Original Article

Comparison of cooling methods on denture base adaptation of rapid heat-cured acrylic using a three-dimensional superimposition technique

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Abstract

Aim: To investigate the effect of different cooling methods on denture base adaptation of rapid heat-cured acrylic resin using 3D superimposition technique.

Setting and Design: *In vitro* - Comparative study.

Materials and Methods: Denture base adaptation of two different rapid heat-cured polymethyl methacrylate acrylic resins using five different cooling methods were compared. Forty maxillary edentulous stone cast were prepared to produce the denture bases with standardized thickness. The specimens were divided into five groups ($n = 8$) according to type of materials and cooling methods. The master stone cast and all forty denture bases were scanned with 3Shape E1 laboratory scanner. The scanned images of each of the denture bases were superimposed over the scanned image of the master cast using Materialize 3-matic software. Three dimensional differences between the two surfaces were calculated and color surface maps were generated for visual qualitative assessment.

Statistical Analysis Used: Generalized Linear Model Test, Bonferroni Post Hoc Analysis.

Results: All bench-cooled specimens showed wide green-colored area in the overall palatal surface, while the rapid cooled specimens presented with increased red color areas especially at the palate and post dam area. Generalized Linear Model test followed by Bonferroni post hoc analysis showed significant difference in the root mean square values among the specimen groups.

Conclusion: Samples that were bench cooled, demonstrated better overall accuracy compared to the rapid cooling groups. Regardless of need for shorter denture processing time, bench cooling of rapid heat-cured PMMA is essential for acceptable denture base adaptation.

Keywords: Three-dimensional-superimposition, cooling methods, denture base adaptation, rapid cured polymethyl methacrylate

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INTRODUCTION

Polymethyl methacrylate (PMMA) first introduced in 1937, was commonly used to fabricate removable prosthesis due to its favorable working characteristic, adequate mechanical strength, and comparatively low cost.[1,2] To reduce time taken to issue or deliver a removable prosthesis, there has been continuous development on this material and its related procedures. Since the first rapid 20-min heat-cured PMMA was introduced,[3] studies have shown that there were no significant dimensional variations between conventional long heat curing cycle and rapid 20-min curing cycle.[4,5]

Well-fitted dentures prevent hyperplasic lesion, provide chewing efficiency, and promote patient comfort. Besides the type of acrylic resin used, curing cycle and water uptake, flask cooling method also play an important role in maintaining dimensional accuracies of a removable prosthesis.[6,7] This is because residual internal stress created during heat processing is relaxed in the stone mold with longer cooling period, thereby reducing warpage during deflasking.[6] However, conventional cooling method is time-consuming and is not practical for urgent cases or during community service in rural settings or for the frail older adults whereby shorter denture delivery time is the primary objective. It is therefore important to determine whether sufficient accuracy with good denture base adaptation can be achieved by shorter cooling period. A number of methods were introduced to study the dimensional accuracies of fixed prosthesis or denture base material such as linear measurements between two points[8,9] and quantifying space by weight of silicone.[10] However, these methods were time-consuming and subject to operator error.[11] It is clinically more relevant to relate denture base adaptation as well as fitting of crowns by three-dimensional (3D) superimposition.[12]

To date, there has been no study using 3D superimposition technique to assess the effect of different cooling methods on denture base adaptation of rapid heat-cured acrylic. The aim of the present study was to evaluate the influence of different cooling methods on denture base adaptation of two commercially available rapid heat-cured PMMA denture base materials. The null hypothesis was that no significant differences would be recorded in denture base adaptation to the stone model of the tested materials, independently of the applied cooling procedures.

MATERIALS AND METHODS

Reference cast preparation and scanning

The study was approved by institutional review board. In this study, two commercially available rapid curing PMMA were used [Table 1]. The workflow of this study protocol is presented in Figure 1. An edentulous maxillary cast of Class 1 Type A, fulfilling the American College of Prosthodontists classification system,[13] was prepared as a reference cast. The definitive cast was duplicated using silicone-based duplication material (Wirosil, Bego USA) and 40 stone casts were prepared using Type IV dental stone (Elite Rock, Zhermack Italy). Eight casts were assigned to each study group according to the applied cooling procedure as summarized in Table 1. Each cast was labeled and allowed to dry for 24 h before scanning and digitizing with 3Shape E1 dental laboratory scanner (3Shape, Copenhagen, Denmark).

