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WEAR RESISTANCE OF NANO SILICA MODIFIED ACRYLIC DENTURE TEETH AND NANO FILLED COMPOSITE DENTURE TEETH

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ABSTRACT

Artificial denture teeth are subjected to wear from daily masticatory functions. This wear affects the denture esthetics, functions and in turn results in patient discomfort. The purpose of this study was to evaluate the wear resistance of nano composite fabricated artificial denture teeth and conventional acrylic denture teeth reinforced with silica nano particles. A total number of 60 samples were used. Samples were divided into equal four groups (n=15). The first group was fabricated from nano filled composite. The second and third groups were silica nanoparticles modified acrylic denture teeth with two different concentrations 0.1% and 10% respectively. The fourth group was conventional acrylic resin denture teeth and served as a control. The 2-body wear testing was performed with a multi-modal ROBOTA chewing simulator. Wear was then evaluated by the means of weight loss and surface roughness. The nano-composite group recorded significantly higher wear resistance than conventional and silica modified acrylic resin groups. The silica modified acrylic resin group with 0.1% concentration recorded a lower surface roughness than any of the other groups. In conclusion; Nano-composite teeth can be used as artificial denture teeth exhibiting significant higher wear resistance than conventional and silica modified artificial acrylic teeth.

KEYWORDS: Wear; Nano composite teeth; Acrylic resin teeth; Silica nanoparticles.

INTRODUCTION

Teeth are lost due to dental caries, periodontal diseases, accidents or involvement in resected jaw pathologies. During the past century, restoration of lost natural teeth was performed in different ways. The most common way to replace lost natural teeth was by constructing a removable denture [(1)]. A conventional removable denture comprises of two important components; artificial denture teeth and a denture base. Historically, artificial teeth made of stone, ivory and even human teeth were used for teeth replacements [(2)]. Nowadays, denture teeth are made of either methacrylate-based resins or ceramics. Acrylic resins teeth have some advantages over that of ceramics such as the chemical bond to the denture base, lower susceptibility to fracturing, decrease of clicking and decreased wear to opposing

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natural teeth. Nonetheless, the wear resistance of acrylic resin teeth has been questioned for being lower than that of ceramic teeth [3, 4]. Wear resistance of denture teeth materials has a lot of concern in oral rehabilitation of edentulous patients with removable dentures to provide a stable and sustained occlusal support. Wear of the occlusal surfaces may result in insufficient posterior tooth support, loss of chewing efficiency, and nonfunctional activities [5]. The use of silica nano particles fillers in resin polymers, could improve mechanical properties of polymers, this may give rise to a higher wear resistance of acrylic denture teeth [5, 6]. One more addition to improve the wear resistance of dentures teeth was to use resin composites for their fabrication, which have higher strength and wear resistance than acrylic teeth [7]. To find the strategic difference between the wear resistances of both nano filled composite denture teeth and nano silica modified acrylic teeth, an in vitro study was planned. The hypothesis of this study was that nano filled composite denture teeth could have higher wear resistance than conventional and nano silica modified acrylic teeth. The objective of our study was to compare the amount of wear from silica modified acrylic teeth with newly introduced Nano filled composite teeth.

MATERIALS AND METHODS

In the current study, two materials were used to construct the artificial denture teeth, nano-filled composite (Filtek Z350 XT Universal Restorative, 3M ESPE, St. Paul, MN, USA) and conventional acrylic resin (Acrostone, Headquarters, London, England). Silica nanoparticles (NT- Sio2-NP, Nanotech, Egypt) with two different concentrations (0.1%, 10%) were used to modify the conventional acrylic resin (AR) teeth.

A total number of 60 samples divided into equal four groups (n=15) were used (table1). The first group of denture teeth was fabricated from nano filled composite. The second and third groups were silica nanoparticles modified acrylic denture teeth with two different concentrations 0.1% and 10% respectively. The fourth group was conventional acrylic resin denture teeth and served as a control.

