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ZIRCONIA VERSUS COBALT CHROMIUM MESHWORK REINFORCEMENT OF IMPLANT-ASSISTED MANDIBULAR OVERDENTURE

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ABSTRACT

Introduction : This work aimed at testing the mechanical behavior of non-metallic enforcement of an implant-assisted mandibular overdenture denture base with a zirconium meshwork and compared its behavior to that of cobalt chromium meshwork under fatigue cyclic loading and fracture resistance.

Materials and Methods: Thirty completely edentulous models in which 2 laboratory implant analogues were secured in the position of the teeth 33 and 43 with ball abutments were used, 10 overdentures of group I had cobalt-chromium meshwork reinforcement of 1mm thickness, group II had 10 overdentures reinforced with 0.5 mm zirconia framework, and group III had 10 dentures with 1 mm zirconia reinforcing framework, the 3 groups were subjected to fatigue cyclic loading and fracture testing.

Results: Group I did not show complete fracture, only cracks in the denture base. group II showed complete fracture of its samples, and only 6 samples of group III showed complete fracture with cracks in the remaining 4. There were significant differences between groups I and II, groups I and III, and groups II and III where the fracture load was significantly greatest for group I, followed by group III, and finally group II.

Conclusion: The Co-Cr meshworks provided the strongest reinforcement of the overdenture bases as compared to zirconia frameworks. The 1 mm thickness zirconia meshwork was more resistant to fracture than the 0.5 mm zirconia framework, but weaker than the Co-Cr framework, however, its recorded resistance to fatigue cyclic loading and fracture was thought to provide an acceptable clinical service lifetime.

KEY WORDS: Denture base fracture, cobalt-chromium meshwork reinforcement, zirconia

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INTRODUCTION

Whether implant-supported mandibular overdentures were made of conventionally heat cured or CAD/CAM milled acrylic resin, fracture of the denture bases was encountered, specifically near the abutment housings. [1] A claim has been made that at least 2 mm thickness of acrylic resin should exist at these fracture sites to provide resistance against fracture, [2] however, the use of a metal framework to reinforce the denture bases was found more efficient in two-implant assisted overdentures to counteract the effect of the cantilever distal to the abutments. [3-5]

Zirconia was recently suggested to replace metals in dental prostheses, and improve the mechanical properties of complete denture bases, [6,7] where its addition in nano particles form improved the transverse strength of the heat polymerized denture bases, [8, 9] however, still the addition of cobalt chromium meshes or stainless-steel wires produced better fracture resistance. [10]

The combination of nano-zirconia, titanium dioxide and other several organic and inorganic fillers was shown to increase the impact and flexural strength as compared to non-reinforced acrylic resins. [11-17] Such improvements in material science offered better strength and esthetics of denture base materials, [18,19] however, there was a possibility of particle agglomeration as the nano-particle concentrations increased; this paved the way for the use of unidirectional E-glass fibers which were found to provide better mechanical properties to denture bases than zirconium and titanium oxide particles,[20,21] but was still inferior to cobalt chromium mesh reinforced denture bases. [22]

Several other improvements of the denture base mechanical properties exist, such as the use of Metrocryl HI high-impact resins that, when combined with zirconia particles, increased the transverse strength by 76%,[23] or the addition of elastomers that improved the acrylic resin impact strength with minimal effect on Youngs modulus.[25-30] However, in spite of all such improvements, complete denture bases suffered localized fractures and cracking under fatigue cyclic loading whether with zirconia impregnated polymethyl methacrylate (PMMA), [31] or when made out of high-impact (HI) heat-polymerized PMMA resin. [32]

Based on the previously presented data, it seemed that the mechanical enforcement of the denture base with metal substructure provided the best results,[33-37] However, further studies were still needed to study the behavior of metal free reinforcements of the denture base,[38,39] specifically under cyclic loading.[40-43] This work aimed at testing the mechanical behavior of non-metallic enforcement of an implant-assisted mandibular overdenture denture base with a zirconium meshwork and compared its behavior to that of cobalt chromium meshwork under fatigue cyclic loading and fracture resistance.