Preparation of denture base specimens

Wax pattern of approximately 2.0 mm thickness throughout was prepared over the reference cast. For replication of waxed denture base specimens, a silicone matrix (Exaflex Putty, GC USA) was used to standardize the thickness of all specimens.[14] Each denture base specimen was flasked by compression molding technique,[15] and heat cured in 100°C water bath for 20 min.

Denture base cooling process and three-dimensional analysis

All 40 rapid cured specimens were cooled down according to the selected groups as shown in Table 1 and hydrated in distilled water for 24 h before scanning procedure. Intaglio surface of each denture base was scanned using the 3Shape E1 scanner. Silicone putty (Exaflex Putty, GC USA) was used to ensure an identical scanning position for each specimen.

The 3D scanned data of the denture bases were saved in a standard tessellation language (STL) format and exported to a reverse engineering software (3-matic®, Materialise, Leuven, Belgium). After virtual removal of all irrelevant scanned surfaces, STL file of every intaglio surface of the denture base was superimposed with the corresponding scanned file of the master stone cast to compare the degree surface adaptation of each specimen [Figure 2]. The entire tissue surfaces of the denture bases were superimposed with only the corresponding denture bearing area of the master cast. Superimposition was done by point-to-point matching of four anatomical landmarks, namely the buccal frenum, incisive papillae, and fovea palatine on both the surfaces. This was followed by fine tuning with automated registration, by global registration adopting closest point algorithm of the software.

Dimensional differences between the two surfaces were calculated and color surface maps were generated for visual

