Investigation by the Photoelastic Stress Analysis of the Effect of Implant Inclination and Precision Connections Load Transfer in the Mandibular Implant-Retained Overdenture Designs

İmplant Destekli Mandibuler Overdenture Vakalarında İmplant Açısı ve Hassas Bağlantıların Kuvvet İletimine Etkisinin Fotoelastik Stres Analiziyle Değerlendirilmesi

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ABSTRACT Objective: The purpose of this photoelastic study was to evaluate the effect of implant inclination and attachments on load transfer, and to compare different attachment designs. **Material and Methods:** Two photoelastic models of edentulous mandible were fabricated having 2 cylindrical implants (Calcitek, 4x13 mm) embedded in the parasymphyseal area. In the first model the implants were placed parallel to each other and the midline, in the second model the implants were 17 degrees divergent from the midline. Four attachment systems were evaluated: single anchor attachment (ERA), bar-clip, bar with distally placed ball attachments, and bar with distally placed extracoronal rigid attachments (Easy slot). A vertical force of 30 lb was applied unilaterally to the central fossa of the right first molar. The resulting stresses of the models were observed and recorded photographically in the field of a circular polariscope. **Results:** The highest stresses were observed with bar with distally placed extracoronal rigid attachment (Easy slot) design, followed by bar-ball, bar and the single anchor attachment (ERA) respectively for the model with vertical orientated implants. For the model with inclined implants, although the bar with distally placed extracoronal rigid attachments (Easy slot) and bar-ball designs showed similar stress patterns, the highest stresses were observed with the bar with distally placed extracoronal rigid attachment (Easy slot) design. The lowest stress was observed with the single anchor attachment (ERA) design for both models. **Conclusion:** More equitable stress patterns were observed on the vertical orientated implants than inclined orientated implants. The single anchor attachment (ERA) transferred the lowest stresses and bar with distally placed extracoronal rigid attachment (Easy slot) system transferred the highest stresses to the implants on both models.

Key Words: Dental prosthesis, implant-supported; dental stress analysis; denture precision attachment

ÖZET Amaç: Bu fotoelastik çalışmanın amacı, implant eğimlerinin kuvvet iletimine etkisini değerlendirmek ve farklı hassas bağlantı sistemlerini karşılaştırmaktır. **Gereç ve Yöntemler:** Parasimfiz bölgeye yerleştirilmiş iki adet silindirik implant (Calcitek, 4x13 mm; Zimmer Dental Inc, Carlsbad, Calif), 2 dişsiz mandibula modeli fotoelastik model olarak elde edilmiştir. Birinci modelde implantlar birbirlerine ve orta hatta paralel, ikinci modelde ise orta hattan 17 derece açılı olacak şekilde yerleştirilmiştir. Dört hassas bağlantı sistemi değerlendirilmiştir: stud tipi (ERA), bar-klip, bar ve distale konulmuş ball tutucu, bar ve distale konulan kron dışı hassas tutucu (easy slot). Sağ birinci moların santral fossasından 30 lb vertikal yük uygulanmıştır. Oluşan stresler polariskopla incelenmiş ve kaydedilmiştir. **Bulgular:** İmplantların birbirine paralel olduğu modelde, en yüksek stres bar ve distaline yerleştirilmiş kron dışı rijit hassas bağlantı (Easy slot) gözlenmiş; sırasıyla bar-ball, bar ve stud ataçmanlarda stres izlemiştir. Açılı yerleştirilmiş implantlı modelde, bar ve distale yerleştirilmiş rijit ataçman ile bar-ball benzer stres şekilleri gösterse de, en yüksek stres bar-Easy slot tasarımda gözlenmiştir. Her iki modelde de en düşük stres dağılımı ERA ataçmanda görülmüştür. **Sonuç:** İmplantların birbirine paralel yerleştirildiği modelde diğer modele göre daha dengeli stres dağılımı gözlenmiştir. ERA ataçman en düşük, bar-Easy slot ataçman ise her iki modelde en yüksek stres dağılımını göstermiştir.

Anahtar Kelimeler: Diş protezi, implant destekli; diş stresi analizi; hassas tutuculu protez

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Treatment of the edentulous patient with implant-retained overdentures has been shown to provide predictable and successful results.[1] Three advantages of the overdenture concept are: a reduced number of necessary implants, an easier surgical procedure, and an easier restorative technique due to the use of prefabricated attachments.[2] Although Fitzpatrick has reported that there is no strong evidence for a single, universally superior treatment modality for the edentulous mandible, the overdenture retained by 2 implants has been advocated as the treatment of choice for the edentulous mandible which has been reported to improve the quality of life of patients regardless of the attachment system used.[3,4]

