Official Dental Journal of Suez Canal University
DENTAL SCIENCE Updates
Print ISSN 2636-3836
Online ISSN 2636-3844
www.dsujournals.ekb.eg
DSU
DSU — Vol. 5, No. 2, September (2024) — PP. 463:472

EVALUATION OF DIMENSIONAL CHANGES OF ACRYLIC RESIN MAXILLARY COMPLETE DENTURES REINFORCED WITH SILICA DIOXIDE AND ZIRCONIUM OXIDE NANOPARTICLES: AN IN –VITRO COMPARATIVE STUDY

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DOI: 10.21608/dsu.2024.275231.1230
Manuscript ID: DSU-2403-1230 (R2)

KEYWORDS

Thermocycling;
Maxillary complete denture;
Teeth movement;
Dimensional changes

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ABSTRACT

Introduction: Nanomaterials are mainly used in ceramics, resins, and metals, providing a huge space for the improvement and innovation of dental materials. Nanoceramic materials have a small grain size, and a greatly reduced inherent porosity of materials. **Aim:** This study aims to do an evaluation and comparison of the dimensional changes and teeth movement of acrylic resin maxillary complete dentures reinforced with silica dioxide and zirconia nanoparticles before and after thermocycling. **Methods:** In vitro study using a special software to measure denture adaptation and teeth movement in twenty maxillary dentures , ten of them reinforced with zircon oxide nanoparticles and ten with silica dioxide nanoparticles before and after 5000 cycle of thermocycling process at temperarture ranges from 5 to 55ºC. **Results:** Regarding the adaptation, silica showed a significantly more adaptation (130%) as compared to zirconia (932.4%) which showed less adapatation , Regarding teeth movement silica revealed a significantly lower movement (0.019mm) as compared to zirconia which showed (0.035mm). **Conclusion:** Within the limitations of this study, it could be concluded that, There is a change in teeth position in Zro and SiO_2 reinforced maxillary dentures before and after thermocycling but teeth movement happened in SiO_2 reinforced maxillary dentures is less than the changes in Zro reinforced maxillary dentures.Regarding denture adaptation of both groups before and after thermocycling, there a changes in denture adaptation happened in Zro reinforced denture bases before and after thermocycling, and changes in SiO_2 reinforced denture bases before and after thermocycling according to paired samples t-test. Regarding comparison between both groups before and after thermocycling there is a difference in denture base adaptation, but silica group showed a more adaptation as compared to zirconia group which showed less adaptation.

INTRODUCTION

Denture base is a fragment of the denture, resting on the underlying tissues, and to which artificial teeth are attached either in the maxilla or the mandible. Furthermore, relocating the dense occlusal intensities to the supporting constructions, as well as substituting the absent alveolar tissues in both bulk and shape is one of the substantial utilities of denture base (1).

The most frequently employed acrylic resin denture base is the heat-cured type, which necessitates thermal energy to initiate additional polymerization reaction. The energy compulsory for polymerization of heat activated PMMA is regularly provided in the form of either a short or a long cycle of water bath(2). Both water sorption and solubility are considered as essential physical criteria that influence the clinical success of the denture base material, as the PMMA absorbs relatively minute amounts of water when positioned in an aqueous environment. This water exerts a remarkable outcome on both the mechanical and dimensional criteria of the polymer.

Several materials and techniques have been employed to reinforce the acrylic resin, and the incorporation of nanoparticles into acrylic resin has been investigated (2). Nanomaterials are mainly used in ceramics, resins, and metals, providing a huge space for the improvement and innovation of dental materials. Nanoceramic materials have a small grain size, and a greatly reduced inherent porosity of materials. Furthermore, flexibility, strength, and plasticity are improved, having an elastic modulus similar to natural bone, which greatly improves the mechanical, and biocompatibility (3).

One of the most widely used particles for acrylic reinforcement were silica dioxide (SiO_2) nanoparticles. The addition of SiO_2 nanoparticles to dental polymers and other dental composites has revealed their effectiveness. Zirconia nanoparticles have also been investigated for denture base acrylic resins reinforcement to help improve their mechanical strength and avoid premature fatigue or fracture failures.

According to a previous study, denture base nanocomposites developed with 5 wt% of zirconia PMMA matrix has revealed improved mechanical properties (4).