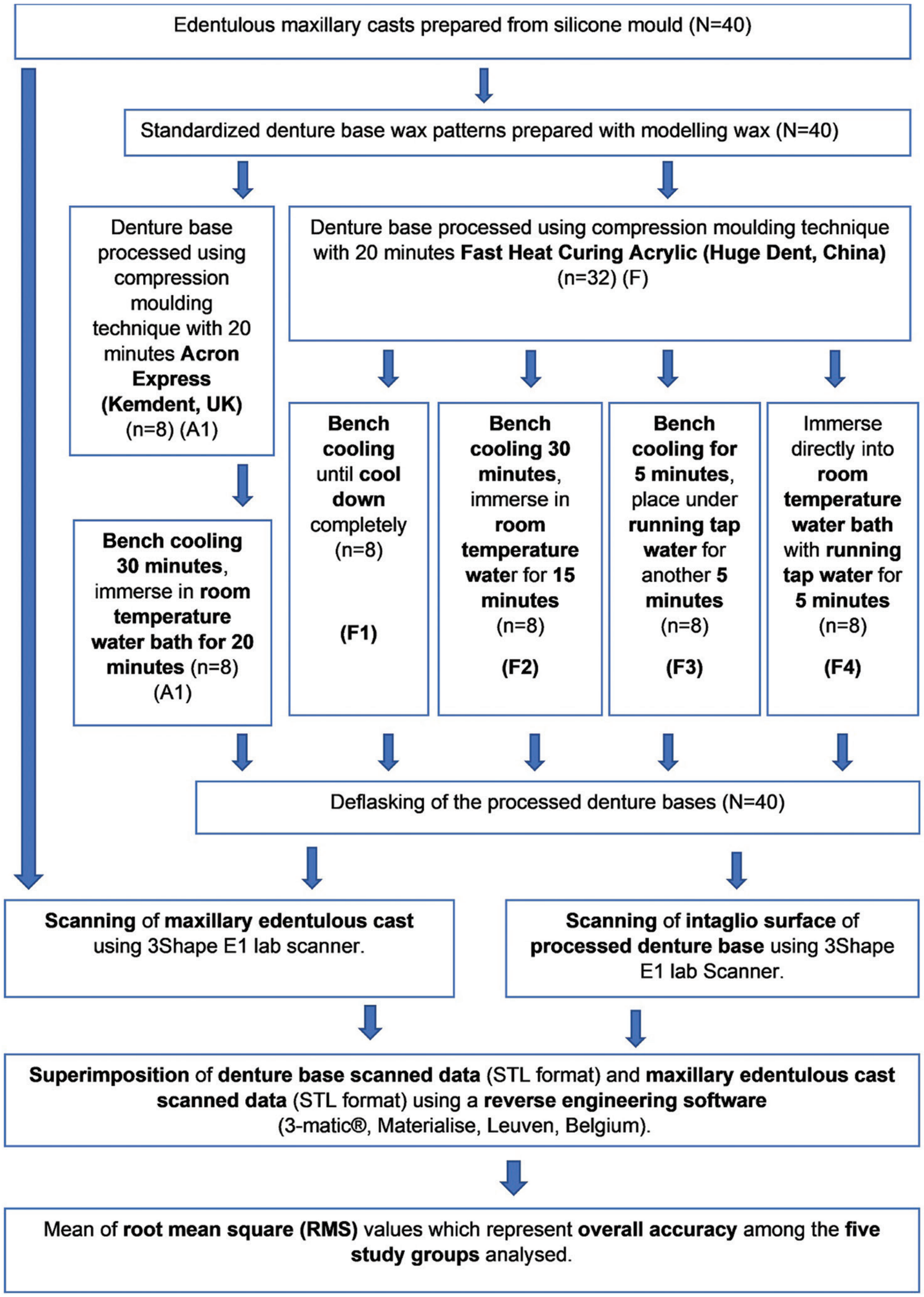

Figure 1: Workflow of research protocol

qualitative assessment. An ideal denture would show a color map which is entirely green, giving a measurement of 0, indicating ideal adaptation of denture base to master cast. Positive deviations, from color yellow to red, show misfit with gap while negative deviations, from cyan to blue color indicates tissue compression, implicating impingement of denture base into master dental cast.

Statistical analysis

Generalized linear model test compared the accuracy of the five different specimen groups followed by Bonferroni *post hoc* analysis ($P < 0.05$). The root-mean-square (RMS) values of each superimposition were recorded for each specimen. Besides that, the mean, median, and interquartile range (IQR) of numeric distance for each superimposition were recorded. All statistical values were analyzed using the Statistical Package for Social Sciences version 22.0 (SPSS Inc., Chicago, II, USA). All scanning and superimposition procedures were performed by a single investigator. Intra-class correlation coefficient with the score of 0.85 was reported to ensure high intra-ratter reliability.

Table 1: The acrylic denture base products tested and cooling procedure used in the study

Material	Lot number	Code	Manufacturer	Group	Cooling procedure description
Acron Express	Powder: 210605 Liquid: 24512	AE	Associate Dental Products Ltd., Kemdent Works, U.K.	A1	Bench-cool for 30 min, and then immerse in 23°C room temperature water bath for 20 min[a]
Fast Heat Curing	Powder: 1809141101 Liquid: 1808271049	FHC	Huge Dental Material Co. Ltd., Shanghai, China	F1	Bench-cool until cool down completely[a]
				F2	Bench-cool for 30 min, and then immerse in 23°C room temperature water for 15 min[b]
				F3	Bench-cool for 5 min, and then place under running tap water for another 5 min[c]
				F4	Immerse directly into room temperature water bath with running tap water for 5 min[c]

[a]According to manufacturer's instructions, [b]Based on Phillip's Science of Dental Material textbook, [c]Experimental shorter cooling methods