The high success rate of interforaminal implants used to support mandibular overdentures has been well documented.[5-7] It has been recommended that implants, especially when individual ball attachments are contemplated, be placed parallel to one another and to the path of insertion of the prosthesis, to prevent incomplete seating of the prosthesis and premature wear of the attachments and to provide axial loading of implants without producing a bending moment.[8-11] Retention is also maximized when the attachments are parallel.[12] However, the optimal placement of implants is also dependent on the anatomy and morphology of the bone, meaning that clinically these guidelines may not be fulfilled and the misalignment of implants may result.[13-15]

In general, implant-supported overdenture attachments can be classified as single anchors, magnets, bars and telescopic copings.[8,16] Determinants for attachment selection include type of prosthesis, the length of the bar, the number and inclination of implants, manual dexterity, expectations and financial status of the patients.[17]

The attachment systems connecting the implant and overdenture affect load transfer.[18] Numerous studies on implant stress distribution have been reported.[19-25] However, load transfer of implant-retained overdenture with inclined implants is limited in the overdenture literature.[26] The purpose of the study was to compare the load transfer characteristics of different mandibular overdenture designs on 2 photoelastic models which had vertically oriented and inclined implants.

MATERIAL AND METHODS

Two photoelastic models of an edentulous mandible were fabricated with a photoelastic resin (PL-2; Vishay Intertechnology, Malvern, PA). Two cylindrical implants (Calcitek; Zimmer Dental Inc, Carlsbad, Calif), 4 mm diameter and 13 mm long, were placed in the interforaminal region representing complete integration. The implants were placed in wax mandibular models, which were obtained from a mandible. Once the wax models were prepared, the implants were embedded into wax model with the aid of a parallelometer. In the first model the implants were parallel to each other and the midline, and in the second model the implants were 17 degrees divergent from the midline.[26] The crestal exit of the implants was on the top of the ridge crest. The interimplant distance between the implants was 22 mm.[27,28] Silicone impressions of the models with implants were prepared, wax was removed. Photoelastic resin was poured into the silicone moulds according to the manufacturer's recommendation. After setting procedure of the photoelastic resin, the stress-free condition was determined by the absence of significant stress fringes in a circular polariscope (Measurements Group, Instruments Division, Raleigh, NC) for both models.

Four retention mechanisms were evaluated for each model (Figure 1). The first design was a single anchor attachment (ERA; Sterngold Dental, Attleboro, Mass); the second design was round bar-clip (Bredent; Senden, Germany); the third design was bar with 2 distally placed ball attachments (Bredent) and an anterior clip (Bredent) and the final design was bar incorporating 2 distally placed extracoronal rigid attachments (Easy-Slot; Servo-dental, Hagen-Halden, Germany) and an anterior clip (Bredent). A 2-piece ERA angled abutment for divergent implants was used on the model with inclined implants.

Baseplate wax (Cavex Dental Base Plates; Cavex Holland B.V., Haarlem, Holland), approxi-