TABLE (1) Wear test parameters of ROBOTA chewing simulator machine

Wear test parameters	
Vertical movement: 1 mm	Horizontal movement: 5 mm
Rising speed: 90 mm/s	Forward speed: 90 mm/s
Descending speed: 40 mm/s	Backward speed: 40 mm/s
Cycle frequency 1.6 Hz	Weight per sample: from700gr
Torque; 2.4 N.m	

Die Making (Duplicating the metal model that fits in the receptacle in the upper compartment of ROBOTA chewing simulator), fig. (1).

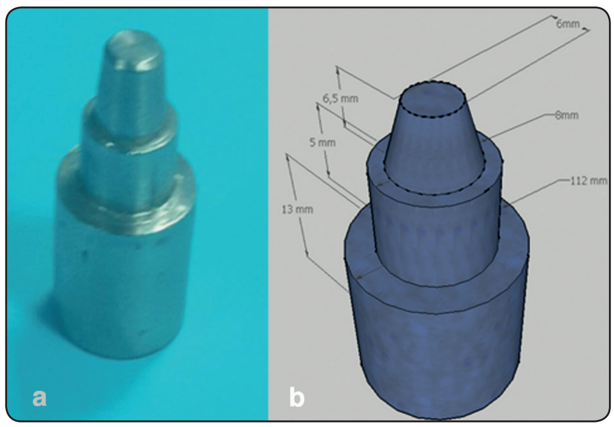

Fig. (1) The metal mold (a) and metal mold dimensions(b).

A metal model with the dimensions (13mmx5mmx6.5mm height X 12mmx8mmx6mm width) was inserted into a flask containing hard dental stone slurry (Hard stone, Spain) after painting it with separating medium to allow easy removal from the stone, then it was allowed to set. Mixing of the powder and monomer of acrylic denture teeth (nano silica 0.1% & 10% modified acrylic resin and conventional acrylic resin) was carried out according to manufacturer instructions (2.5:1 by weight) until reaching the dough stage. When the resin reached the dough stage, the stone surfaces in the flask was treated with separating medium (water soluble alginate) and the acrylic resin was packed in the test part of the model, and the two sections of the flask were closed together. Polymerization by short curing cycle was carried out and then allowed to cool at room temperature. After that the base part of the model was filled with chemical cure acrylic resin, then the flask was closed until setting occur. The investing stone was removed carefully, and the acrylic samples were removed from the flask. Finishing and polishing of samples were made using silicon carbide (SiC) abrasive papers.

Samples fabrication for Nano filled composite group:

An impression was taken for the metal model using addition-silicon rubber base impression material (Elite P & P Regular Body, Zhermack, Italy) then the model was removed making a mold. Composite was added in the test part of the mold with layering technique, while each layer was cured by a light curing device. After filling the test part of the mold by composite, the remaining part of the mold was filled with a chemical cure acrylic resin, then the sample was removed. Finishing and polishing of the samples were done using silicon carbide (SiC) abrasive papers.

Samples fabrication for conventional and nano silica modified acrylic resin groups:

Nano silica particles were added to the powder of conventional heat cure acrylic resin with concentrations of 0.1% and 10% by Wt. using electronic analytical balance (Sartorius, Biopharmaceutical and Laboratories, Ger.). To ensure the appropriate distribution of silica nanoparticles, a magnetic stirrer (LABINCO, BV Model L-81) was used to mix silica with heat cure acrylic powder.

Wear test; The 2-body wear testing was performed using programmable logic controlled equipment using the newly developed four stations multimodal Dual-axis ROBOTA chewing simulator integrated with thermo-cyclic protocol operated on servo-motor (Model ACH-09075DC-T, AD-TECH Technology Co., LTD., Germany). The device allows simulation of the vertical and horizontal movements simultaneously in the thermodynamic condition. The ROBOTA chewing simulator has four chambers, each consisting of an upper part as tooth or antagonist holder and a lower plastic sample holder fig. (2). Samples were mounted into the metal receptacle present in the chewing simulator upper part. All the samples were tested under standard conditions in which bovine teeth were used in the lower plastic holder of the device acting as antagonist. The samples were positioned on the upper samples holder in point contact with the bovine teeth. A weight of 700 grams, which is comparable to 7N of chewing force was exerted.