Intraorally, the denture prostheses are usually subjected to thermal variations due to the ingestion of hot and cold liquids. Such thermal cycling in a wet environment may cause degradation of the denture polymers. Thermocycling is a laboratory method of exposing dental restorative materials and artificial teeth to temperature ranges similar to those occurring in the oral cavity that could produce adverse consequences as a result of different coefficients of thermal expansion between the tooth structure and the denture base.

Up to date there are not enough comparative studies on dimensional changes and tooth movement between dentures reinforced with silica dioxide (SiO_2) and zirconia (ZrO) nanoparticles of a 5% concentration compared to a group of conventional acrylic maxillary denture.

Null hypothesis

The null hypothesis was that there would be no significant differences between zirconium oxide reinforced maxillary dentures and silicadioxide reinforced maxillary dentures before and after thermocycling process.

Ethical Approval

This research was waived from the approval of the Research Ethics Committee (REC) of the Faculty of Dentistry, Suez Canal University since it was conducted on an educational completely edentulous model. Ethical considerations regarding patients or experimental animals were therefore not applied.

MATERIALS AND METHODS

Sample size calculation

Current research was performed to evaluate the acrylic resin maxillary complete dentures reinforced with silica dioxide (A_1) and zirconia nanoparticles

(A_2), both before and after thermocycling timepoints (T_0, T_1); repeated measures analysis of variance is proposed (ANOVA). A minimum total sample size of 20 samples will be sufficient to detect the effect size of 0.40 according to Cohen (1988), at a power (1-β=0.90) of 90% at a significance probability level of $p<0.05$, and a partial eta squared of 0.14.

According to sample size calculations each treatment group (A_1, A_2), and time of investigations (T_0, T_1) would be represented by a minimum of 10 samples as shown in Tables 1 and 2. Each treatment group e.g. timepoint (e.g. A_1T_1, A_2T_1) will be represented by a minimum of 10 samples. The sample size was calculated according to G*Power software version 3.1.9.6.

Where; *f:* is the effect size; α= 0.05; β=0.10; Power= 1- β = 0.90

$$f = \frac{\sigma_\mu}{\sigma}$$

$$\sigma_\mu^2 = \frac{\sum_{i=1}^{k} n_j\left(\mu_i - \mu\right)^2}{N}$$

Master casts fabrication

Stone educational casts without undercuts were obtained by pouring hard dental stone type III in standardized readymade silicon mold of completely edentulous maxillary and mandibular arches. Then, occlusion blocks were constructed.

The trial denture bases were fabricated with auto polymerizing acrylic resin using finger adapted method, where the polymer and monomer were mixed in a ratio of 3:1 respectively. The desired thickness was performed by pressing the dough stage mix against two glass slabs protected by cellophane separated by four uniform thickness pieces of wax at each corner. Then, was adapted to the cast by fingers, trimmed and finished.

The occlusion rim was fabricated from pink baseplate wax warmed and rolled to the shape of the underlying residual ridge. Mounting the master casts: The maxillary and mandibular occlusion blocks were sealed together in the correct centric relation obtained from the parallelism between the heels of the master casts. The incisal pin of the fixed condylar path articulator was adjusted to the predetermined position then the screw was tightened.

The maxillary cast was mounted according to Bonwill's triangle. While the mandibular cast was mounted according to the parallelism between the posterior heels of the maxillary and mandibular casts.

A set of anatomical cross linked acrylic resin teeth with suitable size was selected for the setting up of teeth for the mounted master occlusion blocks and then the trial dentures were waxed up to form a master maxillary and mandibular waxed up trial dentures that represented the standard model

Fabrication of identical maxillary waxed up dentures

The mandibular cast with the waxed-up trial denture was unscrewed and duplicated with epoxy resin in a prepared silicon mold. The simulated epoxy mandibular dental arch was returned back in the same position preoccupied with the mounted mandibular master cast and the waxed up trial denture. This assembly acted as a jig to guide the setting of the maxillary teeth in the same position in all twenty samples

To reproduce the same maxillary trial dentures base contour and teeth position, the standard waxed up maxillary trial denture with the maxillary master cast was duplicated to form a silicon mold. Duplication was done using custom plastic flask, to provide support and rigidity to the duplicating material. The cast to be duplicated was positioned on its base such that there was at least 5mm clearance all around and sealed in place using soft wax.