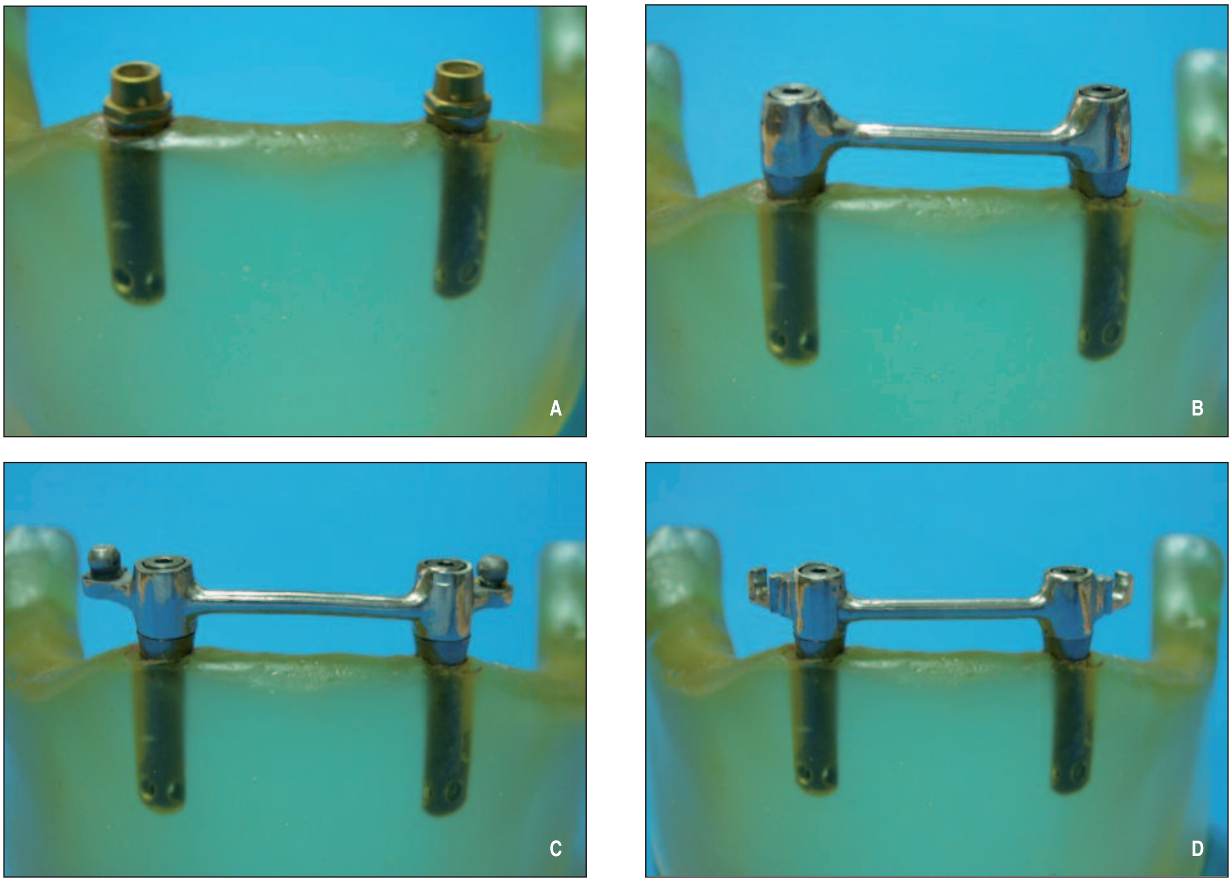

FIGURE 1: Attachments evaluated on photoelastic models. **A.** Single anchor attachment (ERA). **B.** Bar attachment. **C.** Bar with distally placed ball attachment. **D.** Bar with distally placed easy-slot attachment.
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mately 3 mm thick, was adapted to the posterior edentulous areas of both photoelastic models to represent the thickness of the soft tissue. This created a standard thickness for vinyl polysiloxane impression material (Oranwash L; Zhermack S.p.a., Badia Palestine, Italy) that would be added to the intaglio surface of the denture. Two definitive casts with implant carriers (Calcitek; Zimmer Dental Inc) were generated from each of the photoelastic models.[20]

For bar fabrication, shouldered abutments (Calcitek) and plastic castable copings (Calcitek) were placed on the implants. Plastic castable bar material (Bredent) was sectioned and fixed between plastic castable copings. For bar-ball and bar with distally placed extracoronal rigid attachment (Easy slot) designs, after bar was fixed, ball and easy slot attachments were placed on the distal side of the copings by using a surveyor (Paraskop M; BEGO, Bremen, Germany). These bar designs were cast with a base metal alloy (Biosil-F, Degudent GmbH, Hanau, Germany), sectioned and soldered to ensure a passive fit. Bar, bar-ball and bar with distally placed extracoronal rigid attachment (Easy slot) designs were attached to the abutments by tightening to 10 Ncm. Also, single anchor attachments (ERA) were placed on the implants and tightened to 20 Ncm.

A metal framework extending to distal sides of the bar with distally placed extracoronal rigid attachment (Easy slot) design was prepared and cast (Biosil-F) only on the bar-easy slot design, due to the mechanism of the attachment. The original metal piece of the attachment that was on the intaglio side of the denture was fixed to the metal framework with autopolymerizing acrylic resin

(Paladur; Heraeus Kulzer GmbH, Hanau, Germany).

One layer of baseplate wax (Cavex Dental Base Plates; Cavex Holland B.V.) was applied to stone cast. Artificial teeth (Major; Major Prodotti Dentari, Torino, Italy) were arranged on the metal framework of bar with distally placed extracoronal rigid attachment (Easy slot) design. The model with arranged teeth was placed into the lower part of the injection flask (SR-Ivocap; Ivoclar Vivadent, Schaan, Liechtenstein). Heavy body elastomeric impression material (Zetaplus; Zhermack S.p.a) was placed into the upper part of the injection flask (SR-Ivocap) to obtain a negative silicone mold. This silicone mold enabled duplication of the wax denture and fabrication of identical surfaces of the prostheses. After the waxed denture was removed from the cast, the cast was isolated with separator liquid (Al-cote separating agent; Dentsply, York, PA), and clear autopolymerizing acrylic resin (Futura Self; Schutz-Dental Group, Rosbach, Germany) was injected through the holes of injection flask (SR-Ivocap) into the space between the silicon mold and the definitive cast for each attachment designs.[29] Before the cast with attachments was placed into the flask (SR-Ivocap), plastic bar clips and plastic caps of ball attachments were placed on bar and ball attachments. Block-out was provided under the bar and for the undercuts. Totally, 8 dentures were fabricated. The use of clear acrylic resin (Futura Self) material was required to allow light transmission through the model for stress pattern observations.[22]

A light body elastomeric impression material (Oranwash L; Zhermack S.p.a) was applied to the intaglio surface of the extension base of the dentures. All dentures were sequentially placed on the models with the attachments engaged and examined photoelastically. All photoelastic models exhibited negligible initial stresses in the field of the polariscope before force application.[30]

