Official Dental Journal of Suez Canal University
DENTAL SCIENCE Updates
Print ISSN 2636-3836
Online ISSN 2636-3844
www.dsujournals.ekb.eg
DSU — Vol. 3, No. 1, April (2022) — PP. 85:91

EFFECT OF ZIRCONIUM OXIDE NANO-FILLERS ON DIMENSIONAL ACCURACY OF ACRYLIC RESIN MAXILLAY COMPLETE DENTURES: AN IN VITRO STUDY

Mina Samy Tawfick Zakhary [1], Sayed Mohamed Mohamed El Masry [2], Hala Mohamed Abd El Hameed [3], Kowkab Mohammed Eltamimi [4]

DOI: 10.21608/dsu.2022.100934.1085
Manuscript ID: DSU-2110-1085

KEYWORDS
Acrylic resin denture base,
Zirconium oxide nano fillers,
Dimensional accuracy,
Teeth movement,
Denture base adaptation.

• E-mail address: dent.minasamy@gmail.com

1. Demonstrator in Removable Prosthodontic Department, Faculty of Dentistry, Suez Canal University.
2. Professor of Removable Prosthodontics, Faculty of Dentistry, Suez Canal University.
3. Assistant Professor of Removable Prosthodontics, Faculty of Dentistry, Suez Canal University.
4. Lecturer of Removable Prosthodontics, Faculty of Dentistry, Suez Canal University.

ABSTRACT

Introduction: Addition of nanofillers to the denture base material in order to enhance its mechanical properties may contribute to the dimensional accuracy of the processed dentures. **Aim:** This study was conducted to investigate the effect of zirconium oxide nanofillers addition on the dimensional accuracy of maxillary heat cured acrylic dentures. **Materials and Methods:** Thirty six identical maxillary waxed up dentures were constructed, divided into two equal groups(n=18), control group processed into conventional heat cured acrylic resin dentures and test group processed into 5% zirconium oxide nanofiller reinforced heat cured acrylic resin dentures. Teeth movements were estimated linearly using digital software after processing and vertically using digital caliper before and after processing. Changes in denture adaptation were measured immediately after processing and after seven days hydration in distilled water using digital software. **Results:** After processing, both groups showed increased Vertical dimension of occlusion with less increase with the test group. Both groups showed changes in teeth position with non-significant difference. Test group showed more tendency to inward tooth movement. Test group showed significant more denture adaptation after processing. However, denture hydration caused decrease in denture adaptation in the test group while causing enhancement in denture adaptation with the control group. **Conclusion:** Zirconium oxide nanofillers reinforcement showed nearly comparable results of dimensional accuracy to the conventional dentures with negative results on hydration.

INTRODUCTION

Poly methyl methacrylate (PMMA) acrylic resin is a preferred denture base material due to its low cost, ease of application, good polishability and simple processing equipment [(1)]. Dimensional changes of denture base were found to be unavoidable during denture fabrication. Several laboratory factors may cause changes in the denture occlusion during complete denture construction, these factors are related to intrinsic features of the materials and techniques as well as potential extrinsic errors from the dental technician or dentist [(2)]. Another factor should be kept in consideration is the watery nature of the oral cavity. Water sorption and water solubility of denture base resin affect the dimensional accuracy and denture serviceability [(3,4)].

These adverse effects result in alternations in the artificial teeth position and decrease in the intimate contact between the denture base and underlying mucosa; resulting in an ill-fitting denture. It has been claimed that an accurate adaptation is the key factor of the physical means of complete denture retention [5,6].

The occlusion developed in the waxed up trial denture should be ideally maintained throughout the polymerization process and during its serviceability. However, denture base resin shrinkage during polymerization is an inherent problem which distort the palate of maxillary dentures resulting in an inaccurate fit, also it affect teeth position and thus the final occlusion. Therefore, the adaptation accuracy or dimensional changes in the denture bases has become a focus of many studies in removable prosthodontics [7].

With the continuous progress of sciences and technology many investigations were designed to improve not only their physical and mechanical properties but also the working properties, durability and serviceability either by modification of processing techniques or addition of modifiers that facilitate laboratory techniques for denture construction [8].

Nanotechnology is applied in the field of prosthodontics for material improvement purposes to enhance the properties and behavior of PMMA[9,10] depending on several features including polymer-particle interface, particle size and shape, fabrication technique, and particle dispersion in the PMMA matrix [11]. One of the recent approaches for enhancement of acrylic resins properties is the addition of zirconium oxide as nanofillers.