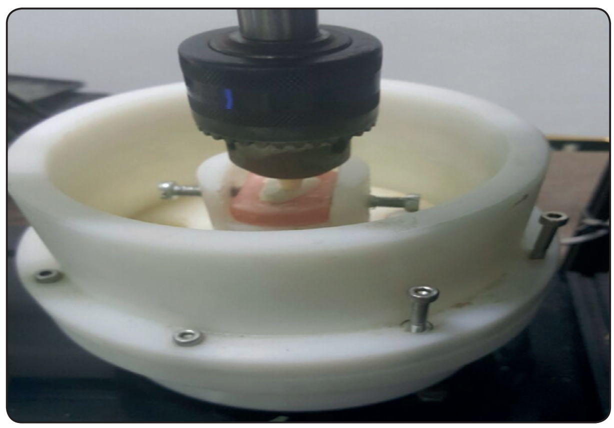

Fig. (2) showing shows the ROBOTA chewing simulator chamber with loaded sample.

Teeth were subjected to 37,500 cycles to simulate three months of clinical function. After 37,500 cycles, the samples were removed from the holder, cleaned with running water, and followed by cleaning in ultrasonic cleaner for 2 minutes to remove any abraded particles from the surface prior to measuring. The weight of samples was checked to calculate the weight loss. Table 1 demonstrated the wear test parameters of the ROBOTA chewing simulator device.

Wear measurements by weight loss: The difference in weight measurements before and after wear simulation determined the weight loss. This was done by weighing samples in the electronic analytical balance (Sartorius, Biopharmaceutical and Laboratories, Germany) with an accuracy of 0.0001 gram to show the difference in weight before and after wear test.

Surface roughness evaluation: to achieve a better reflection on the surface of the teeth and qualitative analysis of the roughness areas, roughness of surfaces was photographed using USB Digital microscope with a built-in camera (Scope Capture Digital Microscope, Guangdong, China) connected with an IBM compatible personal computer using a fixed magnification of X25. Images were cropped to 350 x 400 pixels and then analyzed using WSXM software. Three D images of the surface profile of the samples were created using a digital image analysis system (Image J 1.43U, National Institute of Health, USA). The change in surface roughness measurements (Ra. in nanometers) before and after wear simulation was calculated.

Statistical analysis: Data analysis was performed in several steps. Initially, descriptive statistics for each group results. One-way ANOVA followed by pair-wise Tukey's post-hoc tests were performed to detect significance between groups. Student t-test was done to compare roughness before and after wear simulation. A statistical analysis was performed using Asistat 7.6 statistics software for Windows (Campina Grande, Paraiba state, Brazil). P values ≤ 0.05 are considered to be statistically significant.

RESULTS

Wear evaluation by weight loss results

The mean values and standard deviations (SD) for wear test measured by weight loss (gram) recorded on all materials group before and after 3 months are graphically represented in fig. (3).

The highest weight loss mean value after wear simulation was recorded for conventional AR group (0.03240±0.0009 gr) followed by 0.1 % Silica modified group weight loss mean value (0.027292±0.0065 gr) then 10 % Silica modified group (0.025858±0.0012 gr) while the lowest weight loss mean value (0.007825±0.0015 gr) was for Nano-composite group. The difference between all groups was statistically significant as indicated by ANOVA test ($F=25.39$, $p=<.0001<0.05$). Pair-wise Tukey's post-hoc test showed that the difference between Silica modified and conventional AR groups was statistically non-significant ($p>0.05$) - table 2.

Wear evaluation by Roughness results: Before wear simulation, the difference between all groups was statistically non-significant as indicated by ANOVA test ($F=4.9$, $p=.1232>0.05$). Meanwhile, it was noted that after wear simulation, differences between all groups was statistically significant as indicated by ANOVA test ($F=9.4$, $p=.0248<0.05$) Fig. (4). All groups showed non-significant ($p>0.05$) difference between roughness mean value before and after wear simulation except for 0.1% Silica modified AR where the difference was statistically significant as proven by paired t-test ($p<0.05$) table 3.