Mineral oil (Castrol, Istanbul, Turkey) was applied on the models to facilitate photoelastic observation. Loads were applied with a loading device (Custom-made; Gazi University, Technical Education Faculty, Mechanical Education Department, Teknikokullar-Ankara, Turkey). A vertical force of 30 lb was applied unilaterally to the central fossa of the right first molar.[21]

The resulting stresses of the models were observed and recorded photographically (Canon Powershot G3; Tokyo, Japan) in the field of a circular polariscope (Measurements Group, Instruments Division). All photographs were evaluated visually for stress-induced fringes. The stress intensity and their locations were subjectively compared. In the evaluation of this stress data, the following terminology was adopted: “Low stress”-1 fringe or less, “moderate stress”-between 1 and 3 fringes, and “high stress”-more than 3 fringes.[19]

RESULTS

VERTICALLY PLACED IMPLANTS

For the single anchor attachment (ERA) retained overdenture design, moderate stress was observed on the apical and distal side of the ipsilateral implant. Little or no discernible stress was noted on the contralateral implant (Figure 2). For the bar-clip design, moderate stress was recorded through the long axis and apical of the ipsilateral implant. Also, moderate stress was observed on the mesial side of the contralateral implant, which shows that the load was transferred on both implants (Figure 3). For the bar-ball design, symmetric moderate stress on the

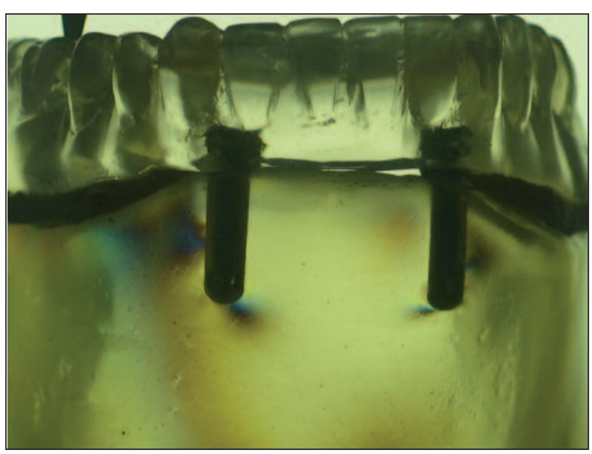

FIGURE 2: . Stresses produced by single anchor attachment (ERA) retained prosthesis on vertical oriented implants.
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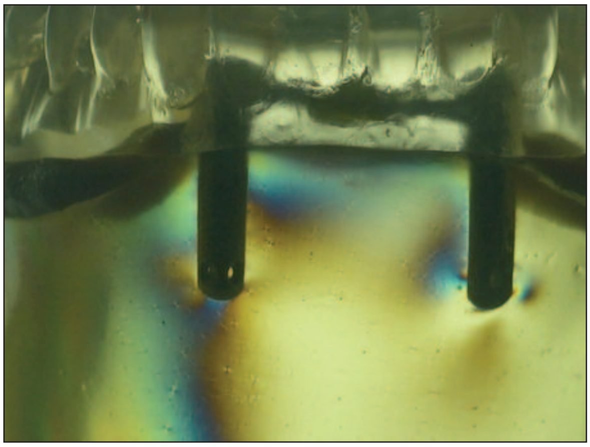

FIGURE 3: Stresses produced by bar-clip retained prosthesis on vertical oriented implants.
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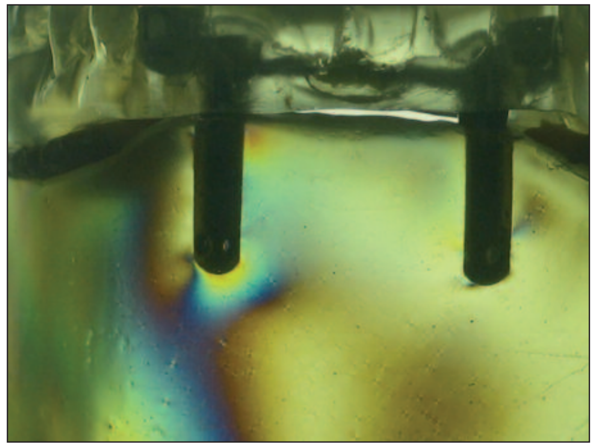

FIGURE 4: Stresses produced by bar-ball attachment retained prosthesis on vertical oriented implants.
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apical and low stress on the coronal region was observed on the ipsilateral implant. Little or no discernible stress was noted on the contralateral implant (Figure 4). For the bar with distally placed extracoronal rigid attachment (Easy slot) design, symmetric moderate stress on the apical and low stress on the coronal region of the ipsilateral implant was recorded. Moderate stress was observed on the mesial side of the contralateral implant (Figure 5).

For all designs, stress was concentrated on the ipsilateral implant. Although moderate stresses were observed, the resultant stress patterns were greater for the bar with distally placed extracoronal rigid attachment (Easy slot) design. No stress was transferred to the contralateral implant with single anchor attachment (ERA) and bar-ball attachment.

