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Original Article

Stress Distribution in Natural Tooth and Implant Supported Removable Partial Denture with Different Attachment Types: A Photoelastic Analysis

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Abstract

Background and Aim: Different attachment designs have been developed to connect implant to natural teeth in partial dentures; however, adequate studies have not been performed to determine stress distribution patterns in these designs. The present study aimed to assess stress distribution patterns in natural tooth and implant supported removable partial denture with different attachment designs using photoelastic analysis.

Materials and Methods: In this in vitro, experimental study**,** a photoelastic model of a partially edentulous mandible was fabricated and two Ankylosis implants were inserted at the site of first molar teeth bilaterally. Implants and teeth were connected by a partial denture and the acrylic base and implants were connected using ball and telescopic crown attachment types. Two crowns, one with resilient and the other one with rigid attachment were fabricated on the abutment teeth. Separate frameworks were designed and removable partial dentures were fabricated. Next, 100 N load was applied vertically to the area between implant and tooth. The pattern of stress distribution in implant in use of different implant-tooth attachment designs was studied by means of photoelastic method.

Results: The lowest stress concentration was noted in use of resilient attachment while rigid attachment showed the highest level of stress concentration.

Conclusion: Resilient attachment between implant and tooth created minimum stress concentration in implant; however, removable partial dentures were slightly instable in use of this attachment type. The decision to use different implant-tooth attachment types must be made based on clinical conditions.

Key Words: Denture, Partial, Removable, Dental Stress Analysis, Dental Implants

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Received: 25 July 2015
Accepted: 28 Feb 2016

Journal of Islamic Dental Association of IRAN (JIDAI) Winter 2016 ;28, (1)

Introduction

Patients may develop many problems when using free end partial dentures [1]. Absence of posterior tooth support and difference in elasticity of tooth and soft tissue result in development of destructive forces in supporting structures [2]. Impaired function, increased rate of caries and periodontal disease, unaesthetic appearance and inherent mobility of this type of denture are among common problems encountered in use of free-end dentures [3]. Several methods have been recommended to decrease these problems such as obtaining maximum coverage possible, functional impression making, regular periodic examinations and occlusal adjustment [2]. All these methods aim to control loads and direct them axially to minimize destruction [1]. Increasing use of dental implants resulted in advances in treatment planning

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for prosthetic rehabilitation of free-end cases and many of these patients can now receive fixed partial dentures [4]. However, removable partial dentures are still recommended for cases with anatomical or financial limitations for use of fixed partial dentures. It appears that use of dental implants combined with removable partial dentures enables the patients to benefit from both modalities. In implant-supported partial dentures, the destructive lever arm is minimized, bone is preserved, prosthetic retention increases and unaesthetic prosthetic components can be eliminated [2]. To increase the treatment success rate, mechanical loads on implants and the supporting bone must be minimized and load distribution must be uniform. Loads applied to implants and the supporting bone can be minimized by precise placement of implant with correct angulation. Also, biological reaction of bone to application of mechanical loads may affect the clinical service and longevity of dental implants [5]. Peri-implant bone loss due to change in level of stress applied to implants may compromise implant survival [4,5]. Since load is transferred to bone through prosthesis and implant, proper design and precise fabrication of prosthetic component and implant-supported denture play an important role in uniform stress distribution in peri-implant bone [6]. Thus, all attempts in such treatments must be made to achieve proper stress distribution pattern in dental implant and natural tooth abutments and to prevent adverse effects of improper stress distribution [7]. Considering all the above, this study aimed to determine the pattern of stress distribution in implant and natural tooth supported removable partial denture using photoelastic method.

Materials and Methods

In this in vitro, experimental study, a photoelastic model of a free-end partially edentulous mandible (second premolars and molars were missing) was used (Nissin, Tokyo, Japan). A duplicate was made using silicon and poured with type IV dental stone (Fuji Rock, GC, Alsip, USA) and placed in pressure chamber (Krupp, Auschwitz, Poland) for 40 minutes for complete setting.

The obtained gypsum model was inspected under adequate lighting at x2 magnification to ensure absence of voids or inaccuracies. If the model was not accurate, the respective step was repeated. An index was obtained of abutment teeth using addition silicon impression material and the teeth received chamfer preparation using round-end, taper diamond bur (D & Z, Quezon City, Philippines) according to the silicon impression to standardize the preparation at both sides (although thickness of crowns was not among the confounding factors affecting the results). The accuracy of preparation was ensured by inspection under adequate lighting at x2 magnification. The model was duplicated using silicon (Elite Zhermack, Badia Polesine, Italy) and the mold was poured with two different consistencies of photoelastic resin such that 5 mm was poured by hard-set resin (Pl1 2152 Hardner:1 Ghafory Co., Tehran, Iran) and the rest was poured with medium-set resin (Pl1 2152 Hardner: 2; Ghafory Co., Tehran, Iran) to simulate the difference between crestal bone density and that of other parts of bone (Figure 1).