MATERIALS AND METHODS

Thirty identical study models were used in this work, which were duplicates of a completely edentulous patient master model, in which 2 laboratory implant analogues were secured in the position of the teeth 33 and 43, the models were poured in type III extra hard dental stones (Model Hard Stone, ENRST HIRNICHS Dental GmbH, Germany). Tow ball abutments (Zimmer, Inc, TSV, Carlsbad, Calif, USA) were secured to the implant analogues with their metal housings seated in place as seen in figure 1.

For group I, relief wax was adapted to 10 of the study models, and tissue stops spaces were created in the posterior areas of the edentulous arches. These modified study models were duplicated to provide the refractory casts on which the cobalt chromium (TALLADIUM Vi-Tal, Batch # 060413, Talladium, Inc. CA, USA) meshwork wax patterns were fabricated, sprued, invested, cast, and finished. The metal meshworks were then seated on the study models to ensure passive fit over the metal hosing of the implants ball abutments, and were bonded to the metal housings with acrylic resin. The mandibular complete overdentures were fabricated to the wax stage, and flasked on duplicates of the study model to which the metal meshworks were secured to produce 10 overdentures of group I as seen in figure 2.

For group II, 10 study models were modified as for group I with relief wax, with the metal housings of the implants ball abutments secured in place, then these models were scanned using the bench top scanner (Kavo ARCTICA AutoScan) to produce a virtual model on which the zirconium meshworks were designed to be 0.5 mm in thickness, milled using Cercon disk, (Dentsply, Sirona, Germany) seen in figure 3, with the Sirona CAD/CAM, and sintered. For group III, ten zirconium meshworks were produced exactly as for group II, however, their thickness was set to be 1 mm. The zirconia meshworks of groups II and III were then seated on the study models to ensure passive fit over the metal housings of the abutments, and similar to the procedures in group I, 10 overdentures were produced as seen in figure 4. The acrylic resin used in making the overdentures in the three groups of this study was the conventionally heat cured acrylic resin (Vertex SR, Vertex Dental, Zeist, Netherland) with conventional compression molding using slow heat curing cycle at 74 C for 9 hours.

The overdentures in each group were subjected to cyclic fatigue loading using a T-shaped bar applied to the second molar area while the dentures were fixed in place anteriorly at three points namely: the midline, and at each metal housing of the abutments, on an acrylic duplicate of the study model that was relieved starting from the area distal to the ball abutments and covered with a soft silicone layer to mimic the cushioning effect of the mucosa overlying the edentulous ridge. The fatigue loading was conducted using a chewing simulator (CS-4.8, SD Mechatronik, Feldkirchen-Westerham, Germany) at 80 N at 1 Hz for 300,000 cycles. Then, as seen in figure 5, the soft silicone was removed from the acrylic cast and fracture loading of each group was conducted using a universal testing machine (Lloyd LRX, Lloyd Instruments) applying a stainless-steel ball 1 cm in diameter to the free end of each denture bilaterally at a cross head speed of 1 mm/min until fracture occurred. Finally, the statistical analysis of the fracture values was statistically analyzed using the one-way ANOVA (SPSS version 20 for windows) at a significance level of $p<.05$.

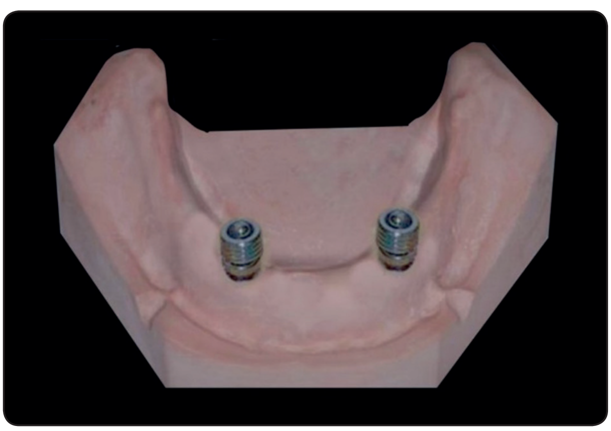

Fig. (1): The study model with the ball abutments and metal housings.

