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Effect of Nano-Zirconia Reinforcement on Stresses and Fracture Resistance of Lower Implant retained Overdenture.

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ABSTRACT

This study evaluates the effect of denture base reinforcement by Nano-zirconia oxide on the stresses transmitted to the implants and the fracture resistance of manibular implant retained overdenture base. Two mandibular completely edentulous heat-cured acrylic resin models were made. Two identical mandibular complete overdentures were processed on the resin models; one made from heat-cured acrylic resinandthe other one from heat-cured resin reinforced with nano zirconia oxide. On each the acrylic model two parallel regular diameterimplants were inserted in the canine region with ball abutments. Strain measurements were performed under bilateral and unilateral loading using a universal testing machine. The experimental overdentures were also tested for fracture resistance by the universal testing machine. Data were statistically analyzed. Although, Nano-zirconia oxide reinforced overdenture recorded higher mean values during all loading situations. No statistical significant difference between reinforced overdenture and heat cured overdenture base was detected (p>0.05). Nano-zirconia oxide reinforcement denture showed a statistically higher significant difference in fracture resistant compared to heat-cured acrylic resin (p<0.05). Reinforcement of mandibular overdentures by Nano-zirconia oxide increases its fracture resistance successfully. Hence reinforcement of acrylic resin with such material may help to decrease the problem of repeated denture fracture, however, further laboratory and clinical studies are required.

Keywords: Implant retained overdenture, Nona- zirconia oxide, Strain gauge analysis, Fracture resistance.

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INTRODUCTION

Many studies have shown that implant retained mandibular overdenture is the simplest and most effective solution compared to conventional complete denture regarding retention, stability and patient satisfactions [1,2].

Although, heat-cured acrylic resin is the most commonly used denture base material, it has some disadvantages regarding the mechanical strength that is not sufficient to maintain the longevity of denture base[3-5]. Fracture of the denture base is the frequent problem that occurs with heat-cured acrylic resin overdenture prostheses [6-9].

The high incidence of denture base fracture in implant retained overdentures is due to, high masticatory load, reduced thickness of the denture base over the abutments, and inevitable bone resorption causing the abutment to act as a fulcrum causing denture base fracture. The abutments occupy space inside the denture base and acts as a fulcrum upon which movement of the overdenture occurs resulting in overdenture fracture in regions where housings exist. Overdenture fracture occurs as a result of initiation and propagation of cracks from areas of high stress concentration over the implant abutments and cause denture base fracture [8,9].

Several studies have attempted to strengthen the acrylic denture base using different approaches, aiming to improve the impact strength, fatigue resistance and transverse strength of the acrylic resin. Reinforcing the denture base with carbon fibers, glass fibers, ultra- high molecular and metal powders are one of the modifications to produce an acrylic co-polymerized with high impact strength [10-13].

The addition of inorganic nanoparticles into Poly methyl methacrylate (PMMA) is one of the recent modifications used to improve the mechanical properties of PMMA. Zirconia is one of the biocompatible dental ceramic materials that improved the mechanical properties especially the fracture resistance. Stabilizing oxides are added to zirconia to retain a metastable condition at room temperature, enabling a phenomenon called transformation toughening to occur. The partially stabilized crystalline zirconia exhibits good response to mechanical stimuli, such as tensile stress at crack tips resulting in local increase in volume of approximately 4%. This increase in volume closes the crack tips, effectively reducing crack propagation. The transformation-toughening process of zirconia increases the flexural strength and toughness of zirconia to be twice that of the alumina, because of the zirconia grain size [14-16].

Zirconia implants with modified surfaces exhibits osseointegration similar to those of titanium implants. Thus it seems promising to use zirconia for different dental applications[17]. Nano zirconia oxide (ZrO2) was used to improve the mechanical properties and to achieve maximum radio-opacity without affecting the mechanical properties of the denture base material. The advantages of Nano ZrO2 are excellent biocompatible material and the white color doesn't alter the esthetic[18,19].