Scanning electron microscopic evaluation

For conventional AR group: rough surface with several cracks between polymeric networks which can be described as fatigue type of wear, fig (5-a).

For 0.1% Silica modified AR group; the action of the enamel surface imperfections which have higher hardness, therefore can plow out the polymer matrix and/or silica particles from the sample surface, resulting in the scratches shown, fig. (5-b).

For 10% Silica modified AR; the wear scratches on the samples surface are just a reunion of smaller wear defects, arranged in a linear fashion, comprising different mass loss processes, fig. (5-c).

For nano-composite group; relatively smooth and uniform wear surface without significant filler protrusion or pits from filler dislodgement in the surrounding matrix was shown. Wear scars appear as brighter regions parallel to the sliding direction that result from the removal of the polymeric matrix and nanoparticles, fig (5-d).

Three dimensional surface roughness images using WSXM software:

Fig. (6) shows the three dimensional surface roughness topographic features for all samples groups before and after wear simulation.

TABLE (2) Weight results (Mean values ±SD) for conventional and experimental groups before and after wear simulation

Variables		*Samples weight*		
		Before	*After*	*Weight loss*
Conventional AR		2.382417±0.0449	2.350017±0.0442	0.03240^{A}±0.0009
Experimental group	*0.1% Silica modified AR*	2.440042±0.0469	2.41275 ±0.0457	0.027292^{A}±0.0065
	10 % Silica modified AR	2.361867±0.0260	2.336008±0.0250	0.025858^{A}±0.0012
	Nano-composite	2.39635 ±0.0547	2.388525±0.0545	0.007825^{B}±0.0015
ANOVA	*F value*	25.39		
	P value	<.0001*		

different letter indicating significant (Tukey's p<0.05) *; significant (p<0.05) ns; non-significant (p>0.05)

TABLE (3) Roughness results (Mean values ±SD) for conventional and experimental groups before and after wear simulation.

Variables		*Samples Ra*			
		Before	*After*	*t-value*	*P value*
Conventional AR		0.25435 ±0.0005	0.255825±0.0011	2.1	.0647 ns
Experimental group	*0.1% Silica modified* AR	0.256908 ±0.0009	0.253867±0.001	3.3	.0102*
	10 % Silica modified AR	0.254133 ±0.002	0.25435±0.0005	0.2725	.7921 ns
	Nano-composite	0.255825 ±0.0011	0.256908±0.0009	1.3	.2485 ns
ANOVA	*F value*	4.9	9.4		
	P value	.1232 ns	.0248*		

****; significant (p<0.05) ns; non-significant (p>0.05)***

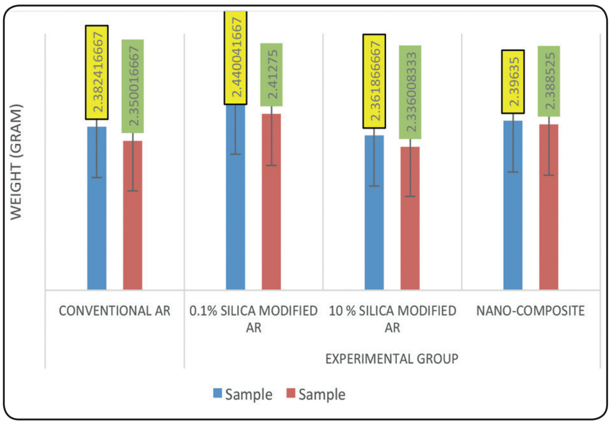

Fig. (3) Column chart showing weight mean values for conventional, experimental groups before and after wear simulation.