Fig. (2): Group I chrome-cobalt reinforced overdenture

Fig. (3): The zirconium CAD/CAM disk.

Fig. (4): Group II zirconium reinforced overdenture

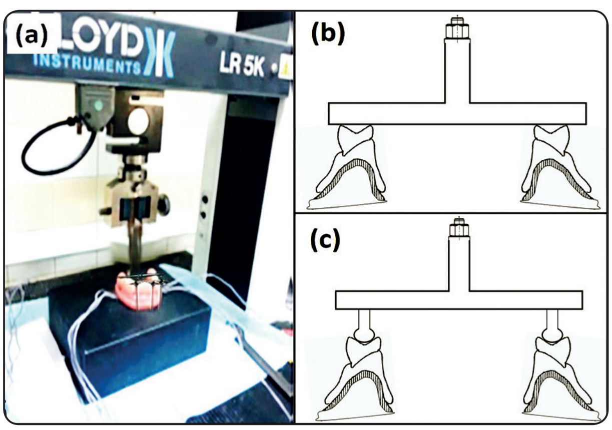

Fig. (5): The mechanical testing: (a) the universal testing machine, (b) schematic illustration of the T-bar used for cyclic fatigue testing, (c) schematic illustration of the stainless-steel ball used for fracture testing.

RESULTS

Considering the fracture modes, the samples of group I did not show complete fracture, their failure was in the form of cracks in the denture base starting from the location of the metal housing of the ball abutments to the location of the loading stainless steels balls with only bending of the Co-Cr meshwork located within the denture bases, the samples of group II showed complete fracture in its 10 samples immediately distal to the housing of the ball abutments with the zirconia meshworks fractured at such locations, on the other hand, only 6 samples of group III showed complete fracture at locations distal to the fracture locations reported in group II. Comparison of the fracture strength between groups revealed a significant difference between groups I and II, groups I and III, and groups II and III where the fracture load was significantly greatest for group I, followed by group III, and finally group II as seen in figure 6 and tables 1 and 2.

TABLE (1): Fracture strength (N) for each group

Group	Fracture strength (N)
Group I	4756.4 ± 564
Group II	2078.3 ± 289.6
Group III	3296 ± 320.2

TABLE (2): Comparison of fracture strength between groups

Group I versus group II	*P* = 0.01
Group I versus group III	*P* = 0.02
Group II versus group III	*P* = 0.04

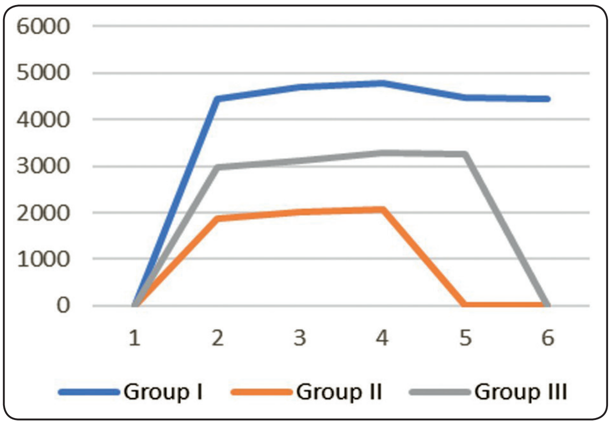

Fig. (6): Fracture loading (N/min) of the studied reinforced denture bases.

DISCUSSION

According to Radi and Abdel-Hamid[29] heat cured acrylic resin provided denture base material that can easily be repaired and relined as compared to other available metal or ceramic materials, Aguirre et al[27] further added that when these bases were made out of CAD/CAM milled pre-polymerized disks; their resistance to fatigue was increased, however, when acrylic resin overdentures were considered, Aly[1] found that there was no significant difference between conventionally cured and CAD/CAM dentures specially near the abutment housings locations. Increasing the denture base resistance to fracture was advocated by Tokgoz et al[2] who suggested increasing the denture thickness to a minimum of 2 mm, or by Zidan et al[31] and Rodrigues[32] who used zirconia nanoparticles, however, these bases still suffered cracking and fractures. On the other hand, the work of Alrashed[3] suggested a maneuver similar to that used in the current work in which a metal framework was used to reinforce the denture base, and make it resistant to the stresses of the cantilever distal to the abutments of the 2 implant assisted overdentures as proved by Farrag et al,[4] and El-Zawahry et al[5] who favored the use of 2 implants in the canine region to support mandibular overdentures.

