Estimation of the linear dimensional changes of autoclave cured acrylic resin with multiple palatal depths and investment materials

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ABSTRACT

Background: Dimensional changes of acrylic denture bases after polymerization results in need for further adjustments or even ends with technical failure of the finished dentures. The purpose of this study was to estimate the linear dimensional changes for different palatal depths when using multiple investment materials and polymerization techniques.

Materials and methods: Ninety upper complete denture bases were constructed for this study. They were divided into two main groups according to the polymerization methods: conventional water bath and experimental autoclave (short and long cycles). Each main group was further subdivided into three subgroups according to the palatal depth (shallow, medium and deep). Furthermore, for each palatal depth; complete denture bases were invested either with dental stone or laboratory silicone. For each upper complete denture, measurements of linear dimensional changes were done by fixation of metallic screws on the tissue surface of the denture base. The distances were measured by using travelling microscope with an accuracy of 0.001 %. The data were statistically analyzed using three way analysis of variance (ANOVA) for three variables, which were (palatal depth, investments and polymerization techniques), LSD test and student T test for comparisons between groups.

Results: There were significant improvements in the dimensional accuracy of denture bases cured with autoclave compared with water bath. Also, silicone investments were a successful alternative to stone, study data shows that short autoclave processing with silicone reduces the magnitude of the linear dimensional changes. On the other hand, long autoclave processing and stone investments were better than silicone in reducing dimensional changes.

Conclusion: The findings of this study indicates that the use of autoclave processing in acrylic curing is a promising alternative to the conventional water bath and leads to better dimensional stability for the finished dentures in all oral configurations and palatal depths. Also, Silicone is more preferable than stone, although it's not as strong investing materials when compared with stone.

Key words: linear dimensional changes, laboratory silicone, autoclave polymerization, travelling microscope. (J Bagh Coll Dentistry 2015; 27(2):32-42).

INTRODUCTION

The inaccuracy of maxillary complete denture represents a major clinical and technical issue caused by: type of investment materials, powder/liquid ratio of acrylic, packing and polymerization technique and finally temperature used during processing of the resin. So, changes in resin polymers were not uniformly distributed and many factors may act and affect each other at the same time. [(1)] During acrylic resin polymerization, the accumulative effects of the post polymerization dimensional changes combined with a variety of shrinkages occurs during both flask cooling and opening leads to distortions by stress relaxations, all these factors leads to linear dimensional changes. [(2)]

One of the major factors that locally plays vital role in the success of maxillary complete denture is palatal depth and shape. [(3)] Denture stability and retention depends to a greater extent on the depth of the palate. [(4)]

Water bath curing, regarded as the most favorable processing technique, its multiple benefits includes; easy and simple procedure and low price equipments, but still had main drawback of being time consuming method. [(5)]

The highly favorable technique for acrylic resin processing is the fast one, and the researchers reported that this technique is acceptable for processing of denture bases at different volumes, configurations and depths. [(6)]

Autoclave polymerization was evaluated as processing technique for acrylic resin and the results showed acceptable improvements in the transverse strength of the tested samples when compared with samples processed with conventional polymerization even when both short and long curing cycles examined. [(7)]

As an alternative to the strong dental stone which has been used as a conventional investment material, laboratory silicone represents a good choice with a higher accuracy. [(8)] The advantages of the laboratory silicone includes; flasking being further simpler, faster and without processing mess and decreasing the opportunity of denture distortions after flask opening. On the other hand, the knowledge about the effect of this investment material on the linear dimensional changes is still limited. [(9)]

The establishment of linear dimensional changes was correctly done with the aid of a travelling microscope, with a higher accuracy to be able to record minimum dimensional changes in the acrylic resin. These changes were the

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reasons for inaccuracies and leads to errors in the complete dentures. [4]

The aim of this study was to estimate the influence of different palatal depths (shallow, medium and deep) on linear dimensional changes of denture bases invested with two types of investment (stone and laboratory silicone) and cured by two curing methods (conventional water bath and autoclave polymerization; short and long cycles).

MATERIALS AND METHODS

A universal metallic edentulous cast (**standardized metal brass, New York, USA**) represents maxillary arch with a uniform residual alveolar ridge free from any discrepancies used to construct master silicon mold (**Columbia dent form Corp.**). As shown in figure 1.

Figure 1: Silicone molds in the initial stages of making the casts.

The master silicon molds were modified in order to make three molds simulating multiple palatal depths (shallow, medium and deep) so: the mold without modification was for shallow palate cast, while medium palate mold was made by placing two layers of base plate wax (Shanghai New Century Dental material, China) on the palatal part of the mold to increase the depth of the palate to (13mm). On the other hand, deep palate was made by placing four layers of wax so increasing depth to 18mm. Then the modified molds were poured with type IV dental stone (Elite model, Zhermack technical, Italy) using P/W ratio of 100gm to 30ml and with the aid of vibrator (Quayle Dental, England). The casts were allowed to sets for 45min and then taken from the molds to form three palatal depth casts measured with digital vernier (Shanghai Shenhanme asuringtools Co., LTD, China) by attaching the master cast to a dental surveyor (Milling machine, AF30, Switzerland) in order to creates a zero tilting.

During depth measurement, two standardized points were selected; first point represents the center of the incisive papilla and the second point at the center of fovea palatina. Straight lines joined them together was drawn, the middle of that line (at 39mm from the anterior edge of the cast) was bisected by a second line horizontally in the center, so the intersection point of these two lines represent center of the palate and from this point palatal depth was measured by horizontal placement of a plastic ruler (China plastic industry) on the alveolar ridge and the measuring point of the vernier touch the selected point to estimate the depth and standardize measurements for all casts. [10]

The casts were duplicated to form 90 stone casts by using a plastic duplication flask (Clear Cast flask, vertex, Netherlands), the cast was placed at the bottom (base) of the flask and fixed with hot wax, then the upper part of the flask was placed on the base. Mean while, agar duplication material (Castagel, Vertex-Dental, Netherlands) was liquefied at (92ºC) and tempered at (48ºC) in a water bath (EWL 55 01, West Germany) and poured until totally filled the flask and left to cool for 60 min. [11] The master cast was removed and mold space was filled with type IV dental stone. This operation was repeated until the planned number of the casts for the study was reached.

