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Original article

Effect of Denture Base Material on The Stresses Induced on Implant Supporting Mandibular Bar - retained Over-denture

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Abstract
The aim of this study was to evaluate and compare the effect of heat cured acrylic resin denture base and glass fiber reinforced denture base on stresses induced on mandibular implant overdenture supporting structures by bar attachment using strain gauge analysis. Mandibular overdenture supported by a rigid interconnecting bar retained attachment connecting the two implants was constructed. According to the denture base material, mandibular overdentures were classified into Group I: Mandibular implant- supported overdenture was constructed using heat cured acrylic resin. Group II: Mandibular implant- supported overdenture was constructed using fiber reinforced acrylic resin**.** Two strain gauges were installed at the distal aspects of the implant to record the strain induced by anterior, unilateral and bilateral posterior loading of each overdenture using universal testing machine. Data was collected, tabulated and statistically analyzed. The result of this study showed that the highest stresses on the implant were recorded for the conventional heat cured acrylic denture base, and the difference was found to be statistically significant $P<0.05$ for both anterior and unilateral load. Within the limitation of this in vitro study, the use of fiber reinforced acrylic resin denture base material for implant supported overdenture leads to better stress distribution to the implant supporting bar attachment.
Keywords. Denture Base Material, Stresses, Mandibular, Denture.

Introduction

Edentulism, the condition of complete tooth loss, poses significant challenges to oral function and quality of life for affected individuals. Numerous studies have shown that the mandibular two-implant overdenture is a simple and effective solution and leads to significant improvement of patient-based outcomes as compared to conventional dentures Implant-supported overdentures showed improvement in stability, retention, and chewing efficiency compared to conventional complete dentures [1-3]. The use of a wide variety of attachment systems, including stud, magnet and bar attachments have proven both clinically predictable and effective results. The design of attachments should provide equal implant-tissue support and optimum force distribution around the implants to allow bone loading within physiologic levels [4,5].
Splinting implant togather with bar can reduce the risk of overload on each implant by offering several biomechanical benefits, the increased surface area provided by the bar allows for better distribution of forces, while connection between implants ensure load sharing and preventing excessive stress on any single implant. The design also improves the overall distribution of biomechanical forces, minimizing the risk of localized stress and enhancing the stability and longevity of the implant overdenture. [6-8]. The bar ability to minimize the potential for micromotion at the bone-implant interface may help successful osseointegration of immediately loaded implants dentures [9,10].
Bar attachment are classified according to their biomechanical behavior into rigid and resilient attachments. In comparison to resilient bar attachment, rigid anchoring of removable prosthesis creates stable occlusal plane, reduces loading of denture-bearing areas, and minimizes posterior mandibular ridge resorption. One of the major drawbacks of rigid bar attachment is over loading of the abutments, however resilient bar attachment encourages torsion-free load transmission to implants dentures [11,12]. Long-term success of implant-supported overdentures relies on minimizing stress-induced complications, such as implant failure, bone resorption, and prosthesis fracture [4]. The denture base material plays a critical role in distributing occlusal forces and reducing stress transmission to the underlying implants and surrounding bone. Various denture base materials, including acrylic resin, cobalt-chromium alloy, and polyetheretherketone (PEEK), are commonly used in implant-supported prosthodontics [5]. Although PMMA based resins are not ideal in every respect, the combination of properties such as working characteristics, minimum expense, excellent esthetics, accuracy of fit, stability in the oral environment, and ease of processing account for their popularity and universal use [6].
Several approaches were attempted to strengthen the acrylic base using different methods and materials. The aim was to improve the impact strength, fatigue resistance and transverse strength of the acrylic resin [7]. In aim to provide superior mechanical properties fiber-reinforced plastics as fiber composites are introduced. Fiber composites for reinforcement of removable acrylic resin dentures have been used since the 1960 [8].

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An ultimate goal during an implant over denture construction would be to optimize stress distribution and minimize both the forces transmitted to the implants as well as peri-implant bone loss [9-11]. Stresses transmitted to the implants are multi-factorial with numerous etiologies currently debated in the dental literature, among these factors is the denture base material [12].
Heat cured acrylic resin has been the most commonly used denture base material for more than 60 years. However, its mechanical properties can limit durability [13-15]. One frequent problem that occurs with heat cured acrylic resin in over denture prosthesis is fracture. Eventual fracture of acrylic resin denture base occurs due to initiation and propagation of cracks from areas of high stress concentration over the abutments. At a critical point probably coincident with a particular heavy bite, the crack propagates through the denture base [16].
Many experimental stress analysis methods have been employed to evaluate biomechanical loads. These techniques compromise photo-elastic stress analysis, strain gauge analysis, holographic interferometry and finite element stress analysis [17-20]. Understanding the biomechanical behavior of denture base materials and their impact on stress distribution is vital for optimizing the design and clinical outcomes of implant-supported mandibular overdentures. Accordingly, the aim of this stress analysis study was to evaluate the effect of different denture base material on the stresses induced on mandibular implant overdenture supporting structures by bar attachment using strain gauge analysis.