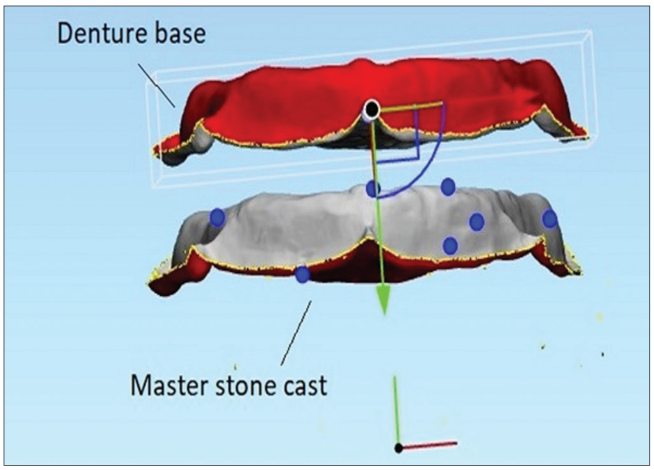

Figure 2: Superimposition of denture base standard tessellation language file on master stone cast standard tessellation language file

RESULTS

Color deviation map indicating the denture base adaptation of each specimen group between the master model and the intaglio surface of denture base are shown in Figure 3. Specimens A1, F1, and F2 showed wide green-colored area in the overall palatal surface. F3 and F4 presented with increased red color areas, especially at the palate and post dam area.

Table 2 shows the descriptive statistics of the study which includes mean, IQR, median, and RMS value of numeric superimposition distance for each specimen groups. With regard to accuracy of denture base adaptations, lowest RMS mean value was recorded in F1 group and highest RMS mean value was found in F3 group. Significant difference was reported in the RMS values among the specimen groups ($P = 0.002$) according to the Generalized Linear Model test. Overall accuracy of F1 was comparable to ISO certified A1 when cooled down according to the manufacturer's instructions as the difference was not statistically significant. Based on Bonferroni *post hoc* analysis, F3 was significantly different from F1 and F2, while F4 was significantly different from F1.

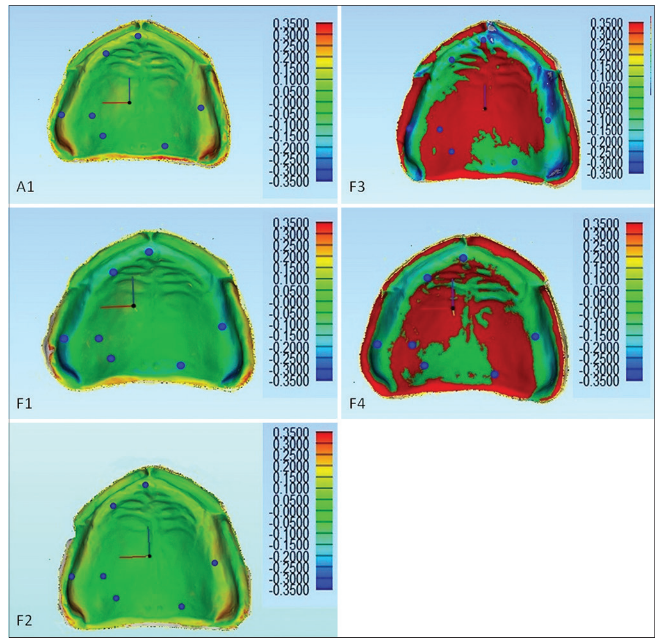

Figure 3: Color maps of intaglio surface of maxillary denture base. Nominal deviation (green); positive deviation (yellow to red) misfit with space; negative deviation (cyan to blue) tissue compression

DISCUSSION

An affordable, stronger, and shorter duration for denture processing is crucial to reduce denture delivery time for targeted special needs population who suffer from physical ailment, chronic diseases, or other social and economic challenges.[16,17] Simultaneously, good denture base adaptation with limited deformation and shrinkage is vital to every aspect of the wearer's experience.[18-20]

Many methods have been used to study the dimensional accuracies of denture base materials, ranging from measuring between two reference points on denture base with optical comparator, measuring microscope,[20] post dam discrepancies,[21] vertical dimension or incisor pin movement,[22,23] quantifying space between denture and master cast with the weight of silicone material[10,19,24] and lately by superimposing scanned data using specified software.[12,25-27]

Table 2: Measured surface deviations between scanned master casts and maxillary denture bases

Specimen groups	Mean±SD (mm)	IQR (mm)	Median (mm)	RMSE (mm)
A1	−0.003±0.007	0.143	0.387	0.385
F1	0.372±0.008	0.115	0.362	0.372
F2	0.375±0.003	0.128	0.376	0.375
F3	0.407±0.110	0.143	0.404	0.407[ab]
F4	0.402±0.009	0.157	0.392	0.402[a]