A 2mm thickness of a clear thermoplastic acrylic cakes for record base (Biocryl C, SCHEU-Dental, Iserlohn, Germany) was used for all stone casts by similar construction procedure using universal Biostar machine (SCHU-DENTAL, Germany) following manufacturer instructions. Each record base thickness was calibrated and standardized with digital vernier. Also, for each palatal depth, a red colored template was constructed from biostar materials to standardize the locations of the perforations of all record bases of the study. [12]

The template record base perforated (drilled) with round bur attached to laboratory engine (W&H torque, Germany) attached to surveyor in order to form 7 uniform perforations in a previously selected region marked on the cast with black ink and with fixed distances between them. The regions were: P: center of incisive papilla; RC&LC: right and left canine; RT&LT: right and left tuberosity and M&V: anterior and posterior midpoint between (RC&LC and RT&LT) and the distances between these regions were measured by using travelling microscope (Leitz /WETZLAR, Germany) to make a preprocessing twelve equal measurements, then the clear thermoplastic record bases were placed above the red template in order to correctly copy positions of perforations to all the record bases. Then a 3mm length and 2mm diameter screw made from copper (Dentsply-Maillefer, Swiss).

Were placed and fixed inside the perforations and distances were in following arrangements; ridge arch (RT-RC,RC-P,RT-V,LT-LC,LC-P,LT-V) and palatal arch (P-M,M-V,RT-M,RC-M,LT-M and LC-M).(13) as shown in figure (2).

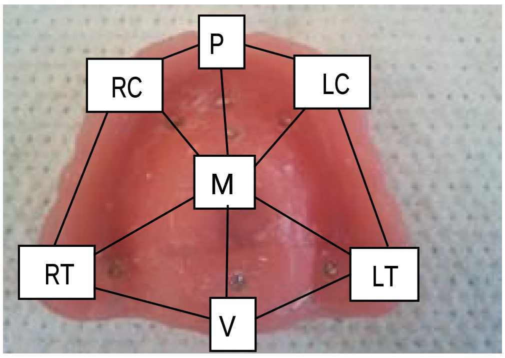

Figure 2: Selected points for measurements of linear dimensional changes.

The measurements between the reference points were evaluated and recorded in the record base before acrylic resin polymerization in order to make a comparison with the post polymerization measurements with the aid of a travelling microscope with an accuracy of 0.001mm as illustrated in figure 3.

Figure 3: Travelling microscope used to determine dimensional changes.

The record bases were organized according to the polymerization techniques, so casts were divided in to two major groups: first group was polymerized with conventional water bath and contain 30 samples and second group was polymerized with experimental autoclave including two cycles (short and long curing). Each one contains 30 samples. each major group were divided into two groups each one contains 15 samples according to the type of investment weather stone or silicone and for each one; there were three subgroups represent various palatal depths (shallow, medium and deep) and each subgroup contains 5 samples.

In flasking procedure, record bases with their casts were placed in the lower portion of a universal brass dental flask (BRODEN, Sweden) and type II dental plaster (AL-AHLYA, Iraq) was poured and filled the lower part. After a 45 min of setting period, sodium alginate separating medium (Kamadent, Swindon, England) was applied and after setting of 5 min, the upper portion of the flask was placed and a second mix of type IV stone fill the flask and upper cover was placed and the flask was left for 1 hour for final setting. [14] For samples invested with laboratory silicone, the same procedure was followed but instead of stone, a 200ml of silicon base and catalyst (Castasil 21, Vertex-Dental, Netherlands) were mixed homogenously in glass plate following manufacturer recommendations, when even mixture reached, same previous procedure was followed but a 20 minute for silicon setting was allowed. [15] Then after the flask was opened, two layers of sodium alginate separating medium was applied on the flask two parts [14] as shown in figure 4.

Figure 4: Half of the flask after opening and separation medium application.

Acrylic resin was (Regular, TM, Vertex-Dental, Netherlands) manipulated and used with dry and clean mixing jar for mixing a ratio of 1:3 by stiff and clean spatula for about 30 seconds. the mixing jar with its content was covered with glass slap and allowed to be doughy in about 15 minutes, resin packed in the flask in organized groups with the aid of polyethylene sheet (Amalgamated dental Trade Distributors LTD, London, England) served as a separation tool in primary flask closure under a pressure of 20 bars. [13] After the primary closure, polyethylene sheets discarded and any acrylic flashes at the periphery of the mold space were cut away with a sharp knife. Then, groups polymerized with water bath were processed as follows: flasks were pressed in a hydraulic press (Bremer Goldschlagerei Herbst West Germany) for duration of 5 minutes and pressure of 20 bars and clamped in usual manner by using universal clamp (Ash Co., England). then, the flasks with their clamps were placed in a water bath machine (Digital water bath, Lab Tech) and temperature was set for 90 minutes at 73C° then half an hour of boiling at 100°C [14] as shown in figure 5.

Figure 5: Electronic water bath machine with its control panel.

On the other hand, experimental specimens were processed using an electronic sterilization autoclave (Euronda, type B inspection) according to two selected programs represents long and short curing cycles. So flasks with their clamps were placed inside sterilizing chamber then the door was closed and secured, the two selected programs were operated in order to polymerize the acrylic resins as follows:

1. Short curing cycle: 121°C and 210 KPa for 15 minutes.
2. Long curing cycle: 121°C and 210 KPa for 30 minutes. [16]

The chosen cycles were monitored by control panel of the machine in order to control operation stages including: evacuation of air, entrance of steam and starting sterilization with raising temperature and keeping it and finally lowering it for cooling. Water steam was evacuated and curing cycle was finished. The device was shown in figure 6.