Many experimental stress analysis methods have been employed to evaluate biomechanical loads. Photo-elastic stress analysis, strain gauge stress analysis, holographic interferometry and finite element stress analysis are the frequently used methods to evaluate the biomechanical loads [20].The purpose of reinforcement is to prevent fracture as well as to improve functional rigidity, and to distribute occlusal stress to the underlying denture-bearing areas as uniformly as possible.

Accordingly, the objective of this study was to assess the effect of denture base reinforcement by Nano-zirconia oxide on the stresses and the fracture resistance of manibular implant retained overdenture

MATERIAL AND METHODS

Test models and overdenture fabrication

In this in-vitro study two mandibular completely edentulous heat cured acrylic resin models were obtained from a medium body rubber base impression (Speedex; Coltene, Altsẗatten, Switzerland) of an educational mandibular edentulous stone model. Molten base plate wax (Cavex modeling wax-USA) was

poured into the impressions; the two wax casts were processed into pink heat cured acrylic resin (Acrostone, WHW plastic, England Packed by Anglo Egyptian Lab).

The surface of denture bearing area was replaced by a 2 mm- thickness layer of silicone impression material (Affinisregular,Colte'ne/Whaledent, Switzerland) to serve as alveolar mucosa. The elastic modulus of silicone impression material was reported to be in the same range of the alveolar mucosa[21].On eachacrylic model, one sheet of shellac base plate(Cavex dental base plate-USA) was adapted. Two identical sheets of acrylic teeth (Vita-pan acrylic teeth, Vita Bad Sackingen- Germany) were used for setting up of teeth, according to the anatomical and mechanical considerations[22].Waxing up, flasking, wax elimination and packing of acrylic resin were performed. For experimental denture (I) conventional heat cured resin (Vertex regular, Zeist, Netherlands) was used and processed following manufacturer instructions

Regarding experimental Denture (II)nano zirconia oxideof particle size5-10 um, (Promochem GmbH Postfach, Wesel, Germany) 5% by weight was added to the acrylic powder (Vertex regular, Zeist, Netherlands).   Before incorporation of nano-ZrO2 into acrylic resin powder it was first treated with silane coupling agent (ultra dentcoupleing agent-methacryloxyprophy, Dentsply, India). A solution of 0.3 gm. of zirconia coupling agent in 100 ml of acetone was used to treat 30 g of zirconia powder (ZrO2). The oxide powder was stirred in the coupling agent/acetone solution with a magnetic stirrer, for 60 minutes, after which acetone was completely evaporated using a rotary evaporator [23]. Thorough mixing of the oxide powder with the acrylic polymer powder (Vertex regular, Zeist, Netherlands) was carried out using porcelain mortar and pestle, then, the monomer was added to the mixture. Then mix was packed in to flask at the dough stage and cured according to manufacturer instructions.

On each acrylic model two implants 4.0 mm in diameter and 12 mm in length (Oraltronics, Pitt Easy, Germany) were inserted bilaterally in the canine region. Self-cured acrylic resin was used to fix the implants in their beds (Acrostone, WHW plastic, England Packed by Anglo Egyptian Lab). The two metal ball abutments were screwed to the implants.

For picking up of the implant attachment, a space was created in the fitting surface of overdentures and two vent holes were opened in the lingual flange. The female metal housings with O-rings were placed on the implants. Auto-polymerizing acrylic resin (Acrostone, WHW plastic, England Packed by Anglo Egyptian Lab)was applied in space created opposite female housing and the overdenture was placed on the model. Firm steady pressure was applied on the overdentures bilaterally until complete curing of the resin takes place (Fig 1).
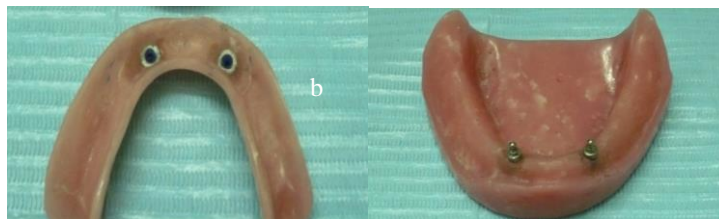