Figure 1. Photoelastic model of mandible

The obtained photoelastic model was evaluated under adequate lighting at x2 magnification and compared with gypsum model. An impression was made of the model using stock tray and irreversible hydrocolloid impression material and the teeth were mounted on the impression (Elite HD; Zhermack, BadiaPolesine, Italy). Then a surgical guide was fabricated using resin. The casts were marked at 12 mm distance from the center of prepared tooth at each side and surgical guide was used with a surveyor to determine the accuracy of distances. These points were drilled at both sides (Figure 2). Two Ankylosis implants (Friadent GmbH, Molndal, Sweden) measuring 4.5 mm in

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Figure 2. Surgical stent prepared for standardized placement of dental implants in edentulous areas

diameter and 11 mm in length were chosen to be placed at the site of first molars (at 12 mm distance from the prepared tooth). Ankylosis system comes with prefabricated telescopic crowns (Friadent GmbH, Molndal, Sweden); thus, this system was used to decrease human and laboratory errors. Also, two implants with the afore-mentioned dimensions were placed bilaterally since in the posterior mandible, bone width is often adequate but bone height is often inadequate due to bone loss and presence of inferior alveolar canal. Implants were placed at 12 mm distance from the center of prepared teeth using a surgical guide and surveyor after drilling (Figure 3).

Figure 3. Photoelastic model of mandible with implants placed in edentulous areas

After placement of implants, an impression was made of photoelastic model using stock tray and putty wash (Elite HD; Zhermack, Badia Polesine, Italy) to fabricate full-metal crowns on prepared teeth. Gold alloy (ESTETI Core Degosa; Co., Rhine Main, Germany) was used for fabrication of full-metal restorations. The full-metal crown in non-rigid (no attachment) type had a lingual ledge (Figure 4). In designing full-metal crowns with attachments, a rigid extra-coronal attachment was used. The attachment pattern was connected to the wax pattern using a surveyor according to the edentulous ridge and cast. After preparation of crowns and their placement on photoelastic pattern, their fit was assessed using Fit Checker (GC, Alsip, USA) (Figure 4).

Figure 4. Prepared crowns with attachment on tooth abutments

To fabricate partial framework, photoelastic model was used directly such that a duplicate was obtained of resin model using agar, and metal framework was fabricated on the cast. A lingual bar as main connector was used for the fabrication of framework (Figure 5), After preparation of framework and ensuring its proper seating on the pattern, crowns of second premolar and first and second molars were mounted according to standard guidelines. After assessment of mounting of teeth, slow heating protocol was applied. Resilient ball attachment (Friadent, Germany) and rigid telescopic crown attachment (Friadent, Molndal, Sweden) were used to connect prosthesis and implant. (Figure 6) Auto-polymerizing resin (GC Reline, Alsip, USA) was used to connect attachments to partial denture chairside. Crowns were cemented using zinc phosphate cement (Figure 7). Implant attachments were placed directly on implant in denture base and rigid-rigid and resilient-resilient designs were prepared. After implant placement, primary stress distribution pattern was determined using photoelastic imaging by applying 100 N/cm load vertically to the area between implant and tooth using photoelastic method (Figure 8).

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Figure 5. Wax pattern and framework prepared on edentulous mandible

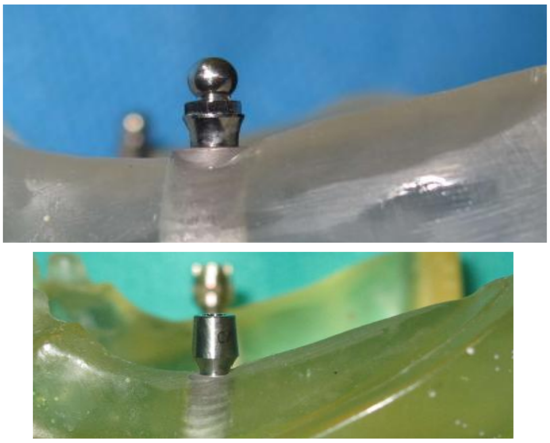

Figure 6. Resilient ball attachment (upper) and rigid telescopic attachment (lower)

Figure 7. Partial denture fabricated on the model for photoelastic analysis

Figure 8. Photoelastic analysis

Results

In vertical application of 100 N load in rigid-rigid attachment type, maximum stress concentration in implant was noted in apical and mesial areas. Also, immediate stress localization was noted in mesio-apical and mesio-cervical areas. Superficial stress distribution was noted in areas close to the two attachments, and its concentration was minimal. In vertical application of 100 N load in resilient-resilient attachment type, stress concentration around implant increased towards the apical in all areas. Stress was higher in mesial than distal and immediate concentration of stress was noted in crestal area. Immediate stress concentration was noted in one small area and had no spectrum.