The two components of the duplicating silicon material were mixed in a ratio of 1:1 in a clean plastic container using stainless steel spatula, until getting a uniformly color mix, the mixing was done slowly to avoid air trapping and then poured slowly and regularly. Mixing and pouring were done under vibration to avoid entrapment of air bubbles and then allowed to set before separation of the cast to be duplicated. Spillway was created in the silicon mold to allow for the escapement of excess soft wax.

Preparation of duplicated waxed up maxillary trial dentures

Twenty identical sets of acrylic resin teeth with same size and shape were selected for each waxed up maxillary trial denture . The acrylic resin maxillary teeth were inserted in their corresponding places in the silicon mold. The interproximal spaces between the artificial teeth act as reference points in the duplicate mold for teeth setting. The space between the teeth and the cast was slightly over filled with molten wax and then the cast was inserted and held in position until the wax hardened and then removed.

This process was repeated until twenty identical waxed up maxillary trial dentures were constructed. Then each one was re-placed on the articulator and final adjustments of the occlusion were done using the simulated mandibular epoxy resin dental arch as a reference jig.

The test groups

There are twenty maxillary dentures divided equally into two groups (Group1) reinforced by silanized zirconium oxide nanoparticles and (Group2) reinforced by silanized silica dioxide nanoparticles.

The silanized zirconium oxide nanoparticles (Test group 1)

The silanated zirconium oxide nanofillers* of average size (16 ± 6 nm) thus allowing for interaction between the resin matrix and nanoparticles.

The powder was incorporated to the heat cure acrylic resin as follow. Silanized nanofillers and PMMA were pre-weighed using the electronic balance so that the silanized nano-filler concentration was 5% by weight, thoroughly mixed with a mortar and pestle foll to achieve an equal distribution of particles. Then the polymer with the silanized nano-fillers was mixed with the monomer with a powder/liquid ratio of 3:1 and all the rest of previous processing steps of the control group were repeated.

The silanized silica dioxide nanoparticles (Test group 2)

The silica dioxide nanofillers with size (25±5nm) were prepared. This study included in this review were in vitro laboratory based using SiO_2 nanoparticles in concentration 5% by weight to reinforce heat-polymerized acrylic denture base resins performing its silanization procedure of the SiO_2 nanoparticles before their incorporation into the resin.. The applied sample size was set to 10 specimens.

The powder was incorporated to the heat cure acrylic resin as follow. Silanized nano-fillers and PMMA were pre-weighed using the electronic balance so that the silanized nano-filler concentration was 5% by weight, thoroughly mixed with a mortar and pestle to achieve an equal distribution of particles. Then the polymer with the silanized nano-fillers was mixed with the monomer with a powder/liquid ratio of 3:1.

Flasking

The maxillary trial dentures after their removal, they are placed on their duplicated master casts, soaked in water for 5 mins. The inner surface of the flask was coated with separating medium as well as the maxillary master cast and occlusion block except the incisal edges and occlusal surfaces.

Plaster was mixed to make the first pour and placed in the base of the flask then the cast was pushed until its border was in the level of the edges of the flask and the occlusal plane parallel to the base. Then the plaster was smoothened, contoured and left to dry.

The upper half was inserted, painted with separating medium and a second pour of a mixture of plaster and stone was poured over the teeth but the incisal edges and the occlusal surfaces were exposed including a portion of the upper half of the flask where after setting of the second pour a third pour of stone was mixed and poured but before its setting, the flask cover was sealed in place and tapped to sit properly allowing excess stone to flow out from its holes.

After flasking, the flask was left undisturbed for 30:60 mins allowing the investing material to reach its final setting time.

Wax elimination

The flask was placed in boiling water for 5 mins, then removed and carefully opened from the junction between the lower and upper halves of the flask using a wax knife. The trial denture base and wax were removed and washed out with stream of boiling water. Then allowed to bench cool until it was comfortable to touch, separating medium was applied to the surfaces of the mold except the teeth then left to dry and second layer of separating medium was applied, and the flask was allowed to cool to room temperature.

Mixing acrylic resin by ratio 3:1. The mix was done in a clean dry mixing jar with the monomer poured first and then the powder slowly until complete wetting to the powder particles, then the mixture was stirred, the jar was closed until the mix reached the dough stage.

Packing of dough material was placed in the upper half over the teeth. Trial packing was accomplished by placing a piece of wet cellophane over the resin before the flask was assembled, the lower half was placed in position on the upper half and pressed by hand then placed in hydraulic press that provide pressure about 100kg/cm3.