Fig1: (a) Two implants with ball attachment in canine regions of the acrylic model, (b)metallic housings in the fitting surface of the overdenture.
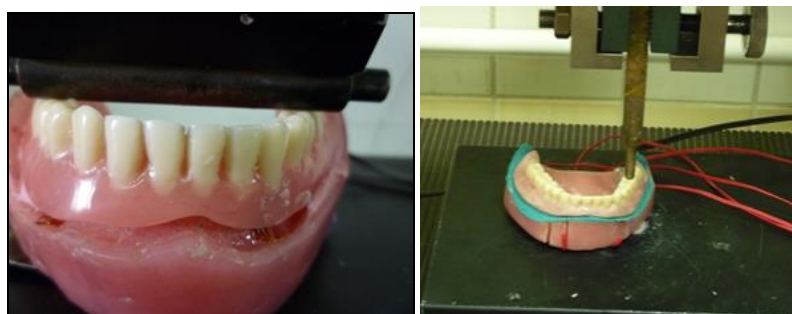

Fig 2: (a & b) bilateral and unilateral Load application on the first molar.

Fig 3: The experimental denture under load applicator of the universal testing machine, (b) denture fracture

The strain gauges were attached at the mesial and distal aspect of the implant, Since it is not feasible to measure the moments generated at an implant directly, it was assumed that strain measured on the resin around the implants could be representative of stress that is introduced to the bone. Therefore, two grooves were created below the crest of the ridge parallel to the long axis of the implant leaving 1mm of resin intact [24]. Then, four linear strain gauges (type: KFG-1-120-C1-11L1M2R; KYOWA electronic instruments CO., Ltd., Tokyo, Japan; resistance 119.6±0.4% Ω; gauge length: 1mm; gauge factor: 2.08±1.0%) were bonded to the acrylic resin at mesial and distal surface of each implant using a Cyanoacrylate adhesive (TML strain gauge adhesive, Tokyo Sokki Kenkyujo Co Ltd, Japan)

Loading tests

Vertical static loads of 100 Newton were applied to the occlusal plane of the overdentures bilaterally and unilaterally using a universal loading device (LLOYD LRX, LLOYD instruments Ltd., Fareham, Hampshire, UK). Unilateralload application was made on the right side only (the functional side), and the left side was considered the non-loading (non functional) side. The point of load application was a notch made in the central occlusal fossa of the 1st molar to accommodate the tip of the loading pin and to provide reproducibility. T-shaped and I-shaped load applicators were used for bilateral and unilateral load applications respectively.

All measurements were repeated 5 times allowing at least 5 minutes for recovery, and the mean of recorded micro strain (μ)values was calculated and tabulated for statistical analysis.

Fracture resistance test

Evaluation of the fracture resistance of the two overdenture bases under bilateral loading was carried out. A vertical load was applied at a crosshead speed of 0.5mm/min until denture fracture occurs as indicated by the break detector of the testing machine. The load- deformation curve for tested denture was plotted by means of data analysis software installed in a PC connected to the testing machine. Maximum load recorded at denture fracture in Newton (N) was recorded.

RESULTS

The results of this study are shown in tables 1to3. Data were presented as meanand standard deviation (SD) values. Student T test was used to compare between the two experimental dentures (table 1,2 and 3). A probability level of P ≤ 0.05 was considered statistically significant.

Comparison of the two denture bases during unilateral and bilateral loading (table: 1 and 2), showed that nanoZrO2 reinforced denture base (experimental Denture II) recorded higher mean values than heat cured resin (experimental Denture I), statistical analysis revealed a significant difference between the two denture bases (P<0.05) during unilateral bilateral loading.

Table (1): Comparison of micro strain µ during unilateral loading on the implants for both heat cured and Nano-ZrO2 reinforced overdenture bases.