Discussion

Considering the high success rate of dental implants reported in many studies, their use combined with a partial denture in free end cases especially in the mandible can be a suitable treatment option because the pressure applied to tooth abutments can be decreased as such; however, implant-abutment tooth attachment type is a matter of discussion [8]. Based on our results, stress accumulation during application of vertical loads in resilient attachments was lower compared to that in rigid attachments. Higher stress accumulation in rigid attachments can cause higher bone loss and increase the frequency of prosthetic complications such as fatigue fracture and screw loosening compared to resilient attachments. Clinically, use of non-rigid attachments may cause dental intrusion. Intrusion of tooth abutment

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decreases support and increases cantilever stresses in implants and the supporting bone. On the other hand, these conditions may occur due to the application of hydraulic loads [9]. However, in attachment of natural teeth and implant by a removable partial denture, intrusion of natural teeth does not seem to be problematic because permanent attachment of prosthesis to tooth and implant must be present in order for frequent elastic recovery between tooth and implant and hydraulic effect of dental prosthesis to causeintrusion of natural teeth. In removable partial dentures, permanent attachment of natural tooth and implant does not exist [10]. Aside from better stress distribution patterns in non-rigid attachments, they have advantages such as enabling retrieval of prosthetic components and their replacement and repair especially when one of the abutments has higher mobility than the other [11]. Although slight stress concentration has been noted in non-rigid attachments, the difference in stress concentration pattern between rigid and non-rigid attachments was significant and thus, rigid attachments may also be used in some treatment plans. Olsson et al, in 1995 reported 91% five-year success rate for these attachments in fixed restorations with two-piece abutments [12].

Despite optimal biomechanical results, making a decision regarding the use of rigid attachments between tooth and implant must be made based on clinical conditions and the need for independent support between implant and tooth. Independent support criteria include use of teeth with favorable prognosis and minimal mobility, successfully osseointegrated implants and retrievability of dental and implant restorations [13].

Based on our results, in rigid-rigid attachments, no mobility was noted in removable partial denture while in resilient-resilient attachment, some degrees of mobility were noted or the removable partial denture was dislodged from the model. Inability of resilient attachment to maintain the tooth position can result in movement and subsequent occlusal instability. This attachment causes improper distribution of occlusal loads in implants [14]. It may be stated that use of non-rigid attachment is not beneficial if not harmful. Non-rigid attachment does not transfer load and results in stress accumulation in the attachment itself and its subsequent transfer to implant. In this situation, the natural tooth abutment has the smallest share in supporting the implant and a substantial cantilever is formed on implant. In this condition, risk of wear of prosthetic components and implant failure increases compared to other situations especially because implant does not have periodontal ligament and so there is no cushion effect [15]. The only factor that might possibly minimize this rotational movement is high quality impression making and maximum fit of denture on the tissue.

In rigid-rigid attachment, flexibility of prosthesis due to its plastic structure and relatively long length of framework may somehow compensate for the vertical movement of natural tooth; however, not much stress is accumulated during continuous application of lateral loads to removable partial dentures (as the result of wider extension of prosthesis and presence of flanges) and it appears that loads applied to implant in this state may be destructive [16]. Moreover, although rigid attachments were used in this state, the attachment was actually semi-rigid in natural teeth due to the function of periodontal ligament and thus, the same limitations of resilient-rigid attachments are partially applied to this situation [17].

In resilient-resilient attachment, stress distribution has the most favorable pattern and the denture can also receive support from the soft tissue. Thus, natural tooth and implant are not over-loaded. However, although in many studies including ours better stress distribution patterns have been reported in this attachment type [18], it has also been emphasized that splinting of tooth with implant clinically increases the risk of failure of both components and prognosis decreases compared to the use of each component alone [19].

Conclusion

Use of resilient-resilient attachment resulted in minimum stress concentration in implant; however, removable partial dentures have lower stability in use of this attachment type. Considering these findings, the decision regarding the use of different attachment types for implant-natural tooth connection must be made based on clinical conditions and the need for independent support between dental implant and natural tooth.

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