Then the flask was removed, opened carefully, excess resin was trimmed with sharp lancet and the process was repeated using new wet cellophane until there wasn’t any excess material. Before closure, the surfaces was coated with layer of separating medium and closed without cellophane. The flasks were placed in the processing press which was firmly closed to ensure metal to metal contact and allowed to stand for 30:60 mins before curing.

Long cycle Curing was carried out in water bath at 74^{o}C for 8 hours in thermo-curing unit. After processing the flasks were removed from curing unit and left for cooling slowly to room temperature. Then dentures were deflasked, finished and polished.

Digital acquisition of the data

The fitting surface of each processed denture, the reference master cast and dentures sitting on cast was scanned using an optical desktop scanner (DOF Inc 3D scanner) and saved in the form of a Standard Tessellation language (STL) file.

Thermocycling process

Thermocycling was done using a thermocycling machine for 5000 cycles, dwell times were 25 sec, in each water bath with a lag time 10 sec, the low temperature was 5°C and the high temperature was 55°C.

After that dentures have been scanned a second time by desktop scanner and saved in the form of a Standard Tessellation language (STL) file to compare between the adaptation and teeth movement of maxillary dentures reinforced by zirconium oxide & silica dioxide before and after thermocycling.

Methods of measuring teeth movement and denture adaptation

Denture adaptation measurements

Denture adaptation depends on comparing the discrepancies between the denture fitting surface and the reference cast. The STL file of the reference cast is a positive image of the denture fitting surface, therefore, to compare adaptation it is necessary to remove any irrelevant data in the cast such as the base and also to inverse the denture fitting surface to positive to be identical to the reference cast.

The dentures fitting surface was imported to a free modeling computer software (MESHMIXER 3.5 software, Autodesk). First, the outline of the denture borders was drawn on using the select software tool then all the irrelevant data beyond the denture borders were removed. Finally, the dentures fitting surfaces were inverted producing a duplicate image of the reference cast surface using the flip normal software tool.

Using Geomagic control x software (software for 3D coordinate measuring technology), the inverted reference cast model was set as a reference in all upcoming comparisons. Then, an initial alignment followed by a best-fit alignment algorithm was used to register the denture fitting surface on the reference data, followed by a 3D surface comparison, and comparison points were picked up at the apex of denture borders, the crest of the ridge, the rugae area, and the palate.

Twenty-eight points are taken on the reference cast for comparison of adaptation of each group:

- 9 points on border of cast
- 10 points on maxillary tuberosities
- 1 point on incisive papilla area
- 4 points on rugae area
- 4 points on palate

The denture adaptation comparison points are labeled either in (+) or (-) numbers, where the (-) signs indicate pressure areas or in-ward movement, and on the contrary, the (+) signs indicate space or outward movement.

The colour maps of each processing technique's adaptation to the reference cast. Between the two compared STL files, the areas in orange denote areas of open space or relief, while the areas in blue denote areas of pressure. The ideal adaptation of the denture would display more green areas that represent the similarity between the two compared STL files and produce a measurement value of zero. It displays the colour maps of how each processing technique was adjusted to the reference cast. Between the two compared STL files, the areas in orange denote areas of open space or relief, while the areas in blue denote areas of pressure. The ideal adaptation of the denture would display more green areas that represent the similarity between the two compared STL files and produce a measurement value of zero.

So, we can make a comparison between the adaptation of 10 dentures reinforced with zircon oxide before and after thermocycle, And the adaptation of 10 dentures reinforced by silicadioxide before and after thermocycling (Fig.1)

Teeth movement measurements

Stl files of denture pre and post thermocycling were imported into Geomagic control x software (software for 3D coordinate measuring technology), Dentures was segmented into 2 parts (teeth denture base) to allow comparison of only teeth movement, Initial alignment and best fit for comparing teeth movement , Pickup comparison points were made on incisal edges of anterior teeth , cusp tips of premolars & molars.

There is a color map showing zero,+ve & -ve signs was created on software (Fig.2).

Green color (zero) shows high adaptation, no movement.

Orange color (+ve) shows a movement away from the denture.

(a) Blue color (-ve) shows an inward movement toward the denture base.