Figure 6: Electronic autoclave machine with control panel.

At the end of the processing procedure, the flasks were allowed to cool slowly at 23ºC of room temperature. The finished dentures were carefully removed from their flasks and any excess acrylic was trimmed away with tungsten burs under continuous water cooling. Polishing was accomplished using pumice in a lathe machine (Bego, Germany), and specimen's storage were adjusted according to ADA specification No.12 for effect of curing methods and investment materials, so for the linear dimensional changes dentures were de-casted before the measurements had been done. [13]

Differences in measurements before and after processing were estimated using travelling microscope and in the same circumstances applied before processing and by the same person to reduce the chances of error to minimum. The differences were represented as + when expansions and – when shrinkages and = when no changes were detected and subjected to statistical analysis using three way variance (ANOVA) to determine variation between (palatal depth, type of investment and polymerization procedure with interferences between them) and least significant test (LSD) for comparison between palatal depth groups for each type of investment material, after that t-Test for comparison between subgroups were used with level of significance of (0.05).

RESULTS

The means and standard deviations for linear dimensional changes were calculated in (mm) and presented in Table 1.

The three way ANOVA table (F test) for the estimation of the relationship between palatal depths (shallow, medium and deep) of tested groups and its influence on linear dimensional changes indicates a high significant differences (P-value<0.01) with the use of both types of investment materials (stone and silicone) and with multiple curing methods (water bath and autoclave; short and long). These results were presented in table 2.

Also the least significant test LSD for the comparison between each palatal depth showed the followings:

In water bath curing: in silicone investment there were significant reduction in the dimensional change magnitude in the medium and deep palate when compared with the shallow one in degree more than when stone investment were used, especially in the comparison between medium and deep palate.

In short autoclave cycle: same finding of water bath curing methods was again found in short autoclave cycle when silicone investment was used except when the comparison was made between medium and deep palate when stone investment was used.

In long autoclave cycle: stone were better than silicone in the reduction of the magnitude of the linear dimensional changes except when the comparison was made between medium and deep palate when silicone investment was used. And this was illustrated in table 3 and 4.

Effect of curing methods

t-test for comparison between control group (water bath and stone investment) with experimental group (short autoclave curing with both stone and silicone investment) revealed a high significant reduction (P-value<0.01) in the linear dimensional changes. Especially, during the use of silicone investment there were reduction in the magnitude of dimensional changes although it was non-significant when compared with stone and this were clear in table 5.

While for long curing cycle when compared with control group, results revealed that best reduction in the dimensional changes were obvious when stone investment was used and these were illustrated in table 6.

On the other hand, t test for the comparison between experimental groups (short and long autoclave) cycles when stone investment material was used, magnitude of linear dimensional changes decrease in the long curing cycle especially in the medium and deep palate and these were illustrated in table 7.

Effect of investment materials

t-test for comparison between investment materials (stone and silicone) for all curing methods and all palatal depths indicated that silicone investment have better reduction in magnitude of dimensional changes than that of stone. Except in case of long autoclave cycle in medium and deep palate when silicone was not better than stone in dimensional change magnitude and this was illustrated in table 8.

DISCUSSION

Dimensional stability of acrylic resins was regarded as an essential physical characteristic of the dental prosthesis to secure final configuration in oral services. The anatomical shape of the oral land marks which is reflected in its corresponding denture bases may leads to unorganized distortions linearly rendering the dentures functionally useless. [17]

The effect of curing methods

When water bath curing was applied, the acrylic resin processed at a temperature below the standard glass transition temperature, and when its cooled down to ambient temperature, internal stresses would be generated by shrinkage and distortion inside the resin mass. [18] so, during further processing at fast polymerization cycle, which means the final half an hour at 100°C of boiling water, release of the stored internal stresses within the resin mass occur. [19] Also, further releasing of stresses from the flask opening leads to more distortion of the denture bases. [20] On the other hand, a high degree of variations in curing temperature by different positions of the flask within water bath machine, so heat is not uniformly distributed, leading to less degree of polymerization, higher ratio of residual monomer and less cross linking between polymer chains in some areas. So more dimensional changes will be resulted. [21]

The short and long curing cycles during autoclave processing is characterized by more dimensional accuracy compared with conventional water bath and that's because the uniform temperature distribution in the autoclave machine leads to spreading of heat more uniformly inside the mass and higher degree of cross linking between polymer macro-molecules, leading to formation of bridging structures connecting the linear polymer chains and formation of rigid and strong 3D network and less dimensional change when compared with the water bath. [22] Also, the high pressure exerted during autoclave processing resulted in increasing the rate of reaction and raising the temperature of the monomer above boiling points so any excess monomer will be depleted, decreasing the dimensional changes of the cured acrylic resin by a higher degree of final polymerization. [23]

The effect of the length of autoclave curing cycle

The long one with stone investment showed better dimensional stability this could be explained by continuous heat supply from heat source which would be exaggerated by the exothermic nature of the polymerization reaction of the mass. So less residual monomer were present. Although larger amount of internal stress were generated in the cured resin and when the curing time increased, the amount of the stresses increased too, but these stresses were restricted by the strong stone investment material. While for the short cycle, because of less curing time in both types of investments, more dimensional changes occurred, this may be due to more residual monomer. [24]

The effect of investment

The influence of stone on the degree of stress relaxation of denture base is very clear because this strong material is the hardest investment to deal with during flask opening and denture retrieving. It generates high stress inside the resin mass that will be later released during removing the denture from the cast. Also, stone is subjected to expansion either by setting (0.15-0.25%) or by water sorption during flasking and curing in water bath when water molecules penetrate the semi-preamble separating medium. [25] Also, great variation in coefficient of thermal expansion between stone cast (11*10-6) and acrylic resin (81*10-6) leads to formation of a gap between denture base and cast. [26] So, silicone is easier during investment removal because it has a moderate tear resistance so need scalpel to tear the mold and taking out the denture. [26] And as a result, investing with silicone will leads to better dimensional stability compared with stone. [14]

As conclusion; Autoclave curing procedure for acrylic resin is better when compared with traditional water bath curing. Silicone investment had shown to be a good replacement to the conventional stone investment in multiple palatal depths. The long autoclave curing method is better than the short one especially when stone investment was used.