Methods

This In-vitro study was conducted on duplicated modified educational mandibular model. Mandibular overdenture supported by a rigid interconnecting bar retained attachment connecting the two implants was constructed.
According to the denture base material, mandibular overdentures were classified into: Group I; Mandibular implant- supported overdenture was constructed using heat cured acrylic resin. Group II; Mandibular implant- supported overdenture was constructed using fiber reinforced acrylic resin. An impression of an educational mandibular edentulous stone model was made using medium body rubber base impression material. Molten base plate wax was poured into the rubber impression using a mechanical vibrator. The cast in wax was processed into pink heat cured acrylic model through flasking, wax elimination, packing and curing before finishing and polishing of the model.
Two educational mandibular stone models were used to construct two identical complete dentures. On each stone model, one sheet of shellac base plate was adapted. Acrylic teeth were used for setting up of teeth, according to the anatomical and mechanical considerations (where incisal edges of anterior teeth and central fossa of posterior teeth were arranged on the crest of the ridge). The occlusal plane was set from the tip of the canine to the level of the two thirds of the retromolar pad. The waxed-up denture was then flasked and wax elimination was carried out.

Construction of the heat cured implant- supported overdenture

For denture I, heat cured acrylic resin was packed into the flask and heated at 78C° for eight hours following the long curing cycle.

Construction of the fiber reinforced implant- supported overdenture

For denture II, fiber silanation procedure was performed, the glass fibers were treated by preparing a 95% ethanol solution and adjusting the PH value to 5 with acetic acid. Silane was added by stirring to yield a final concentration of 2%. The solution was kept for 5 min for hydrolysis and silanol formation. Fiber particles were silanated by stirring them in the solution for 2 min and then decaoting the solution into filter paper, the particles were rinsed twice with ethanol and the silane layer was cured for 10 min at 110 C°.
The dried silanated fibers were added to the monomer first and was calculated at 5% weight of the monomer polymer mix making a ratio of 1:2.5 monomer polymer mixes by weight. The mix was packed into the flask at the dough stage and cured using the long curing cycle.

Implant insertion and bar construction

To determine the planned implant sites on the acrylic model the areas below the canines were marked by an indelible pencil, and extended to the crest of the mandibular edentulous model. Drilling was made in the canine regions, two implants 4.0 mm in diameter and 12 mm in length were inserted bilaterally and fixed on position using self-cure acrylic resin. A straight plastic bar connecting the two plastic castable bar abutments (10 mm in height) that were placed and screwed to the implants. The plastic bar was placed with its rounded surface facing the ridge, and its flat surface facing occlusally. Spruing, investing, burn out and casting using chrome cobalt alloy were performed for the bar and the two abutments. Casted bar abutments connected with bar were screwed to the implants Fig (1). Auto-polymerizing acrylic resin was used for picking up one bar clip Fig (2). After creating and one vent hole and space in the fitting surface of the denture. Firm steady pressure was applied on the overdenture bilaterally till complete curing of the resin.

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Fig 1. Two implants connected by bar.

Fig 2. Clip embedded in fitting surface of dentures .

Installation of the strain gauges

Two channel strain meters installed at the distal wall of the implants was used to assess the strains induced to the implants. The strain gauges used in this study were supplied with fully encapsulated grid and attached wires. The gauge length was 2 mm, the gauge resistance was 120.4 ohm and the gauge factor was 2.09%. At the distal aspect of the implant where the strain gauges were to be installed, the axial wall below the crest of the ridge was reduced in flat plane parallel to the long axis of the implant. The wires of the strain gauges were impeded in the created groove in the model and fixed in position using bonding agent to measure the amount of deflection resulting from the abutment movement in the plane of motion.

All strain gauges were bonded in position in the acrylic model, with delicate Cyano-acrylate base adhesive for stresses measurement. The acrylic model with the heat cure and fiber reinforced implant supported mandibular overdentures were placed respectively on the lower metal plate of the universal testing machine (Instron 3367, Instron Co., Norwood, MA, USA).