Studies have shown that zirconia is biocompatible and of superior esthetics than other metal fillers [12]. This bioceramic filler has high flexural strength and fracture toughness due to transformation toughening so it has been suggested to improve PMMA properties [13,14]. The properties of the polymer-nanoparticle depend on the type of incorporating nanoparticles, their size and shape, as well as the concentration and interaction with the polymer matrix [15,16].

Although several studies have been performed to evaluate the effect of nano-ZrO_2 addition on different physical and mechanical properties of PMMA denture base material, up to our knowledge and searches, not enough studies were done to evaluate its effect on the dimensional accuracy of denture bases especially with a digital software method.

MATERIALS AND METHODS

1) Sample fabrication:

Stone educational casts without undercuts were obtained by pouring hard dental stone in standardized readymade silicon mold of completely edentulous maxillary and mandibular arches. Occlusion blocks were fabricated then mounted on a fixed condylar path articulator (Artek-pro. France) and acrylic resin anatomic teeth of suitable size were selected and set up. The trial dentures were waxed up. The mandibular arch was duplicated into epoxy resin and remains constant throughout the tests. This assembly acted as a jig to guide the setting of the maxillary teeth in the same position in all thirty six samples. Maxillary dentures were duplicated by using silicon mold (Dupliflex silicones. Protechno. Spain) of the reference maxillary waxed up denture to maintain uniform palatal thickness and teeth arrangement.

The amount of heat cure acrylic resin used for each denture with least excess material was weighted in a pilot study via an electronic balance (Vibra electric balance, Japan three digit numbers). Then the waxed up dentures were divided into two groups.

The control group: Waxed up dentures were packed and processed by compression molding of heat cured acrylic resin using long cycle curing technique.

The test group: the amount of ZrO_2 to be added was subtracted from the preweighted heat cured acrylic resin powder and compensated by the added nanofillers so as not to cause excess material. The zirconium oxide nanofillers (Nanotech Egypt for photo electronics, city of 6th October. Egypt) were silanized using silane coupling agent. The process of silanization involved dissolving 0.25ml TMSPM (3-(Trimethoxysilyl)propylmethacrylate) (Sigma-Aldrich Co., St Louis, MO, USA) in 83.3ml acetone in autoclaved bottle, and then 25gm zirconium oxide nanoparticles were added. The solution was mixed by a stirrer at 60˚C and 300 rpm for 2 hours. After mixing process, the sample was then heated at 120°C for 2 h in nitrogen gas furnace to increase the interaction between nano-ZrO_2 and TMSPM and subsequently coupling reaction to occur and then cooled to obtain silanized nano zirconium oxide particles [15].

The silanized nano-ZrO_2 powder was incorporated into the heat cure acrylic resin powder so that the silanized nano-filler concentration is 5% by weight. Then thoroughly mixed to achieve an equal distribution of particles, mixed with the monomer and processed like the control group. As a verification of the mixing process; a sample from the reinforced processed denture in a pilot study was tested for aggregation using scanning electron microscope. The scans revealed that the zirconium oxide nano fillers were highly dispersed within the heat cured acrylic resin without any signs of aggregation (Fig. 1)

2) Measurements:

Occlusal vertical dimension was measured for all waxed up dentures on a measuring apparatus using digital caliper as an initial measurement and immediately after deflasking and then the difference between them was calculated [7]. (Fig. 2)

An optical 3D scanner was used where each maxillary epoxy cast was scanned and saved as standard tessellation language (STL) file. Waxed up dentures seated on its corresponding casts were scanned and were saved in STL file as virtual planned denture. Immediately after denture processing, then after seven days hydration in distilled water, each maxillary denture was scanned alone and saved in STL file. Then each denture seated on its corresponding cast were scanned and saved in STL file. Scanned processed denture was superimposed on scanned planned denture on its corresponding cast taking the cast as a reference. Superimposition was started manually using 3 points, followed by final adjustment utilizing the best fit function via the software.