The current study suggested the use of zirconia meshwork to reinforce the acrylic denture base, this hypothesis was in agreement with Takano and Sakurai[7] who stated that zirconia had advantageous properties to be used in denture bases, and Kumar et al[6] who claimed that CAD/CAM manufacturing of zirconia reduced its cyclic fatigue failure, however, and in agreement with the results of this study, Bashi and Al-Nema[9] found that the Co-Cr meshworks provided the best reinforcement of denture bases when compared to any other material as also proven by the work of Resin[10] on the metal reinforcement of denture bases.

The experimental design of this study was also in agreement with Özçelik et al[33] who tackled the same problem, and Im et al[22] who used a similar fatigue cyclic loading of 300,000 cycles, and fracture testing, and concluded similar result to that of this study where Co-Cr meshwork reinforcement was significantly better than other forms of reinforcement. Also, similar to the framework design in this study, Poštić[34] suggested the incorporation of the abutment metal housings in the reinforcement framework to prevent fracture of the denture bases in such areas.

The meshwork reinforcement of the denture bases used in this study did not exceed 1 mm in thickness in order not to increase the overall thickness of the denture base that might encroach upon the inter arch space, and though it might seem more suitable for resorbed ridges, Grageda and Rieck[35] recommended such reinforcement even with well-developed edentulous ridges. Cruz et al[36] also suggested the same reinforcement, however, in contrast to this study, they recommended a single implant overdenture with locator attachment.

The results of this study showed that the 1 mm thick Co-Cr meshworks were able to resist fatigue cyclic loading and fracture as compared to the 0.5- and 1-mm thick zirconia frameworks, this finding came in agreement with Zhang et al[40] who studied the fatigue behavior of zirconia and showed that zirconia exhibited more fracture after cyclic loading leading to the recommendation to its use in the anterior rather than the posterior areas of the dental arch, however, it is worth mentioning that Zhang et al[40] used 5 million fatigue cycles similar to 20 years of clinical service. However, in a similar study on the fatigue of zirconia under cyclic loading, Studart et al[41] found that crack propagation in zirconia frameworks was significantly subcritical, and once the initial mechanical properties of the zirconia frameworks were sufficiently high, then their lifetime was good enough for a minimum of 20 years in clinical service.

In conclusion, and considering the digital transformation of the production of complete dentures, this study recommended the use of the 1 mm thick zirconia frame work to reinforce the implant overdenture bases, and although it is possible to manufacture Co-Cr frameworks digitally as advocated by Piao et al,[37] the zirconia meshworks can similarly be digitally fabricated as conducted in the current study, and as advocated by Cho[38] to provide a metal free reinforcement, that might not be as strong, but of strength close to the metal reinforcement, with potentially long lifetime in clinical service.

Finally, considering the limitations if this study, it was noticed that this study used conventional, non-reinforced acrylic resin, cured with conventional method, and metal frameworks of only one design, and tested only two thicknesses of the zirconia meshworks.

CONCLUSIONS

Taking the limitations of this study in consideration, the followings were concluded:

1- The Co-Cr meshworks provided the strongest reinforcement of the implant assisted overdenture bases as compared to zirconia frameworks.

2- The 1 mm thickness zirconia meshwork was more resistant to fracture than the 0.5 mm zirconia framework, but weaker than the Co-Cr framework, however, its recorded resistance to fatigue cyclic loading and fracture was thought to provide an acceptable clinical service lifetime.

RECOMMENDATIONS

1- Further clinical investigation of the studied zirconia frameworks is required.

2- Further research is required to examine the potential of incorporating the CAD/CAM production of the zirconia frameworks into the full digital workflow of complete dentures.

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