MODEL WITH INCLINED IMPLANTS

Moderate stress was observed on the apical region of the ipsilateral implant of the single anchor attachment (ERA) design. Little or no discernible stress was noted on the contralateral implant (Figure 6). For the bar-clip design, moderate stresses were recorded on the apical region of both implants. Also, a horizontal moderate level stress pattern was produced between the implants (Figure

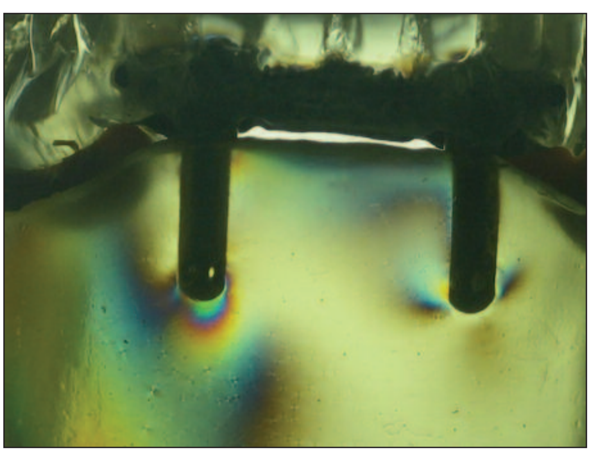

FIGURE 5: Stresses produced by bar with distally placed extracoronal rigid attachment (Easy slot) retained prosthesis on vertical oriented implants.
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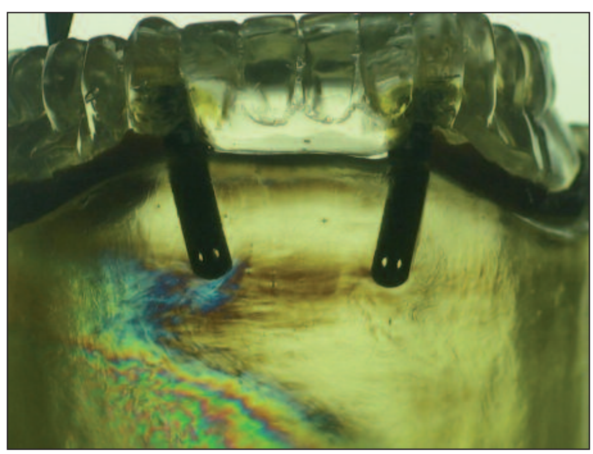

FIGURE 6: Stresses produced by single anchor attachment (ERA) retained prosthesis on inclined oriented implants.
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7). For the bar-ball design, moderate stress at the distal coronal side and low stress at the apical region of the ipsilateral implant were observed. Moderate stress was recorded at the apical region of the contralateral implant. A moderate level stress was observed which was started from the mesial coronal of the contralateral implant and extended through the interimplant area (Figure 8). For the bar with distally placed extracoronal rigid attachment (Easy slot) design, moderate level stress was observed at the coronal and apical region of the ipsilateral implant. Moderate stress was recorded at the apical of the contralateral implant. Similar to the other bar designs, a moderate level stress was observed at the mesial coronal region of the contralateral implant (Figure 9). Bar-ball and bar with distally placed extracoronal rigid attachment (Easy slot) designs showed similar stress patterns. Lowest stress was observed with the single anchor attachment (ERA) design.

DISCUSSION

Load transfer may be dependent on clinical factors such as durability of prosthetic attachments, implant structures and the supporting osseous and soft tissue structures.[22] The in vitro use of the photoelastic technique allows for comparison based on standardized modeling with specific prosthetic designs, attachments and techniques.[22] The modeling system used in this study, as with all modeling systems including finite element analysis, mathematic models or strain gauge studies, can not accurately predict the response of biologic systems to applied loads.[15] Physiological strain thresholds of human jawbones have not been quantified so far and the clinical relevance of strain values remains speculative.[30] However, all of these systems can indicate, under carefully controlled conditions, where the stress related difficulties may arise.[15]

Attachment selection should be based on the degree of retention, the ability to release stress, the restorative space, placement considerations, patient