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Table 1: descriptive statistics (mean differences and standard deviations) for the linear dimensional changes for A: water bath, B: short and C: long autoclave cycles.

Depth	Linear changes	A Water bath				B Short Autoclave				C Long autoclave			
		Stone (Control)		Silicone		Stone		Silicone		Stone		Silicone	
	Points	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Shallow	RT-RC	0.04	0.002	0.04	0.002	0.01	0.0005	0.03	0.0015	0.04	0.002	0	0
	RC-P	0.01	0.0005	-0.03	-0.0015	-0.06	-0.003	-0.02	-0.001	0.04	0.002	-0.01	-0.0005
	RT-V	0.05	0.0025	-0.01	-0.0005	0.06	0.003	0.03	0.0015	0.02	0.001	-0.05	-0.0025
	LT-LC	0.01	0.0005	-0.03	-0.0015	-0.02	-0.001	-0.04	-0.002	-0.67	-0.0335	0.01	0.0005
	LC-P	0.02	0.001	-0.02	-0.001	0.04	0.002	-0.01	-0.0005	-0.03	-0.0015	0.03	0.0015
	LT-V	-0.02	-0.001	0.06	0.003	-0.07	-0.0035	0.01	0.0005	0.03	0.0015	0.02	0.001
	P-M	-0.04	-0.002	0.05	0.0025	-0.01	-0.0005	0.02	0.001	0.03	0.0015	0	0
	M-V	0.12	0.006	0.01	0.0005	-0.03	-0.0015	0.05	0.0025	0.05	0.0025	0.13	0.0065
	RT-M	-0.01	-0.0005	-0.05	-0.0025	0.02	0.001	0.01	0.0005	-0.02	-0.001	0.04	0.002
	RC-M	0	0	0.04	0.002	0.04	0.002	-0.01	-0.0005	0.04	0.002	0.05	0.0025
	LT-M	0.03	0.0015	0.04	0.002	0	0	0.02	0.001	-0.03	-0.0015	-0.01	-0.0005
	LC-M	-0.02	-0.001	0.05	0.0025	0.02	0.001	0.04	0.002	0.04	0.002	0	0
Medium	RT-RC	-0.03	-0.0015	-0.01	-0.0005	0.04	0.002	0.02	0.001	0.01	0.0005	-0.03	-0.0015
	RC-P	0.03	0.0015	0	0	-0.01	-0.0005	-0.02	-0.001	-0.01	-0.0005	0.05	0.0025
	RT-V	0.05	0.0025	-0.04	-0.002	-0.01	-0.0005	0.04	0.002	0.02	0.001	0.03	0.0015
	LT-LC	-0.01	-0.0005	-0.02	-0.001	0.04	0.002	0.01	0.0005	0.01	0.0005	-0.03	-0.0015
	LC-P	0.04	0.002	0.06	0.003	0.01	0.0005	0.03	0.0015	0.02	0.001	0.05	0.0025
	LT-V	0.37	0.0185	0.01	0.0005	0.04	0.002	-0.01	-0.0005	-0.02	-0.001	0.05	0.0025
	P-M	0.03	0.0015	-0.04	-0.002	0.03	0.0015	-0.02	-0.001	-0.01	-0.0005	0.03	0.0015
	M-V	-0.01	-0.0005	0.08	0.004	0.03	0.0015	-0.03	-0.0015	-0.04	-0.002	0.03	0.0015
	RT-M	0.03	0.0015	0.05	0.0025	0.02	0.001	0.01	0.0005	0.02	0.001	0.04	0.002
	RC-M	-0.02	-0.001	0.01	0.0005	-0.05	-0.0025	0.03	0.0015	0.02	0.001	-0.04	-0.002
	LT-M	0	0	-0.02	-0.001	0.04	0.002	-0.04	-0.002	-0.02	-0.001	0.03	0.0015
	LC-M	0.02	0.001	0.03	0.0015	0.04	0.002	0.02	0.001	-0.02	-0.001	0.04	0.002
Deep	RT-RC	0.05	0.0025	0.04	0.002	-0.01	-0.0005	-0.04	-0.002	-0.02	-0.001	0.05	0.0025
	RC-P	0.04	0.002	-0.05	-0.0025	-0.05	-0.0025	0.03	0.0015	-0.04	-0.002	0.02	0.001
	RT-V	-0.04	-0.002	0.08	0.004	-0.03	-0.0015	-0.01	-0.0005	-0.04	-0.002	0.04	0.002
	LT-LC	0.05	0.0025	-0.03	-0.0015	0.01	0.0005	-0.04	-0.002	0.01	0.0005	-0.05	-0.0025
	LC-P	0.01	0.0005	0.05	0.0025	-0.01	-0.0005	-0.02	-0.001	0.02	0.001	0.04	0.002
	LT-V	0.01	0.0005	0.04	0.002	0.03	0.0015	0.01	0.0005	0.02	0.001	-0.05	-0.0025
	P-M	-0.04	-0.002	0	0	0	0	-0.02	-0.001	0.05	0.0025	-0.01	-0.0005
	M-V	0.03	0.0015	0.02	0.001	-0.01	-0.0005	-0.01	-0.0005	0.02	0.001	0.04	0.002
	RT-M	0.05	0.0025	-0.01	-0.0005	0.02	0.001	0.02	0.001	-0.03	-0.0015	0.03	0.0015
	RC-M	0.01	0.0005	-0.03	-0.0015	0.02	0.001	-0.01	-0.0005	-0.04	-0.002	0.01	0.0005
	LT-M	0.02	0.001	-0.02	-0.001	0.02	0.001	0.05	0.0025	0.01	0.0005	0	0
	LC-M	0.02	0.001	-0.01	-0.0005	0.03	0.0015	-0.04	-0.002	-0.03	-0.0015	0.05	0.0025

Table 2: F test for comparison between the palatal depths (shallow, medium and deep) for all curing methods and investment materials for the linear dimensional changes.