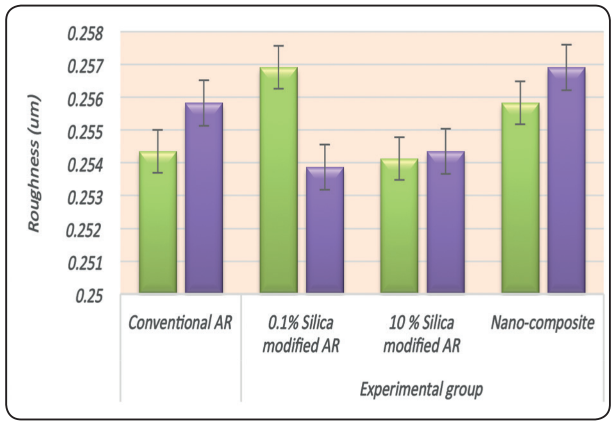

Fig. (4) Column chart showing roughness mean values for conventional and experimental groups before and after wear simulation.

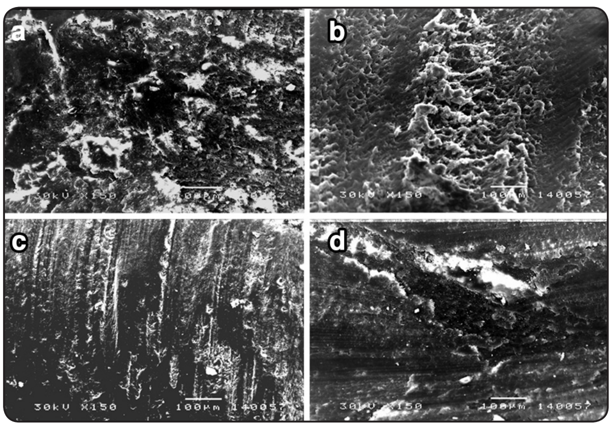

Figure 5: SEM photomicrographs of conventional heat cure tooth shade acrylic resin samples (a) showing rough surface with several cracks between polymeric network. For 10% silica modified acrylic resin sample (b) showing plowing out the polymer matrix and or silica particles from the sample surface. For 0.1% silica modified acrylic resin sample (c) showing the wear scratches on the samples surface are just a reunion of smaller wear defects. For nano filled composite resin sample (d) showing that wear scars appear as brighter regions parallel to the sliding direction.

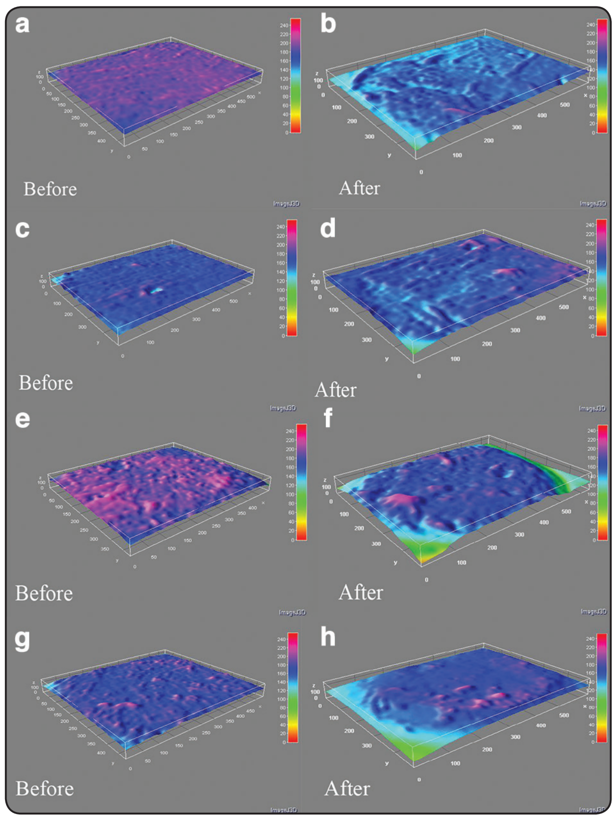

Fig. (6) Three dimensional surface topographic features of; conventional AR group before(a) and after (b) wear simulation. 0.1 % Silica modified AR group before (c) and after(d) wear simulation. 10 % Silica modified AR group before (e) and after (f) wear simulation. Nano-composite group before (g) and after (h) wear simulation