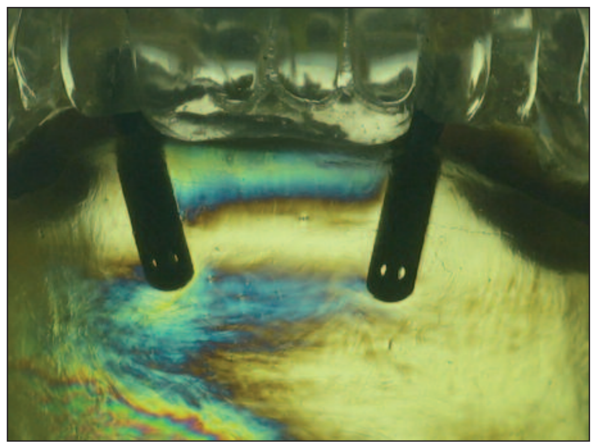

FIGURE 7: Stresses produced by bar-clip retained prosthesis on inclined implants.
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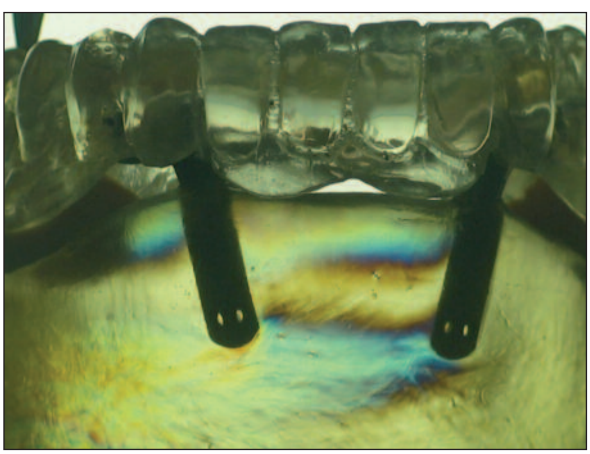

FIGURE 8: Stresses produced by bar-ball attachment retained prosthesis on inclined implants.
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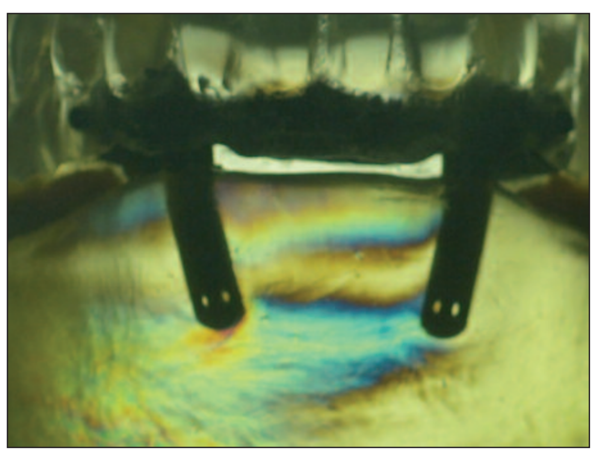

FIGURE 9: Stresses produced by bar with distally placed extracoronal rigid attachment (Easy slot) retained prosthesis on inclined implants.
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compliance for recall and cost effectiveness.[21,31,32] For bone preservation, the retention system that provides the most equitable transfer of occlusal forces is preferred.[26]

Several studies have compared the effect of attachment systems on the stress transfer of mandibular overdentures. Using a photoelastic stress analysis, Kenney and Richards concluded that ball/ O-ring attachments transferred less stress to implants than the bar-clip attachments when the model was subjected to a posterior vertical load.[23] In a recent study, Mazaro et al. also stated that the use of an O-ring attachment better distributes the stress to the ridge/implant, compared to bar-clip overdenture.[33] Similar results were observed by Barao et al, which compared the stress distribution on complete dentures and implant-retained overdentures with different attachments in finite element models.[34] Porter et al. compared various single anchor attachments and bar-clip by means of load distribution, and concluded that ERA attachments exhibited lowest stress values around implants.[24] Menicucci et al. compared the stresses on the mandible with either a bar-clip or ball attachments for 2 implant retained overdentures using a 3-dimensional finite element model.[25] They found that the stress distribution with the ball and socket attachment systems was more favorable. The conclusion of the current study is in agreement with these studies. On the contrary, Tabata et al. compared the stress distribution of bar-clip and O-ring retained mandibular overdentures over 2 implants.[35] They concluded that O-ring attachment showed higher stress concentrations than bar-clip system. Assuncao et al. concluded that the use of splinted implants associated with the bar-clip attachment system favored a lower stress distribution over the supporting tissue than the unsplinted implants with an O-ring abutment to retain the mandibular overdenture.[36] Machado et al. compared O-ring, bar-clip and their association with photoelastic stress analysis.[37] They concluded that the use of bar-clip is a better alternative, because it showed more uniform stress distribution than the ball system. Although these studies compare bar-clip and O-ring system, it should be noted that the biomechanical behavior of the O-ring and the ERA attachments may differ depending on the location, the relationship between the attachment height and occlusal plane, and the axis of insertion.[33]

In this study, resultant stresses were greater on the side of the load application for vertical orientation of the implants. Although minor differences in stress patterns were developed among the 4 attachment systems, the single anchor attachment (ERA) transferred less stress to the implants. This result was in agreement with previous studies.[23-26,28] The bar with the distally placed extracoronal rigid attachment (Easy slot) design caused the highest stress pattern. The reason why the single anchor attachment (ERA) caused less stress may be related to the stress absorbance character of the plastic matrix component and supporting implant number.[28]

When comparing these results to the results of inclined oriented implants, similar stress patterns were observed. However, more equitable stress patterns were observed around the vertical oriented implants. Single anchor attachments (ERA) transferred the lowest stress. Only for bar-ball and bar with distally placed extracoronal rigid attachment (Easy slot) designs, stresses were observed on the distal coronal side of the loaded implants. This demonstrates the rigid character of the attachment systems and is compatible with the study of Federick and Caputo.[26]

Even though the resultant stresses were generally moderate and small differences were found among attachment systems for both models, resilient systems such as the single anchor attachment (ERA) or round bar, may provide equitable stress distribution to the supporting implants. In general, the forces and moments on an implant were greater when the external load was applied directly to the prosthesis over the implant or between the 2 implants located in the mid-anterior region.[24] In the present study, the load application from the first molar may be the explanation of the minor differences in stress patterns of 4 attachment systems.