Linear changes Points		F test between shallow & medium &deep					
		Stone			Silicone		
		F test	P value	sig	F test	P value	sig
Water bath	RT-RC	36.56	P<0.01	HS	22.03	P<0.01	HS
	RC-P	30.44	P<0.01	HS	26.3	P<0.01	HS
	RT-V	44.23	P<0.01	HS	28.01	P<0.01	HS
	LT-LC	41.23	P<0.01	HS	25.09	P<0.01	HS
	LC-P	47.36	P<0.01	HS	12.3	P<0.01	HS
	LT-V	26.3	P<0.01	HS	33.3	P<0.01	HS
	P-M	25.02	P<0.01	HS	12.22	P<0.01	HS
	M-V	30.03	P<0.01	HS	14.52	P<0.01	HS
	RT-M	31.05	P<0.01	HS	21.03	P<0.01	HS
	RC-M	33.06	P<0.01	HS	22.5	P<0.01	HS
	LT-M	10.06	P<0.01	HS	30.03	P<0.01	HS
	LC-M	0.00	1.00	NS	12.22	P<0.01	HS
Short cycle	RT-RC	15.33	P<0.01	HS	23.04	P<0.01	HS
	RC-P	30.2	P<0.01	HS	41.06	P<0.01	HS
	RT-V	33.03	P<0.01	HS	44.02	P<0.01	HS
	LT-LC	30.6	P<0.01	HS	23.33	P<0.01	HS
	LC-P	22.3	P<0.01	HS	20.9	P<0.01	HS
	LT-V	36.03	P<0.01	HS	19.05	P<0.01	HS
	P-M	15.6	P<0.01	HS	0.00	1.00	NS
	M-V	28.3	P<0.01	HS	30.3	P<0.01	HS
	RT-M	0.00	1.00	NS	44.03	P<0.01	HS
	RC-M	30.3	P<0.01	HS	45.02	P<0.01	HS
	LT-M	33.6	P<0.01	HS	22.03	P<0.01	HS
	LC-M	41.0	P<0.01	HS	26.3	P<0.01	HS
Long cycle	RT-RC	12.22	P<0.01	HS	52.22	P<0.01	HS
	RC-P	14.52	P<0.01	HS	14.52	P<0.01	HS
	RT-V	21.03	P<0.01	HS	21.03	P<0.01	HS
	LT-LC	22.5	P<0.01	HS	23.68	P<0.01	HS
	LC-P	30.03	P<0.01	HS	30.03	P<0.01	HS
	LT-V	30.03	P<0.01	HS	30.03	P<0.01	HS
	P-M	33.3	P<0.01	HS	53.37	P<0.01	HS
	M-V	36.56	P<0.01	HS	36.56	P<0.01	HS
	RT-M	30.44	P<0.01	HS	30.44	P<0.01	HS
	RC-M	44.23	P<0.01	HS	44.23	P<0.01	HS
	LT-M	41.2	P<0.01	HS	41.23	P<0.01	HS
	LC-M	47.3	P<0.01	HS	47.36	P<0.01	HS

Table 3: LSD test for comparison between palatal depths (shallow, medium and deep) for all curing methods and stone investment for linear dimensional change.

Linear changes		LSD (Linear) Stone								
		Shallow & Medium			Shallow & Deep			Medium & Deep		
		P value	Sig	Ch	P value	Sig	Ch	P value	Sig	Ch
Water bath	RT-RC	P<0.01	HS	¤	P<0.01	HS	£	P<0.01	HS	£
	RC-P	P<0.01	HS	£	P<0.01	HS	£	P<0.01	HS	£
	RT-V	1.00	NS	=	P<0.01	HS	¤	P<0.01	HS	¤
	LT-LC	1.00	NS	¤	P<0.01	HS	£	P<0.01	HS	£
	LC-P	P<0.01	HS	£	P<0.01	HS	¤	P<0.01	HS	¤
	LT-V	P<0.01	HS	£	P<0.01	HS	£	P<0.01	HS	¤
	P-M	P<0.01	HS	£	1.00	NS	=	P<0.01	HS	¤
	M-V	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	£
	RT-M	P<0.01	HS	£	P<0.01	HS	£	P<0.01	HS	£
	RC-M	P<0.01	HS	¤	P<0.01	HS	£	P<0.01	HS	£
	LT-M	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	£
	LC-M	1.00	NS	£	1.00	NS	£	1.00	NS	=
Short cycle	RT-RC	P<0.01	HS	£	P<0.01	HS	¤	P<0.01	HS	¤
	RC-P	P<0.01	HS	£	P<0.01	HS	£	P<0.01	HS	¤
	RT-V	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	¤
	LT-LC	P<0.01	HS	£	P<0.01	HS	£	P<0.01	HS	¤
	LC-P	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	¤
	LT-V	P<0.01	HS	£	P<0.01	HS	£	P<0.01	HS	¤
	P-M	P<0.01	HS	£	P<0.01	HS	£	P<0.01	HS	¤
	M-V	P<0.01	HS	£	P<0.01	HS	£	P<0.01	HS	¤
	RT-M	1.00	NS	=	1.00	NS	=	1.00	NS	=
	RC-M	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	£
	LT-M	P<0.01	HS	£	P<0.01	HS	£	P<0.01	HS	¤
	LC-M	P<0.01	HS	£	1.00	NS	£	P<0.01	HS	¤
Long cycle	RT-RC	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	¤
	RC-P	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	¤
	RT-V	1.00	NS	=	P<0.01	HS	¤	P<0.01	HS	¤
	LT-LC	P<0.01	HS	£	P<0.01	HS	£	1.00	NS	=
	LC-P	P<0.01	HS	£	P<0.01	HS	£	1.00	NS	=
	LT-V	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	£
	P-M	P<0.01	HS	¤	P<0.01	HS	£	P<0.01	HS	£
	M-V	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	£
	RT-M	1.00	NS	£	P<0.01	HS	¤	P<0.01	HS	¤
	RC-M	P<0.01	HS	¤	P<0.01	HS	¤	1.00	NS	¤
	LT-M	P<0.01	HS	£	P<0.01	HS	£	P<0.01	HS	£
	LC-M	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	¤