Statistically significant difference found between the following: [a]$P<0.05$ according to Bonferroni *post hoc* analysis for Group F1, [b]$P<0.05$ according to Bonferroni *post hoc* analysis for Group F2. SD: Standard deviation, IQR: Interquartile range, RMSE: Root-mean-square error

Although manual measuring methods are easy to use, inexpensive and readily accessible, they are time-consuming and subject to operator error.[11,28] Furthermore, these methods only measure linear changes between two points, whereas dimensional changes occurred three dimensionally during processing. Therefore, it is more clinically relevant to relate the denture adaptation by superimposing STL files using engineering software.[27,29]

Based on the results of this study, the null hypothesis was rejected because significant differences were observed between the five groups ($P < 0.05$). Comparison between the 3D scanned image of the denture base and stone model of the upper complete edentulous arch revealed that the adaptability of the bench cooled (A1, F1, and F2 groups) denture bases were significantly better than those that were rapidly cooled (F3 and F4) ($P < 0.001$). These findings are consistent with a number of studies[6,19,30] which show better adaptation when bench cooled as compared to rapid cooling. The cooling rate of heat-cured acrylic resins has long been accepted as a means of controlling their crystallinity and shrinkage.[31] This is due to the reaction taking place during heat polymerization,[32] whereby there is a difference in the thermal contraction between stone mold and acrylic resin, leading to the production of internal stress within the processed denture. When this residual stress is released on deflasking, higher shrinkage was observed in rapidly cooled PMMA compared to slow or bench cooled acrylic, since more elastic strain was released during removal from the stone mold.[30,33]

On the color-coded map, ideal adaptation was shown as homogeneous green area as seen in A1, F1 and F2 bench cooling groups. Positive deviation, displayed as yellow to red, was more pronounced in the F3 and F4 rapid cooling groups, indicating the presence of space between the denture base and the cast. This space or gap, especially at the posterior palatal seal area, indicates there was warpage of denture upon deflasking in rapid cooling groups which also coincides with the finding of significantly higher RMS value reported in these groups. It has long been recognized that the least deformation of the prosthesis is achieved when gradual post processing cooling is undertaken. When rapid 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.[33] In addition, poor outcome is also likely due to sudden temperature reduction or quenching[34,35] which creates differential shrinkage vectors and contraction at various denture areas.

In terms of analyzing the digital data, unlike most of the earlier studies[12,36] which only analyzed the median of numeric distance to determine the accuracy of each specimen group, in this study, RMS value was considered to determine the accuracy of each specimen group. According to Pearson's correlation coefficient, there was no correlation between RMS value and median of numeric distance analyzed. Hence, RMS value remains the chosen parameter to evaluate accuracy of each superimposition.

This *in vitro* study has some limitations. The denture base adaptation was compared against a standard edentulous master cast. The master cast does not replicate the dynamic characteristic of oral mucosa during function, including saliva and a limited mouth opening space. Moreover, unlike fixed prosthesis,[37] adaptation of removable prosthesis is highly influenced by compressibility of mucosa during mastication.[38] In addition, the software first performed point-based registration using fixed anatomical landmark followed by overall matching using closest corresponding points between two surfaces. Due to the complicated algorithm in the process of automated superimposition, true individual displacement may not be replicated accurately. Nevertheless, to date, this remains the most updated protocol for studies of similar nature. In order to negate this limitation, haptic technology should be incorporated into the alignment software to relate it to actual tactile sensation occurring during denture base adaptation.[14] More studies that consider the true clinical environment should be undertaken to assess patient-related outcome measures.

CONCLUSION

Within the limitations of this *in vitro* study, the 3D superimposition technique established that the samples that were bench cooled, demonstrated better overall accuracy as compared to the rapid cooling groups. Hence, in situations when time is of essence, bench cooling rapid heat-cured PMMA produces acceptable denture base adaptation.

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Conflicts of interest

There are no conflicts of interest.

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