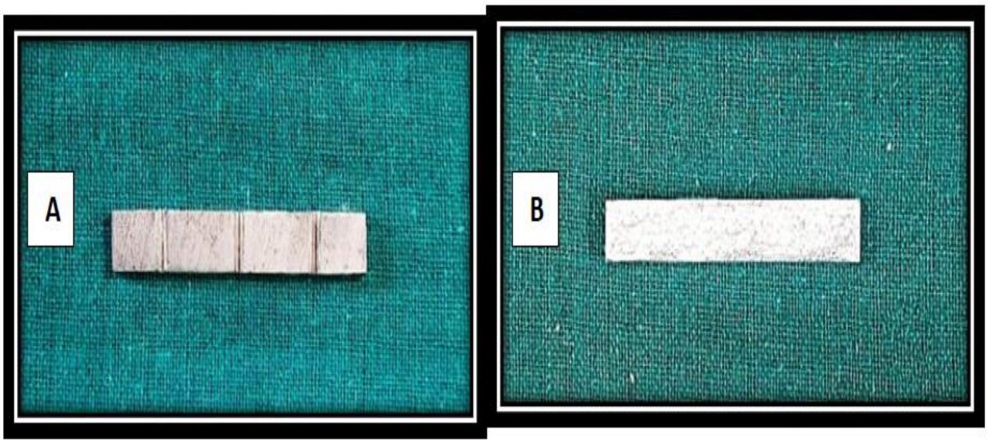

Figure 1: Metal dies A) For dimensional accuracy and B) For flexural strength.

Figure 2: Measurement of linear dimensional change using travelling microscope.

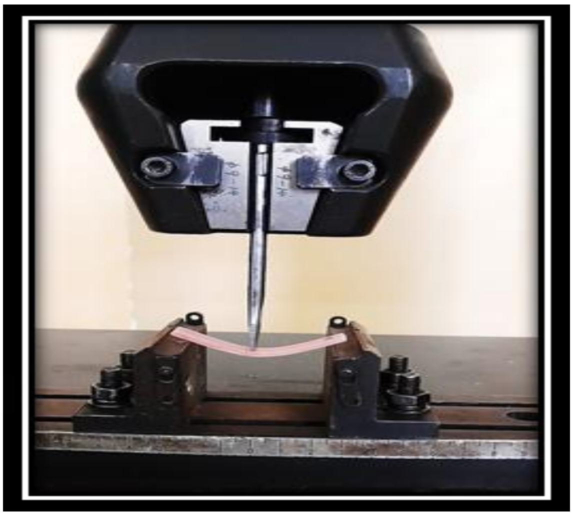

Figure 3: Flexural strength test using Universal testing machine.

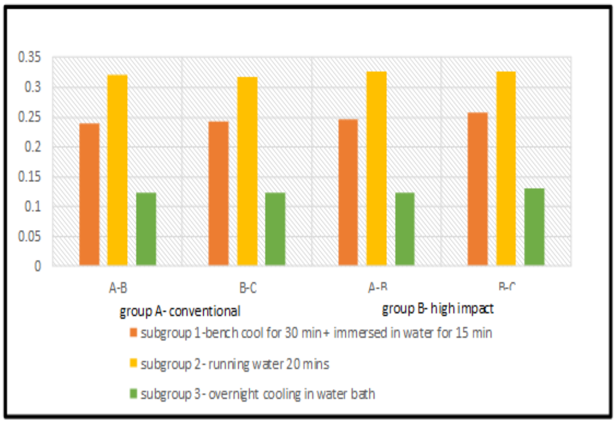

Figure 4: dimensional changes of group A- conventional and group B- high impact the high impact heat cure resin (TREVALON HI) after employing the cooling procedures.

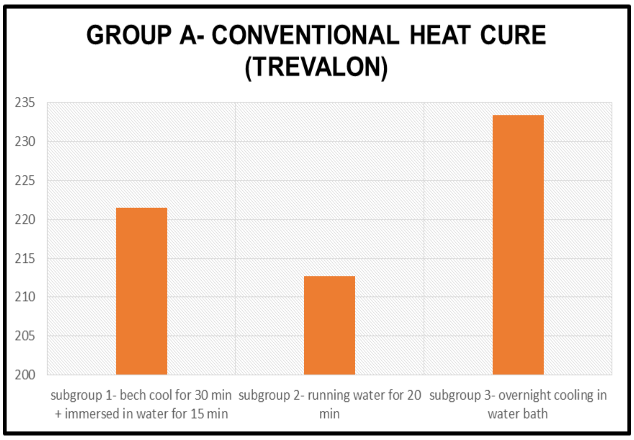

Figure 5: Mean flexural strength of conventional heat cure denture base resin after employing the three different cooling procedures.

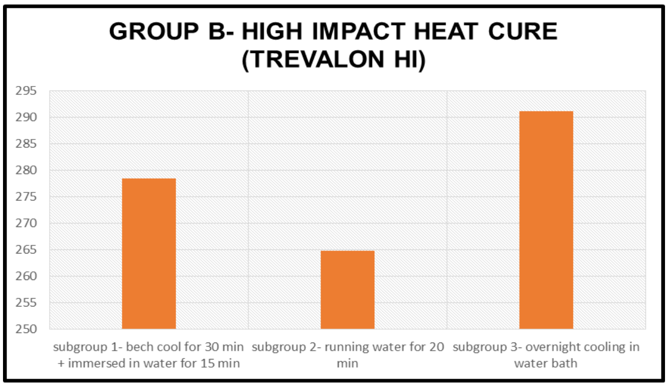

Figure 6: Mean flexural strength of high impact heat cure denture base resin after employing the three different cooling procedures.

CONCLUSION

Within the limitations of the study, following conclusions are drawn:

- Slow cooling in water bath for overnight results in a less dimensional change in comparison with the fast cooling method used.
- Fast cooling should be discouraged as it has shown to result in greater dimensional change.
- Cooling procedures does have an affect on the flexural strength of heat cure denture base resin.
- Slow cooling in the water bath resulted in a higher flexural strength in comparison with the fast cooling method.
- Further studies needs to be conducted to check for the effect of different cooling methods on flexural strength using materials from different manufacturers

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