¤ Mean decreasing changes £ means increasing changes and = means no changes.

Table 4: LSD test for comparison between palatal depths (shallow, medium and deep) for all curing methods and silicone investment for linear dimensional change.

Linear changes		LSD (Linear) Silicone								
		Shallow & Medium			Shallow & Deep			Medium & Deep		
		P value	Sig	Ch	P value	Sig	Ch	P value	Sig	Ch
Water bath	RT-RC	P<0.01	HS	¤	1.00	NS	=	P<0.01	HS	£
	RC-P	P<0.01	HS	£	P<0.01	HS	¤	P<0.01	HS	¤
	RT-V	P<0.01	HS	¤	P<0.01	HS	£	P<0.01	HS	£
	LT-LC	P<0.01	HS	£	1.00	NS	=	P<0.01	HS	¤
	LC-P	P<0.01	HS	£	P<0.01	HS	£	P<0.01	HS	¤
	LT-V	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	£
	P-M	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	£
	M-V	P<0.01	HS	£	P<0.01	HS	£	P<0.01	HS	¤
	RT-M	1.00	NS	£	P<0.01	HS	£	P<0.01	HS	¤
	RC-M	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	¤
	LT-M	P<0.01	HS	¤	P<0.01	HS	¤	1.00	NS	=
	LC-M	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	¤
Short cycle	RT-RC	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	¤
	RC-P	1.00	NS	=	P<0.01	HS	£	P<0.01	HS	£
	RT-V	P<0.01	HS	£	P<0.01	HS	¤	P<0.01	HS	¤
	LT-LC	P<0.01	HS	£	1.00	NS	=	P<0.01	HS	¤
	LC-P	P<0.01	HS	£	P<0.01	HS	¤	P<0.01	HS	¤
	LT-V	1.00	NS	¤	1.00	NS	=	P<0.01	HS	£
	P-M	1.00	NS	¤	1.00	NS	¤	1.00	NS	=
	M-V	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	£
	RT-M	1.00	NS	=	1.00	NS	£	1.00	NS	£
	RC-M	P<0.01	HS	£	1.00	NS	=	P<0.01	HS	¤
	LT-M	P<0.01	HS	¤	P<0.01	HS	£	P<0.01	HS	£
	LC-M	P<0.01	HS	¤	1.00	NS	=	P<0.01	HS	£
Long cycle	RT-RC	P<0.01	HS	¤	P<0.01	HS	£	P<0.01	HS	£
	RC-P	P<0.01	HS	£	P<0.01	HS	£	P<0.01	HS	¤
	RT-V	P<0.01	HS	£	P<0.01	HS	£	P<0.01	HS	£
	LT-LC	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	¤
	LC-P	P<0.01	HS	£	P<0.01	HS	£	P<0.01	HS	¤
	LT-V	P<0.01	HS	£	P<0.01	HS	¤	1.00	NS	¤
	P-M	P<0.01	HS	£	P<0.01	HS	¤	P<0.01	HS	¤
	M-V	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	£
	RT-M	1.00	NS	=	P<0.01	HS	¤	P<0.01	HS	¤
	RC-M	P<0.01	HS	¤	P<0.01	HS	¤	P<0.01	HS	£
	LT-M	P<0.01	HS	£	P<0.01	HS	£	P<0.01	HS	¤
	LC-M	P<0.01	HS	£	P<0.01	HS	£	P<0.01	HS	£

Table 5: t-test for comparison between control and short autoclave cycles for all palatal depths and both investment materials.