The T-shaped load applicator bar of the testing machine was allowed to touch the denture teeth at the incisal edges of the anterior teeth and posteriorly unilateral and bilateral at the distal aspect of second premolar and central fosse of first molar. Simultaneous even contacts between the bar and the artificial teeth on both sides was achieved by spot grinding guided by using articulating paper markings. A loading device (universal-testing machine) was used to apply standardized static load.

The applied load starting from zero up to 60N. The microstrains of the four strain gauges were recorded to measure the strains developed at the buccal wall of the two implants. Once the load was completely applied, the micro strain readings were transferred to micro strain units from the two channels strain meter. Enough time was given to the strain gauges to reach zero balance and to allow complete rebound of the resilient structures before making the next reading.

Results measured with the two strain gauges were analyzed statistically with the SPSS software (ver. 20.0 for Windows; SPSS Inc., Chicago, IL, USA). Paired T-test was used to compare between two different denture base material, and student T-test was used to compare between two different denture base materials during anterior and posterior loading. A probability level of $P \leq 0.05$ was considered statistically significant.

Results

The micro strain was recorded on the implant that supports mandibular over denture, paired T-test was used to compare between two different denture base materials at anterior and posterior loading on both sides.

Comparison between recorded micro strains measured with anterior load application between groups

The mean microstrains recorded at the abutment was found to be between 393.3 to 453.5 for the conventional heat cured denture base, and 350.2 to 413 for the fiber reinforced denture base respectively

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as shown in table 1. The data obtained from this table showed that higher stresses on the implant was recorded for the conventional heat cured denture base with significant difference with P< 0.05.

Table 1. The micro strain induced on the implant for the heat cured and fiber reinforced heat cured acrylic over-denture base during anterior loading.

Side	Heat cured denture base		Fiber reinforced denture base		T- value	P –value
	Mean	SD	Mean	SD		
Left abutment	453.5	26.7	413	11.22	32.1	<0.05
Right abutment	393.3	13.82	350.2	22.9		

Comparison between recorded micro strains measured with posterior load application between groups

Unilateral load

The mean microstrains recorded at the loaded side was found to be 478.5 for the conventional heat cured denture base, and 459 for the fiber reinforced denture base respectively as shown in table 2. The data obtained from this table showed that higher stresses on the implant was recorded for the conventional heat cured denture base, and the difference was found to be statistically significant P<0.05.

The mean microstrain recorded at the unloaded implant was found to be 263.1 and 244.5 for the conventional heat cured denture base, fiber reinforced denture base respectively as shown in table 2 and Fig (4). Statistical analysis of the data revealed insignificant difference between the two studied denture bases P>0.05.

Table 2. The micro strain induced on the implant for the heat cured and fiber reinforced heat cured acrylic over-denture base during unilateral loading.

Side	Heat cured denture base		Fiber reinforced denture base		T- value	P- value
	Mean	SD	Mean	SD		
Left abutment	478.5	44.84	459	4.78	6.9	<0.05
Right abutment	263.1	8.2	244.5	6.65	2.7	>0.05

Bilateral load

The mean microstrains recorded at the left side was found to be 371.7 for the conventional heat cured denture base, and 367 for the fiber reinforced denture base respectively as shown in table 3. Although the data obtained from this table showed that higher stresses on the implant was recorded for the conventional heat cured denture base, the difference was found to be statistically insignificant P>0.05.

The mean microstrain recorded at the right implant was found to be 403 and 373 for the conventional heat cured denture base, fiber reinforced denture base respectively as shown in table 3. Statistical analysis of the data revealed insignificant difference between the two studied denture bases P>0.05.

Table 3. The micro strain induced on the implant for the heat cured and fiber reinforced denture base during bilateral loading.

Side	Heat cured denture base		Fiber reinforced denture base		T- value	P- value
	Mean	SD	Mean	SD		
Left abutment	371.7	19.93	367	18.22	3.23	>0.05
Right abutment	403	17.04	373	5.55	1.2	>0.05

Discussion

Numerous studies have shown that the mandibular two-implant overdenture is a simple and effective solution that leads to significant improvement of patient-based outcomes as compared to conventional dentures [9, 17-19]. Several options have been used for implant retained and supported overdenture attachment, among these is the bar attachment. Bar connection which offers a considerable amount of abutment splinting and horizontal stability and retention [9,10].