The results of the present study were in agreement with Federick and Caputo's study which examined overdentures retained by bar and clip attachments, extracoronal resilient attachments (ERA), and a combination of a bar and clip with distal ERA attachments in a photoelastic model.[26] It was concluded that ERA attachments alone tended to provide the most equitable transfer of load to the bone surrounding implants for both vertical and inclined implant orientations.

When designing a 2 implant-retained prosthesis, in which the implants are planned to be splinted, a round bar-clip design distributes equitably the load to the implants and also does not cause excessive stress on the loaded side implant. This kind of design should be advantageous when the residual ridge is severely resorbed, since the bar provides an additional plane of stability.[25,38] However, the single anchor attachment (ERA) exhibited better stress distribution among the tested attachment designs.

In the current study the effect of axial load application was evaluated. The absence of nonaxial loading is a limitation of this study because the direction of the load can change the patterns of tension. Further studies may be helpful to evaluate the load transfer characteristics with different load directions applied to vertically oriented and inclined implants.

CONCLUSION

Within the limitations of this study the following conclusions were drawn:

1. The single anchor attachment (ERA) transferred the least amount stress to the implants for both models.

2. Higher stresses were observed with the bar with distally placed extracoronal rigid attachment (Easy slot) system for both models. However, the resultant stresses were at moderate level.

3. When the stress distribution of vertical and inclined oriented implants are compared, more equitable stress patterns were observed on the vertical oriented implants. Therefore, vertical implant placement is suggested.

Acknowledgement

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REFERENCES

1. Mericske-Stern R. Three-dimensional force measurements with mandibular overdentures connected to implants by ball-shaped retentive anchors. A clinical study. Int J Oral Maxillofac Implants 1998;13(1):36-43.
2. Setz JM, Wright PS, Ferman AM. Effects of attachment type on the mobility of implant-stabilized overdentures--an in vitro study. Int J Prosthodont 2000;13(6):494-9.
3. Fitzpatrick B. Standard of care for the edentulous mandible: a systematic review. J Prosthet Dent 2006;95(1):71-8.
4. Feine JS, Carlsson GE, Awad MA, Chehade A, Duncan WJ, Gizani S, et al. The McGill Consensus Statement on Overdentures. Montreal, Quebec, Canada. May 24-25, 2002. Int J Prosthodont 2002;15(4):413-4.
5. Mericske-Stern R. Clinical evaluation of overdenture restorations supported by osseointegrated titanium implants: a retrospective study. Int J Oral Maxillofac Implants 1990;5(4): 375-83.
6. Naert I, Quirynen M, Theuniers G, van Steenberghe D. Prosthetic aspects of osseointegrated fixtures supporting overdentures. A 4-year report. J Prosthet Dent 1991;65(5):671-80.
7. Batenburg RH, Raghoebar GM, Van Oort RP, Heijdenrijk K, Boering G. Mandibular overdentures supported by two or four endosteal implants. A prospective, comparative study. Int J Oral Maxillofac Surg 1998;27(6):435-9.
8. Preiskel HW. Stud attachments and magnets. Bar attachments. Implant systems and techniques. Overdentures made easy: a guide to implant and root supported prostheses. 1st ed. London: Quintessence; 1996. p. 81,105,212-32.
9. Banton B, Henry MD. Overdenture retention and stabilization with ball-and-socket attachments: principles and technique. J Dent Technol 1997;14(7):14-20.
10. Wiemeyer AS, Agar JR, Kazemi RB. Orientation of retentive matrices on spherical attachments independent of implant parallelism. J Prosthet Dent 2001;86(4):434-7.
11. Mericske-Stern R. Forces on implants supporting overdentures: a preliminary study of morphologic and cephalometric considerations. Int J Oral Maxillofac Implants 1993;8(3): 254-63.
12. Gulizio MP, Agar JR, Kelly JR, Taylor TD. Effect of implant angulation upon retention of overdenture attachments. J Prosthodont 2005; 14(1):3-11.
13. Walton JN, Huizinga SC, Peck CC. Implant angulation: a measurement technique, implant overdenture maintenance, and the influence of surgical experience. Int J Prosthodont 2001; 14(6):523-30.
14. Khadivi V. Correcting a nonparallel implant abutment for a mandibular overdenture retained by two implants: a clinical report. J Prosthet Dent 2004;92(3):216-9.