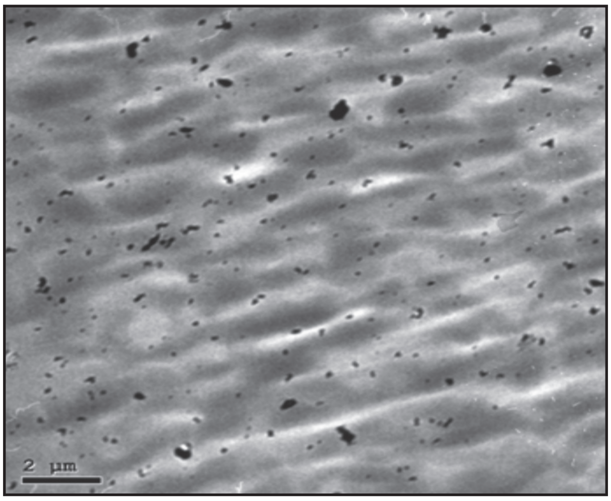

Fig. (1) SEM micrographs without aggregation

Fig. (2) The measuring apparatus.

For teeth movement, deviation was labeled bilaterally at the median region of the incisal border of the incisors and the cusp tips of the canines, premolars and molars to provide multiple points for comparison so as to obtain accurate results. Notice that positive sign (+) means outward movement while negative sign (-) means inward movement [7,8]. (Fig. 3A)

For denture adaptation, deviation was labeled at labial frenum, canines, second premolars and second molars and the following fitting surface locations: median palatine raphae, 6mm from the posterior border, canines, second premolars and tuberosities using an overlay guide to verify the location of the measurements. Notice that positive sign (+) means tissue way shrinkage causing impingement of the denture towards the tissues while negative sign (-) means tissue away shrinkage causing spacing between the denture and the tissues [5]. (Fig. 3B)

The mean value of the points taken in both teeth movement and denture adaptation were collected, tabulated and statistically analyzed. Data was collected, checked, revised, and organized in tables and figures using Microsoft Excel 2016 and SPSS version 26 for Mac OS. Data analyses were carried out using computer software Statistical Package for Social Science SPSS (IBM-SPSS ver. 26.0 for Mac OS).

RESULTS

Regarding the parameters assessed in the current study after processing, the following results were revealed as shown in table (1): **Vertical dimension of occlusion** increased in both groups, where the ZrO_2 group revealed statistically lower increase (Mean value 106.88) in comparison to the control group (Mean value 107.29). **Linear tooth movement** showed changes in both groups with no significant difference between them. ZrO_2 group showed more tendency to inward direction of tooth movement. In regards to **denture base adaptation**, ZrO_2 group revealed higher statistically significant denture adaptation than the control group. However, denture hydration caused statistically significant decrease in denture adaptation in zirconium reinforced group while causing statistically significant increase in denture adaptation with the control group with statistically significant difference between both groups.

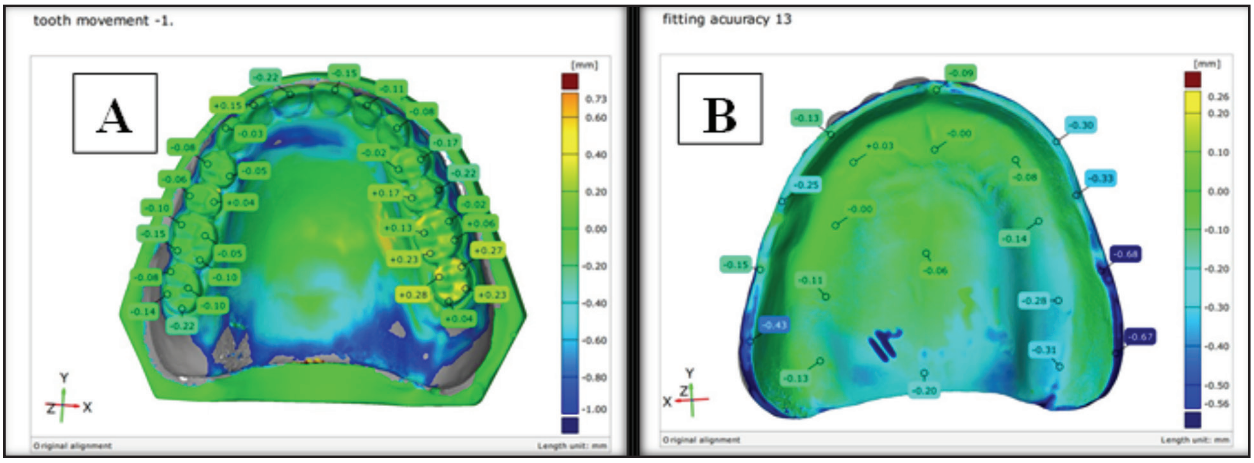

Fig. (3) Software analysis for changes in A. Teeth position B. Denture adaptation

Table (1) *Showing mean values of the test parameters for both groups*

The mean values of the vertical dimension of occlusion (before/after processing) in both control group (acrylic resin), and test group (Zirconium reinforced).