This In-vitro study was conducted to evaluate and compare the stresses induced on the implant supporting structures using fiber reinforced and conventional heat cured acrylic denture base materials. Stresses

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induced on the implant by heat cured acrylic resin and fiber reinforced acrylic resin were evaluate using strain gauge technology.
The results obtained from this study showed that in anterior loading and unilateral posterior loading situations, fiber reinforced acrylic resin implant supported overdenture base caused favorable load distribution to implant supporting structures. This result was supported by previous studies, which showed that Reinforcement the denture base with the fiber is an effective method to increase the impact strength of PMMA denture base resin. The surface treatment of fibers further increases the impact strength significantly [20,21]. Moreover, other study showed that, fiber reinforced acrylic resin undergo a chemical change and they are usually cross linked in this state which leads to dimensional stability with better flexural and impact properties that decrease the transferred forces to the underlying structures compared with traditional denture base material which have poor strength characteristics including low flexural strength [22].
These findings highlight the influence of denture base material on stress distribution around the implant that support the over denture. The conventional acrylic denture base material resulted in higher stress concentrations on the loaded implant, which may have implications for implant longevity and potential complications such as bone resorption.
The insignificant difference between the microstrains that were recorded between the conventional heat cured and fiber reinforced acrylic denture base at the posterior bilateral load, may be attributed to the resiliency of acrylic resin that most probably dampens the applied load, from a theoretical stand point, resiliency of the acrylic resin most probably absorbs energy during loading and reduces the transmission of the functional stresses to the implant and the residual ridge (18,23-25). Moreover, studies have showed that fiber reinforcement resulted in considerably higher flexural and flexural modulus, which leads to reduction on the stress transmission [26,27].
This result supported by previous study which conclude that, the use of a denture base reinforcement can enhance their flexural properties and reduce the overdenture base deformation subsequently strains on the underlying supporting structures of overdenture prostheses including dental implants and the residual ridge can be decreased [28]. Conversely, bilateral loading most probably allows occlusal stability and broad loading distribution that preserve the overdenture supporting structures that supported with previous study which found that the bilateral load in general favors a more uniform stress distribution in both attachments compared to a much greater stress registered with unilateral load in the load side attachments (29).

Conclusion

The use of fiber reinforced acrylic resin denture base leads to better stress distribution to the implant, and the micro stains recorded showed that there was significant difference between the conventional heat cured and the fiber reinforced denture at both anterior and posterior unilateral loading.

Conflict of interest. Nil

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المستخلص

هدف هذه الدراسة هو تقييم ومقارنة تأثير قاعدة طقم الأسنان المصنوع من راتنج الأكريليك المعالج بالحرارة وقاعدة طقم الأسنان المقوى بألياف الزجاج على الإجهادات الناجمة عن هياكل دعم طقم الأسنان فوق الغرسة السفلية عن طريق تثبيت القضيب باستخدام تحليل مقياس الانفعال. تم تصنيع طقم الأسنان فوق الغرسة السفلية المدعوم بقضيب ربط صلب مثبت يربط بين الغرستين. وفقًا لمادة قاعدة طقم الأسنان، تم تصنيف أطقم الأسنان فوق الغرسة السفلية إلى المجموعة الأولى: تم تصنيع طقم الأسنان فوق الغرسة السفلي المدعوم بالغرسة السفلية باستخدام راتنج الأكريليك المعالج بالحرارة. المجموعة الثانية: تم تصنيع طقم الأسنان فوق الغرسة السفلي المدعوم بالغرسة السفلية باستخدام راتنج الأكريليك المقوى بالألياف. تم تركيب مقياسين للانفعال على الجوانب البعيدة للغرسة لتسجيل الإجهاد الناتج عن التحميل الأمامي والأحادي الجانب والثنائي الجانب الخلفي لكل طقم أسنان فوقي باستخدام آلة اختبار عالمية. تم جمع البيانات وجدولتها وتحليلها إحصائيًا. أظهرت نتائج هذه الدراسة أن أعلى الضغوط على الغرسة تم تسجيلها لقاعدة طقم الأسنان الأكريليكي التقليدية المعالجة بالحرارة، ووجد أن الفرق كان ذا دلالة إحصائية $P<0.05$ لكل من الحمل الأمامي والأحادي الجانب. ضمن حدود هذه الدراسة المختبرية، فإن استخدام مادة قاعدة طقم الأسنان الأكريليكي المقواة بالألياف لطقم الأسنان المدعوم بالغرسة يؤدي إلى توزيع أفضل للضغوط على مرفق قضيب دعم الغرسة.

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