15. Jeong CM, Caputo AA, Wylie RS, Son SC, Jeon YC. Bicortically stabilized implant load transfer. Int J Oral Maxillofac Implants 2003; 18(1):59-65.
16. van Kampen F, Cune M, van der Bilt A, Bosman F. Retention and postinsertion maintenance of bar-clip, ball and magnet attachments in mandibular implant overdenture treatment: an in vivo comparison after 3 months of function. Clin Oral Implants Res 2003;14(6):720-6.
17. Block M, Kent J, Guerra L. Implants in Dentistry: Essentials of Endosseous Implants for Maxillofacial Reconstruction. 1st ed. Philadelphia: WB Saunders; 1997. p.100.
18. Ichikawa T, Horiuchi M, Wigianto R, Matsumoto N. In vitro study of mandibular implant-retained overdentures: the influence of stud attachments on load transfer to the implant and soft tissue. Int J Prosthodont 1996;9(4): 394-9.
19. Fanuscu MI, Caputo AA. Influence of attachment systems on load transfer of an implant-assisted maxillary overdenture. J Prosthodont 2004;13(4):214-20.
20. Sadowsky SJ, Caputo AA. Stress transfer of four mandibular implant overdenture cantilever designs. J Prosthet Dent 2004;92(4):328-36.
21. Sadowsky SJ, Caputo AA. Effect of anchorage systems and extension base contact on load transfer with mandibular implant-retained overdentures. J Prosthet Dent 2000;84(3): 327-34.
22. Ochiai KT, Williams BH, Hojo S, Nishimura R, Caputo AA. Photoelastic analysis of the effect of palatal support on various implant-supported overdenture designs. J Prosthet Dent 2004;91(5):421-7.
23. Kenney R, Richards MW. Photoelastic stress patterns produced by implant-retained overdentures. J Prosthet Dent 1998;80(5):559-64.
24. Porter JA Jr, Petropoulos VC, Brunski JB. Comparison of load distribution for implant overdenture attachments. Int J Oral Maxillofac Implants 2002;17(5):651-62.
25. Menicucci G, Lorenzetti M, Pera P, Preti G. Mandibular implant-retained overdenture: finite element analysis of two anchorage systems. Int J Oral Maxillofac Implants 1998; 13(3):369-76.
26. Federick DR, Caputo AA. Effects of overdenture retention designs and implant orientations on load transfer characteristics. J Prosthet Dent 1996;76(6):624-32.
27. Hertel RC, Kalk W. Influence of the dimensions of implant superstructure on peri-implant bone loss. Int J Prosthodont 1993;6(1):18-24.
28. Tokuhisa M, Matsushita Y, Koyano K. In vitro study of a mandibular implant overdenture retained with ball, magnet, or bar attachments: comparison of load transfer and denture stability. Int J Prosthodont 2003;16(2):128-34.
29. Celik G, Uludag B. Photoelastic stress analysis of various retention mechanisms on 3-implant-retained mandibular overdentures. J Prosthet Dent 2007;97(4):229-35.
30. Cehreli M, Duyck J, De Cooman M, Puers R, Naert I. Implant design and interface force transfer. A photoelastic and strain-gauge analysis. Clin Oral Implants Res 2004;15(2): 249-57.
31. Preiskel HW. Precision Attachments in Dentistry. 2nd ed. St. Louis: Mosby; 1979. p.167-8.
32. Steffen RP, White V, Markowitz NR. The use of ballclip attachments with an implant-supported primary-secondary bar overdenture. J Oral Implantol 2004;30(4):234-9.
33. Mazaro JV, Filho HG, Vedovatto E, Pellizzer EP, Rezende MC, Zavanelli AC. Evaluation of stress patterns produced by implant-retained overdentures and implant-retained fixed partial denture. J Craniofac Surg 2011;22(6):2153-7.
34. Barão VA, Assunção WG, Tabata LF, Delben JA, Gomes EA, de Sousa EA, et al. Finite element analysis to compare complete denture and implant-retained overdentures with different attachment systems. J Craniofac Surg 2009;20(4):1066-71.
35. Tabata LF, Assunção WG, Barão VA, Gomes EA, Delben JA, de Sousa EA, et al. Comparison of single-standing or connected implants on stress distribution in bone of mandibular overdentures: a two-dimensional finite element analysis. J Craniofac Surg 2010;21(3): 696-702.
36. Assunção WG, Tabata LF, Barão VA, Rocha EP. Comparison of stress distribution between complete denture and implant-retained overdenture-2D FEA. J Oral Rehabil 2008;35(10): 766-74.
37. Machado AC, Cardoso L, Brandt WC, Henriques GE, de Arruda Nóbilo MA. Photoelastic analysis of the distribution of stress in different systems of overdentures on osseous-integrated implants. J Craniofac Surg 2011;22(6): 2332-6.
38. Karakoca S, Boynueğri D, Yalım M. 3Implant-retained mandibular overdentures: case report. Turkiye Klinikleri J Dental Sci 2010; 16(3):274-81.