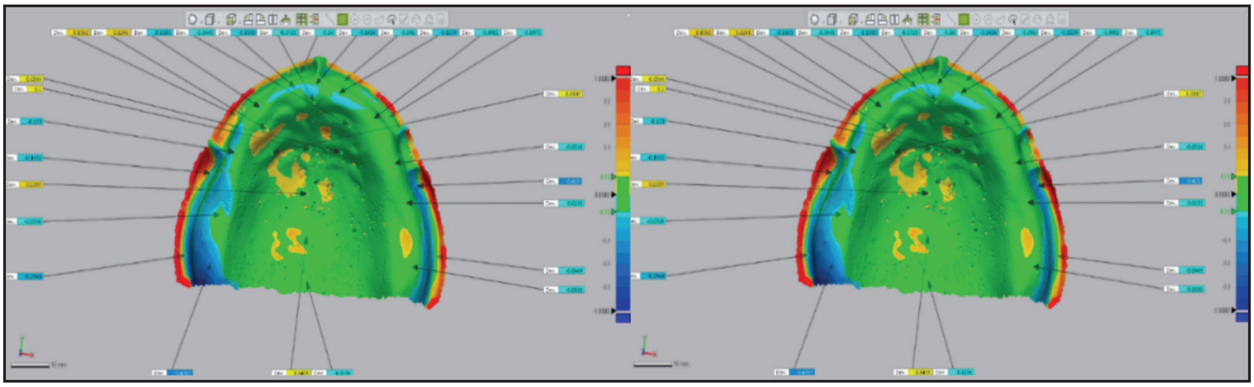

Fig. (1) The color maps of each processing technique’s adaptation to the reference cast.

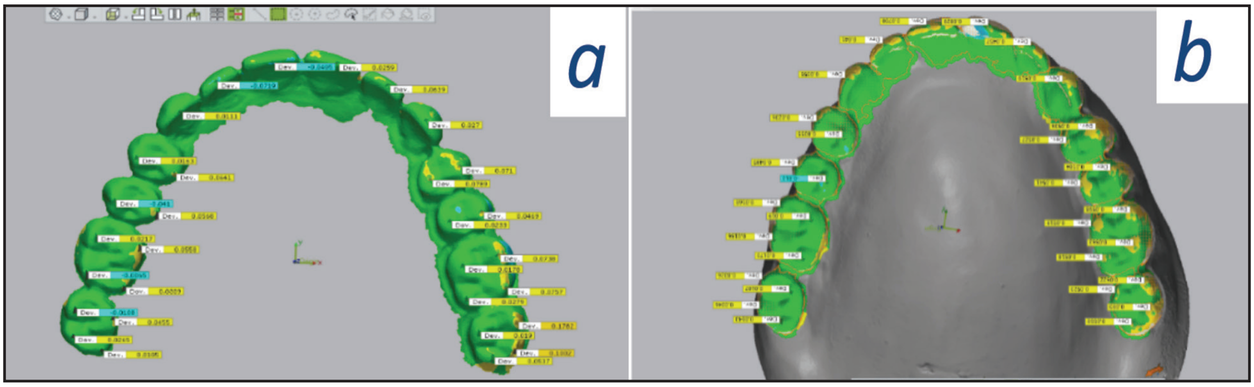

Fig. (2) (a) Teeth movement of dentures before thermocycling (b) Teeth movement after thermocycling on the reference cast.

RESULTS

The denture base adaptation (mm) in Z-group before thermocycling ranged between -0.3081 to 0.6069 with an average (±SD) -0.0061±0.10. However, after thermocycling between -0.553 to 0.5617 mm with an average (±SD) of 0.063±0.167 mm. The difference between before and after thermocycling was significant as revealed by paired samples t-test (p=0.038*).

The denture base adaptation (mm) in S-group before thermocycling ranged between -0.6784 to 0.5767 with an average (±SD) -0.039±0.241. However, after thermocycling between -0.9381 to 0.6627 mm with an average (±SD) of - 0.089±0.239 mm. The difference between before and after thermocycling was non-significant as revealed by paired samples t-test (p=0.070).

The difference between Z and S group in both before thermocycling and after thermocycling were highly significant as revealed by independent samples t-test.

According to repeated measures ANOVA, the overall difference in denture base adaptation was non-significant, however time showed a highly significant difference in denture base adaptation.

For further comparisons, Duncan's Multiple Range Tests (DMRTs), means followed by different letters are significantly different either vertically or horizontally (Table 1).

Regarding the adaptation, silica showed a significantly more adaptation (130%) as compared to zirconia (932.4%) which showed less adaptation.