Side	Site	Heat cured denture base		Nano -ZrO2 reinforced denture base		P value
		Mean	SD	Mean	SD	
Left	Distal	374	38.7	413.3	3.9	0.0282**
	Mesial	296	11.9	286.9	8.2	<0.0001**
Right	Distal	158	5.5	176.4	4.3	0.0002**
	Mesial	104	4.3	121.5	2.6	<0.0001**

M; Mean, SD; Standard Deviation; P; Probability Level **Significant difference (P <0.05)

Table (2): Comparison of micro strain µ during bilateral loading on the implants for both heat cured and Nano- ZrO2 reinforced overdenture bases.

Side	Site	Heat cured denture base		Nano- ZrO2 reinforced denture base		P value
		Mean	SD	Mean	SD	
Left	Distal	282	46.5	327.8	14	0.0203**
	Mesial	267	4.3	315.5	2.6	0.0001**
Right	Distal	289	13.4	317	4.3	<0.0001**
	Mesial	274	0	328.6	5.8	<0.0001**

M; Mean, SD; Standard Deviation; P; Probability Level **Significant difference (P <0.05)

Regarding the denture base fracture resistance (table:3), reinforced nanoZrO2 denture recorded higher mean value compared to heat cured denture and it was statistically significant (P<0.05)

Table (3): Values of loading force (Newton) until fracture in studied groups for both denture bases

Heat Cured AR		Nano Zirconium Reinforced AR		P-value
M	SD	M	SD	
1854.6	26.88	2252.7	32.7	<0.0001**

M: Mean, SD; Standard Deviation; P; Probability Level **Significant difference (P <0.05)

DISCUSSION

Recently, much attention has been directed towards the incorporation of inorganic zirconia oxide nanoparticles into PMMA to improve its mechanical properties [14,19]. The purpose of reinforcement is to prevent fracture, to improve functional rigidity, and to distribute occlusal stress to the underlying denture-bearing areas as uniformly as possible.

In dentistry, laboratory (in vitro), and clinical (in vivo) evaluation methods are frequently used for evaluation of dental materials characteristics. Among in vitro technologies is strain gauge method, which was used in this study. Strain gauge technique offers several advantages such as: sensitivity, stability, accuracy and reproducibility. It can be applied nearly in every situation where strains are to be evaluated [20-22].

In this study, the implants positions in the model were selected according to the strategy suggested by Misch [25] bilaterally in the canine region for edentulous mandible. Loads magnitude was 100 N as it was reported to be a moderate biting force for implant overdentures [26].

In this study, in all loading situations whether unilateral or bilateral, the nanoZrO2 reinforced denture caused slight increase in the amount of strain delivered to the implants. Based on this observation, addition of nano zirconia may account for the detected increase in strain values.

Regarding unilateral loading in this study, it was clear that there was significant increase in the amount of strains transmitted to the implants compared to unloaded site. This increase in strain value is probably due rotation of the prosthesis around a fulcrum axis formed by the crest of the ridge causing excessive torqueing forces on the overdenture supporting structures. Conversely, bilateral loading most probably allows occlusal stability and broader load distribution that preserve the overdenture supporting structures.

Apparently, reinforcement of acrylic resin with silanized nano zirconium oxide fillers did increase the fracture resistance of denture base. This result is in agreement with the previous studies that reported reinforcement of dental restorative resins as well as acrylic resin with zirconium oxide could exhibit improvement in their mechanical properties especially the fracture resistance [18,19].Several reasons may explain these results; Nano zirconium oxide filler reinforcement is based on the principle that a relatively soft ductile matrix is fully capable of transferring an applied load to the strong filler particles. Also may be due to that When sufficient stress develops and a crack begins to propagate, a transformation of zirconium oxide from the metastable tetragonal crystal phase to the stable monoclinic phase occurs which depletes the energy of crack propagation. Also, in this process, expansion of zirconium oxide crystals occurs and places the crack under a state of compressive stress and crack propagation is arrested [14-16].

CONCLUSION

Within limitation of this in vitro study it could be concluded that, reinforcement of mandibular overdentures by Nano-zirconia oxide increases the stress transmitted to implant supporting structures. However, Nano-zirconia improves fracture resistance successfully. Hence reinforcement of acrylic resin with such material may help to alleviate problem of repeated denture fracture cases, however, further laboratory and clinical studies are required.

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