Group	Vertical dimensions of occulusion					Paired t-test
	Before		After		Difference	
	Mean	SD	Mean	SD		
Zirconuim	**106.33**	0.00	**106.88**	0.064	0.55	<0.001***
Control (Acrylic resin)			**107.29**	0.063	0.96	<0.001***
t-test			<0.001***		<0.001***	

Average values of linear tooth movement after processing in both control group (acrylic resin), and test group (Zirconium).

Group	Values of linear tooth movement after processing		
	Mean	SD	SE
Zirconium	**-0.062**	0.13	0.028
Control (Acrylic resin)	**0.056**	0.30	0.067
Independent t-test: (t-stat)		-1.627	
Sign. (2-tailed)		>0.05 ns	

Mean values of denture adaptation (after processing/hydration) in both control group (acrylic resin), and test group (Zirconium).

Group	Denture adaptation				Difference (Hydration effect)	Paired t-test
	After processing (Curing effect)		After hydration			
	Mean	SD	Mean	SD		
Zirconium	**-0.22**	0.00	**-0.27**	0.071	-0.066	0.010 **
Control (Acrylic resin)	**-0.28**	0.00	**-0.24**	0.079	0.044	<0.001***
t-test	0.004**		<0.001***			

NS; non-significant at p-value>0.05
** Significant at p<0.05; ** highly significant at p<0.01; *** very high significant at p<0.001*

DISCUSSION

It is important from a clinical point of view to study the dimensional accuracy during denture processing and throughout hydration process in order to obtain an accurate occlusal contact, retention, esthetics health and functional quality of complete denture which justifies its evaluation in this study [5,7]. Results of this study showed that dimensional changes occurred in all studied samples. This might be attributed to combination of factors such as intrinsic features of the denture base material, stresses released when the flask is removed from the hydraulic press. The polymerization process which involves thermal expansion during heating, contraction during cooling and during polymerization, different thermal contraction during flask cooling method and strain accompanying stress release during deflasking [2].

Linear tooth movement occurred in both groups. However it was noticed that the net changes in linear tooth movement in the control group was in an outward direction while in the test group was an inward direction. These results are in agreement with a study that tested tooth movement between CAD-CAM and conventional denture fabrication techniques, which found that conventional fabrication PMMA dentures expressed linear tooth movement with positive values, meaning that it would cause an increase in the patient's vertical dimension of occlusion [(8)].

After processing both groups showed degree of denture spacing in relation to the cast which is less in the zirconium reinforced group. This may be due to that the presence of fillers replaces the resin causing diminished amount of polymerization shrinkage which could be enhanced through the process of silanization. This explanation is in an agreement with study which tested dimensional changes of denture base polymer reinforced with glass fibers stated that as the fiber content increases, the dimensional changes decrease [(17)]. As well as another agreement with the results of a study tested the effect of different ratios of zirconium oxide nanofillers on processed denture samples [(13)].These results also give an explanation to the change in the vertical dimension of occlusion in the zirconium reinforced group which was less than the control group. Because of less dimensional changes which appears in more denture adaptation after processing and inward linear tooth movement values.

After immersion in water, denture hydration has a reverse effect on the mean values of denture base adaptation for both groups. Regarding the zirconium reinforced group, denture hydration caused more decrease in denture adaptation. This decrease in denture adaptation may be due to water sorption. The presence of fillers causes the separation of the polymer chains further apart from each other and increasing spaces between the polymer chains which facilitate water penetration due to the small size of water molecules[(3)]. Also, fillers addition may contribute to degree of denture porosity which increases water sorption[(9,18)].This result was in agreement with a study that evaluate the effect of filler reinforcement of acrylic denture base material on water sorption, dimensional changes and transverse strength [(14)], as well as another two studies that reported an increase in water sorption within the limit of ADA specifications [(11)].

However in the control group, denture hydration caused positive and enhancement effect on denture adaptation. As PMMA absorbs water slowly in long term and it may enhance its adaptation criteria as it compensate for the thermal polymerization shrinkage following processing that made the dentures of the control group showed more impinging toward the tissues which explained its positive sign values. For this reason, period of keeping in water is important[(1)].