Table (1) *The denture base adaptation (mm) in Z and S-group before and after thermocycling.*

Group	**Before thermocycling**		**After thermocycling**		**Change %**		**Paired t-test**	
	Mean	**SD**	**Mean**	**SD**	**change**	**%**	**t**	**p-value**
Z	-0.006 c	0.100	-0.063 ab	0.167	-0.057	932.4	2.080	0.038*
S	-0.039 b	0.241	-0.089 a	0.239	-0.050	130.3	1.480	0.070 ns
p-value	<0.001***		<0.001***					

Repeated measures ANOVA	
Group	**0.013**
Time	**<0.001*** **
Group x Time	**0.564 ns**

*, **, *** *significant at p<0.05, p<0.01, p<0.001; ns, non-significant at p>0.05.*

Teeth movement in mm before and after cycling:

The Teeth movement in mm before and after cycling in Z groups ranged between -0.6276 to 0.4273 mm with an average (±SD) 0.035±0.099.

However, the Teeth movement in mm before and after cycling in S groups between -0.073 to 0.1148 mm with an average (±SD) of 0.019±0.024 mm. The difference between Z and S groups was highly as revealed by independent samples t-test (p=0.002**). Regarding teeth movement silica revealed a significantly lower movement (0.019mm) as compared to zirconia which showed (0.035mm) (Table.2).

Table 2: *Teeth movement in mm before and after cycling in S and Z groups.*

Descriptive statistic		Teeth movement in mm before and after cycling	
		Z	S
Mean		0.035	0.019
SD		0.099	0.024
Min		-0.6276	-0.073
Max		0.4273	0.1148
Independent t-test	t	2.837	
	p-value	0.002**	

, **, * significant at p<0.05, p<0.01, p<0.001; ns, non-significant at p>0.05.*

DISCUSSION

To assess the overall mean changes that occurred for the tested samples after processing, the mean of all measurements for maxillary dentures were collected as one record for each group in this study.

In this study there are a significantly difference in teeth positions before and after thermocycling in both groups and this is agree with some studies that shown that the thermocycling has a deleterious effect on the bond strength between artificial tooth and acrylic resin, since the thermocycling causes hydrolytic degradation and consequent fracture or displacement of the teeth (5,6). While disagree with the study that evaluated the effect of thermocycling on the bond strength between artificial tooth and acrylic resin denture base, the results demonstrated that the thermocycling did not affect the bond strength in both polymerization methods and all teeth tested (7).

The differences between the results can be related to the number of cycles used in each study (cycles above10,000), besides the time and the storage temperature of the samples (5). A possible explanation for these differences could be related to the composition of the artificial teeth (7).

Thermocycling was used to more closely simulate the oral condition and to assess the durability of the bond among materials, so agreed with that the decrease in these materials' bond strengths may possibly be explained by water absorption and thermal expansion coefficient differences for each material (8).

This study agrees with this hypothesis, that the diffusion of water molecules through the acrylic denture tooth/denture base resin interface may result in bonding failure, causing a decrease in the bond strength. Differences between thermal coefficients can also adversely affect the bond of acrylic denture teeth to denture base resin (9).

The present study show significantly difference in maxillary dentures adaptation reinforced with silica dioxide and zircon oxide nanoparticles before and after thermocycling, that agreed with The study that explain by the fact that the cumulative effect of shrinkage and expansion as a result of temperature changes induces a fatigue or stress in the material and thereby decreases its fitness accuracy (10).

This study agree with That hypothesis that can be related to the release of residual stress as a result of difference in thermal coefficient of expansion due to cooling and heating (11).

CONCLUSIONS

Within the limitations of this study, it could be concluded that;

- There is a change in teeth position in Zro and SiO_2 reinforced maxillary dentures before and after thermocycling but teeth movement happened in SiO_2 reinforced maxillary dentures is less than the changes in Zro reinforced maxillary dentures.
- Regarding comparison between both groups before and after thermocycling there is a difference in denture base adaptation, but silica group showed a more adaptation as compared to zirconia group which showed less adaptation.

RECOMMENDATION

The thermocycling process was used to test the samples in circumstances that mimicked the oral environment. Accordingly, the study's recommendations are to test zirconium oxide and silica dioxide nanofillers in an oral environment after prosthesis are made. It's also necessary to conduct more clinical and in vivo research to learn more about their characteristics.

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