DISCUSSION

Acrylic resin teeth are the most widely used denture teeth. Although acrylic resin has poor wear resistance, they have the distinct advantage of adjustability, lack of clicking sounds, and good bonding to denture base material when compared to porcelain teeth [(7)]. This in vitro study compared the amount of wear which occurred under same laboratory conditions between nano-composite, conventional, and silica modified acrylic resin teeth materials using a two-body wear testing machine. The wear of denture teeth can be studied in vitro by either two or three-body testing methods. Three-body testing usually measures wear characteristics, but the results can be affected by many variables like the abrasiveness of the intermediate material and the pH of this material in addition to the material of the antagonist [(8)]. The two-body wear testing method, on the other hand shows the effect of direct contact between the specimen and the antagonist, as in the case of complete denture with bilaterally balanced occlusion. Therefore, the two-body wear test was selected in this study. In order to prepare the samples of this study, metal models were machined and polished with specific dimensions. This study was carried out for 37,500 cycles to simulate three months of clinical function [(9)]. The material of the antagonist substantially influences the wear rates in two-body wear studies. In the current study each sample was tested against bovine teeth to standardize the surface roughness, hardness, and composition of the antagonist that may affect the wearing of the samples. Due to the difficulty of obtaining human teeth for research or studies, it is necessary to use alternatives with the same physical characteristics. The bovine permanent incisors showed anatomical and histological similarities, and are excellent substitutes to human teeth in dentistry research [(10)].

Wight loss: In this study, silica modified acrylic resin has more wear resistance than control group. This is in agreement with some other studies [(11, 12)]. This is because nano fillers particles are expected to disperse more homogeneously within a polymer host. Homogenous distribution of very fine size and high surface area of nano filler enable them to restrict the motion of macromolecule chains and enhance mechanical properties [(13)]. However, this study is in disagreement with other studies. [(3, 14)] which may be explained by absence of relation between the wear resistance and the chemical composition of the samples [(3)]. Also this contradiction could be due to different materials, test set up, experimental conditions, and sample preparation.

The results of this study showed that nano filled composite samples have statistically significant higher wear resistance than conventional heat cured acrylic samples. This result is in agreement with the previous studies [(15, 16)]. The reason might be due to the fact that nano-composite denture teeth possess unique characteristics in terms of homogeneity, as the material is not highly cross-linked but contains nano-sized inorganic fillers that are well dispersed without agglomeration in the matrix resin which lead to a unique polymer structure consisting of well-dispersed nano-sized fillers [(17)]. However, this study is in disagreement with another studies [(18, 19)] because nano-composite denture teeth contain inorganic salinized SiO_2 fillers, which are incorporated into the structure to increase the hardness of the teeth; however, these fillers may tend to agglomerate into clusters which in turn could be detached from the surface of the denture teeth during function and can lead to excessive wear. [(20)]

Roughness results: The results of this study showed statistical significant difference between the surface roughness changes of the silica modified and nano filled composite experimental groups and the surface roughness changes of control group.

The pair-wise comparisons for the surface roughness of silica modified experimental groups at different concentration showed statistical significant difference at 0.1 % concentration. This may be due to the increasing concentration of nano particles leading to agglomeration of nano-filler on the surface causing wear and roughness of the material. [21] These results are in agreement with the previous work of Vojdani et al. [22]. This may be explained by the better polishability attributed to the use of nano-fillers in such resin, the smaller the filler size, and the lower the degree of filler pluck-out [23]. However, these results are in disagreement with Moudhaffar and his co-workers [12]. This may be due to the fact that the particles of SiO_2 differ in roughness than that of acrylic resin and the distribution of this particles within the matrix of the samples leads to increase the value of surface roughness and coarser surface resulted. [24] The controversy between the results of this study and others studies may be due to the differences in the methodology, concentrations, size, and shape of nanoparticles. In conclusion; Nano composite teeth have more wear resistance than conventional and silica modified acrylic teeth. Modification of conventional acrylic teeth with silica nanoparticles improved their wear. In the light of the obtained result, dentists' decision to indicate any of the artificial teeth tested in this study can be made on the analysis of important characteristics in determining its functionality and aesthetics allied to the cost of the materials. For better judgment of the behavior of dental materials in the oral cavity, additional data from three body wear tests and clinical studies would be of interest.

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