CONCLUSION

Zirconium oxide nanofillers reinforcement shows nearly comparable results of dimensional accuracy to the conventional dentures with negative results on hydration which makes the conventional dentures more applicable with patients use.

REFERENCES

1. Rickman LJ, Padipatvuthikul P, Satterthwaite JD. Contemporary denture base resins: Part 1. Dent Update. 2012; 39:25-28.
2. Alfahdawi I. Effect Type of Flasking Technique and Investing Materials on Movements of Teeth during Complete Denture Construction. IMJ .2019;516–519.
3. Polat TN, Karacaer O, Tezvergil A, Lassila LV, Vallittu PK. Water sorption, solubility and dimensional changes of denture base polymers reinforced with short glass fibers. J Biomater Appl. 2003;17:321-335.
4. Andrade de Freitas SL, Brandt WC, Miranda ME, Vitti RP. Effect of Thermocycling, Teeth, and Polymerization Methods on Bond Strength Teeth-Denture Base.Int J Dent. 2018;4:1-5.

5. Goodacre B, Goodacre C, Baba N, Kattadiyil M. Comparison of denture base adaptation between CAD/CAM and conventional fabrication techniques. J Prosthet Dent. 2016;116:249-256.
6. Salloum AM. Effect of three investing materials on tooth movement during flasking procedure for complete denture construction. Saudi Dent J. 2016;1:56-61.
7. ElHameed H, Mohamed S. Comparative laboratory evaluation of dimensional accuracy for 3D-printed complete maxillary denture. EDJ. 2021;67:661–668.
8. Goodacre BJ, Goodacre CJ, Baba NZ, Kattadiyil MT. Comparison of denture tooth movement between CAD-CAM and conventional fabrication techniques. J Prosthet Dent. 2018;119:108–115.
9. Abdellah M, Ali MS, Abdelrahim RA. Influence of incorporation of SiO2 and ZrO2 nanoparticles on some physical and mechanical properties of thermoplastic resin material. Al-Azhar J Dent Sci. 2020;23:165–171.
10. Ashour AM, El-Shennawy M, M. Althomali Y, Omar A. Effect of Titanium Dioxide Nano Particles Incorporation on Mechanical and Physical Properties on Two Different Types of Acrylic Resin Denture Base. WJNSE. 2016; 06:111-119.
11. Gad M, Fouda S, Al-Harbi F, Näpänkangas R, Raustia A. PMMA denture base material enhancement: a review of fiber, filler, and nanofiller addition. Int J Nanomedicine. 2017; 12:3801–3812.
12. Ayad NM, Badawi MF, Fatah AA. Effect of reinforcement of high-impact acrylic resin with zirconia on some physical and mechanical properties. Rev Clı´nPesqOdontol (Impr) 2008;4:145–151.
13. Begum SS, Ajay R, Devaki V, Divya K, Balu K, Kumar PA. Impact Strength and Dimensional Accuracy of Heat-Cure Denture Base Resin Reinforced With ZrO2 Nanoparticles: An In Vitro Study. J Pharm Bioallied Sci. 2019;11: S365–S370.
14. Al-Rais RY, Al-Nakkash WA, Al-Bakri AK. Filler reinforced acrylic denture base material. Part 2-Effect of water sorption on dimensional changes and transverse strength. J Baghdad Coll Dent. 2005;17:6–10.
15. Gad MM, Abualsaud R, Rahoma A, Al-Thobity AM, Al-Abidi KS, Akhtar S. Effect of zirconium oxide nanoparticles addition on the optical and tensile properties of polymethyl methacrylate denture base material. Int. J. Nanomed. 2018;13:283-292.
16. 16. Zhou S, Garnweitner G, Niederberger M, Antonietti M. Dispersion behavior of zirconia nanocrystals andtheir surface functionalization with vinyl group-containingligands. Langmuir. 2007;23:9178-9187.
17. Cal N, Hersek N, Sahin E. Water Sorption and Dimensional Changes of Denture Base Polymer Reinforced with Glass Fibers in Continuous Unidirectional and Woven Form. Int J Prosthodont.2000 ;13:487–493.
18. Figuerôa R, Conterno B, Arrais C, Sugio C, Urban V, Neppelenbroek K. Porosity, water sorption and solubility of denture base acrylic resins polymerized conventionally or in microwave. J Appl Oral Sci. 2018;26:1-7.