Linear changes	Points	t test control & short cycle					
		Stone			Silicone		
		t- test	P value	Ch.	t- test	P value	Ch.
Shallow	RT-RC	14.05	P<0.01	¤	30.35	P<0.01	¤
	RC-P	15.06	P<0.01	¤	33.26	P<0.01	¤
	RT-V	17.05	P<0.01	£	12.35	P<0.01	¤
	LT-LC	18.09	P<0.01	¤	17.89	P<0.01	¤
	LC-P	22.03	P<0.01	£	34.26	P<0.01	¤
	LT-V	13.25	P<0.01	¤	30.35	P<0.01	£
	P-M	13.47	P<0.01	£	33.26	P<0.01	£
	M-V	18.093	P<0.01	¤	12.35	P<0.01	¤
	RT-M	33.54	P<0.01	£	1	NS	£
	RC-M	1	NS	£	1	NS	¤
	LT-M	1	NS	¤	10.25	P<0.01	¤
	LC-M	1.00	NS	£	10.08	P<0.01	£
Medium	RT-RC	23.54	P<0.01	£	10.05	P<0.01	£
	RC-P	44.06	P<0.01	¤	11.23	P<0.01	¤
	RT-V	45.09	P<0.01	¤	11.98	P<0.01	¤
	LT-LC	88.04	P<0.01	£	15.09	P<0.01	£
	LC-P	13.24	P<0.01	¤	15.47	P<0.01	¤
	LT-V	31.24	P<0.01	¤	16.07	P<0.01	¤
	P-M	1.00	NS	=	16.97	P<0.01	¤
	M-V	27.67	P<0.01	£	17.36	P<0.01	¤
	RT-M	24.68	P<0.01	¤	22.9	P<0.01	¤
	RC-M	30.14	P<0.01	¤	12.65	P<0.01	£
	LT-M	1	NS	£	14.02	P<0.01	¤
	LC-M	27.45	P<0.01	£	1.00	NS	=
Deep	RT-RC	10.12	P<0.01	¤	30.25	P<0.01	¤
	RC-P	14.05	P<0.01	¤	20.14	P<0.01	¤
	RT-V	13.21	P<0.01	£	17.00	P<0.01	£
	LT-LC	33.24	P<0.01	¤	18.08	P<0.01	¤
	LC-P	27.45	P<0.01	¤	14.99	P<0.01	¤
	LT-V	19.35	P<0.01	£	1	NS	=
	P-M	1	NS	£	66.35	P<0.01	£
	M-V	22.31	P<0.01	¤	45.69	P<0.01	¤
	RT-M	24.18	P<0.01	¤	69.35	P<0.01	¤
	RC-M	17.89	P<0.01	£	23.21	P<0.01	¤
	LT-M	1.00	NS	=	13.57	P<0.01	£
	LC-M	23.17	P<0.01	£	12.37	P<0.01	£

Table 6: t-test for comparison between the control and long autoclave cycles for all palatal depths and both investment materials.

Linear changes	Points	t-test control & long cycle					
		Stone			Silicone		
		t-test	P value	Ch.	t-test	P value	Ch.
Shallow	RT-RC	1.00	NS	=	1.00	NS	¤
	RC-P	27.89	P<0.01	£	1.00	NS	¤
	RT-V	12.34	P<0.01	¤	1.00	NS	¤
	LT-LC	44.25	P<0.01	¤	1.00	NS	=
	LC-P	46.28	P<0.01	¤	20.05	P<0.01	£
	LT-V	25.69	P<0.01	£	1.00	NS	£
	P-M	47.08	P<0.01	£	1.00	NS	£
	M-V	19.87	P<0.01	¤	2.35	0.042	£
	RT-M	30.25	P<0.01	¤	13.09	P<0.01	£
	RC-M	1	NS	£	1.00	NS	£
	LT-M	1.00	NS	¤	23.89	P<0.01	¤
	LC-M	10.17	P<0.01	£	1.00	NS	£
Medium	RT-RC	12.36	P<0.01	£	1.00	NS	=
	RC-P	15.29	P<0.01	¤	27.27	P<0.01	£
	RT-V	22.35	P<0.01	¤	26.29	P<0.01	¤
	LT-LC	28.97	P<0.01	£	56.28	P<0.01	¤
	LC-P	24.26	P<0.01	¤	30.08	P<0.01	£
	LT-V	23.58	P<0.01	¤	17.25	P<0.01	¤
	P-M	19.87	P<0.01	¤	1.00	NS	=
	M-V	30.24	P<0.01	¤	12.04	P<0.01	£
	RT-M	31.47	P<0.01	¤	13.06	P<0.01	£
	RC-M	1.00	NS	£	17.89	P<0.01	¤
	LT-M	1	NS	¤	1.00	NS	£
	LC-M	1.00	NS	¤	30.56	P<0.01	£
Deep	RT-RC	10.15	P<0.01	¤	1.00	NS	=
	RC-P	1.00	NS	¤	10.06	P<0.01	¤
	RT-V	1.00	NS	=	1.00	NS	£
	LT-LC	10.12	P<0.01	¤	23.08	P<0.01	¤
	LC-P	11.02	P<0.01	£	17.89	P<0.01	£
	LT-V	12.05	P<0.01	£	81.30	P<0.01	¤
	P-M	1	NS	£	71.31	P<0.01	£
	M-V	13.05	P<0.01	¤	23.56	P<0.01	£
	RT-M	15.89	P<0.01	¤	45.12	P<0.01	¤
	RC-M	13.42	P<0.01	¤	1.00	NS	=
	LT-M	15.69	P<0.01	¤	1.00	NS	¤
	LC-M	14.87	P<0.01	¤	20.38	P<0.01	£

Table 7: t-test for comparison between short and long autoclave cycles for all palatal depths and both investment materials

Linear changes	Points	t-test short & long cycle					
		Stone			Silicone		
		t-test	P value	Ch.	t-test	P value	Ch.
Shallow	RT-RC	27.44	P<0.01	£	1.00	NS	¤
	RC-P	15.69	P<0.01	£	18.88	P<0.01	£
	RT-V	23.44	P<0.01	¤	12.35	P<0.01	¤
	LT-LC	18.98	P<0.01	¤	22.58	P<0.01	£
	LC-P	23.54	P<0.01	¤	28.98	P<0.01	£
	LT-V	44.58	P<0.01	£	10.11	P<0.01	£
	P-M	10.28	P<0.01	£	1.00	NS	¤
	M-V	13.98	P<0.01	£	11.25	P<0.01	£
	RT-M	25.90	P<0.01	¤	28.97	P<0.01	£
	RC-M	1.00	NS	=	14.01	P<0.01	£
	LT-M	1.00	NS	¤	14.56	P<0.01	¤
	LC-M	23.03	P<0.01	£	1.00	NS	¤
Medium	RT-RC	1.00	NS	¤	10.66	P<0.01	¤
	RC-P	1.00	NS	=	10.87	P<0.01	£
	RT-V	47.25	P<0.01	£	9.099	P<0.01	¤
	LT-LC	12.98	P<0.01	¤	8.97	P<0.01	¤
	LC-P	23.03	P<0.01	£	11.23	P<0.01	£
	LT-V	22.09	P<0.01	¤	15.04	P<0.01	£
	P-M	25.36	P<0.01	¤	14.22	P<0.01	£
	M-V	45.89	P<0.01	¤	23.65	P<0.01	£
	RT-M	1.00	NS	=	54.36	P<0.01	£
	RC-M	18.97	P<0.01	£	18.97	P<0.01	¤
	LT-M	12.31	P<0.01	¤	12.31	P<0.01	£
	LC-M	11.89	P<0.01	¤	30.01	P<0.01	£
Deep	RT-RC	8.25	P<0.01	¤	10.14	P<0.01	£
	RC-P	78.98	P<0.01	£	10.87	P<0.01	¤
	RT-V	11.25	P<0.01	¤	30.21	P<0.01	£
	LT-LC	1.00	NS	=	15.98	P<0.01	¤
	LC-P	22.34	P<0.01	£	41.36	P<0.01	£
	LT-V	28.90	P<0.01	¤	23.78	P<0.01	¤
	P-M	1.00	NS	£	12.35	P<0.01	£
	M-V	18.97	P<0.01	£	26.54	P<0.01	£
	RT-M	18.97	P<0.01	¤	18.97	P<0.01	£
	RC-M	23.25	P<0.01	¤	17.14	P<0.01	£
	LT-M	18.74	P<0.01	¤	1.00	NS	¤
	LC-M	23.65	P<0.01	¤	20.31	P<0.01	£

Table 8: t-test for comparison between the stone and silicone investment materials for A: water bath, B: short cycle and C: long cycle.

Linear changes	Points	A			B			C		
		Water bath			Short cycle			Long cycle		
		t-test	P-value	Ch	t-test	P-value	Ch	t-test	P-value	Ch
Shallow	RT-RC	1.00	NS	=	14.25	P<0.01	£	1.00	NS	¤
	RC-P	12.36	P<0.01	¤	10.12	P<0.01	£	10.24	P<0.01	¤
	RT-V	17.25	P<0.01	¤	10.36	P<0.01	¤	11.28	P<0.01	¤
	LT-LC	22.03	P<0.01	¤	11.25	P<0.01	¤	13.65	P<0.01	£
	LC-P	1.00	NS	¤	13.65	P<0.01	¤	9.02	P<0.01	£
	LT-V	25.69	P<0.01	£	12.31	P<0.01	£	9.22	P<0.01	¤
	P-M	56.36	P<0.01	£	22.34	P<0.01	£	1.00	NS	¤
	M-V	45.69	P<0.01	¤	18.74	P<0.01	£	9.87	P<0.01	£
	RT-M	23.36	P<0.01	¤	23.14	P<0.01	¤	18.62	P<0.01	£
	RC-M	1.00	NS	£	10.28	P<0.01	¤	18.74	P<0.01	£
	LT-M	23.58	P<0.01	£	1.00	NS	£	18.03	P<0.01	£
	LC-M	10.04	P<0.01	£	17.89	P<0.01	£	1.00	NS	¤
Medium	RT-RC	25.08	P<0.01	£	27.23	P<0.01	¤	11.24	P<0.01	¤
	RC-P	26.29	P<0.01	¤	28.26	P<0.01	¤	15.24	P<0.01	£
	RT-V	27.04	P<0.01	¤	10.24	P<0.01	£	32.32	P<0.01	£
	LT-LC	30.25	P<0.01	¤	18.97	P<0.01	¤	14.56	P<0.01	¤
	LC-P	14.89	P<0.01	£	18.62	P<0.01	£	10.19	P<0.01	£
	LT-V	78.90	P<0.01	¤	16.32	P<0.01	¤	10.47	P<0.01	£
	P-M	36.58	P<0.01	¤	23.24	P<0.01	¤	41.36	P<0.01	£
	M-V	22.36	P<0.01	£	15.64	P<0.01	¤	18.03	P<0.01	£
	RT-M	20.04	P<0.01	£	18.14	P<0.01	¤	23.33	P<0.01	£
	RC-M	21.05	P<0.01	£	17.23	P<0.01	£	24.30	P<0.01	¤
	LT-M	1.00	NS	¤	18.97	P<0.01	¤	24.87	P<0.01	£
	LC-M	22.89	P<0.01	£	10.25	P<0.01	¤	25.3	P<0.01	£
Deep	RT-RC	17.05	P<0.01	¤	13.21	P<0.01	¤	8.99	P<0.01	£
	RC-P	22.09	P<0.01	¤	13.25	P<0.01	£	8.78	P<0.01	£
	RT-V	28.63	P<0.01	£	15.26	P<0.01	£	12.25	P<0.01	£
	LT-LC	54.26	P<0.01	¤	14.25	P<0.01	¤	23.14	P<0.01	¤
	LC-P	30.69	P<0.01	£	18.14	P<0.01	¤	25.36	P<0.01	£
	LT-V	44.05	P<0.01	£	10.02	P<0.01	¤	14.32	P<0.01	¤
	P-M	1.00	NS	£	1.00	NS	¤	10.35	P<0.01	¤
	M-V	17.08	P<0.01	¤	1.00	NS	=	18.95	P<0.01	£
	RT-M	59.36	P<0.01	¤	1.00	NS	=	25.36	P<0.01	£
	RC-M	31.05	P<0.01	¤	9.014	P<0.01	¤	18.78	P<0.01	£
	LT-M	1.00	NS	¤	8.98	P<0.01	£	1.00	NS	¤
	LC-M	18.09	P<0.01	¤	7.87	P<0.01	£	25.98	P<0.01	£

***P < 0.05 Significant, **P > 0.05 Non significant, ***P< 0.01 High significant.**