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Effect of the Number of Supporting Implants on Mandibular Photoelastic Models with Different Implant-Retained Overdenture Designs

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Keywords
Load transfer; implant-retained overdenture; photoelastic stress analysis; number of implants; prosthesis design.

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This study was supported by the Scientific and Technological Research Council of Turkey (project number SBAG-2713).

The authors deny any conflicts of interest.

Accepted September 6, 2013

doi: 10.1111/jopr.12129

Abstract

Purpose: The purpose of the study was to evaluate the effect of the number of supporting implants and different retentive mechanisms on load transfer characteristics of mandibular overdentures.
Materials and Methods: Two photoelastic models of edentulous mandibles were fabricated having two and four cylindrical implants (Calcitek, 4 × 13 mm) embedded in the parasymphyseal area. 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 133 N vertical force 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 the bar with distally placed extracoronal rigid attachment (Easy Slot) design, followed by bar-ball, bar, and the single anchor attachment (ERA) for both models. The lowest stress was observed with the single anchor attachment (ERA) design for both models. There were slight differences in stress values around implants in both models.
Conclusions: For all tested attachments on both models, the stress was concentrated on the ipsilateral implant. The bar-clip system allowed the distribution of load to all supporting implants in both models. Although the highest stress level observed with all attachment systems was moderate, the bar-Easy Slot attachment showed the highest stresses. The lowest stress was observed with the single anchor attachment (ERA) design for both models. Varying the number of implants had no significant effect on stress values around supporting implants.

Mandibular implant-retained overdentures can provide an effective treatment modality for edentulous patients, especially those who have persistent problems using a conventional mandibular prosthesis. Three advantages of the overdenture concept are reduced number of implants needed, easier surgical procedure, and that an easier restorative technique may be used due to the use of prefabricated attachments.[1] Although Fitzpatrick has reported there is no strong evidence for a single, universally superior treatment modality for the edentulous mandible, the overdenture retained by two implants has been advocated as the treatment of choice for the edentulous mandible and has been reported to improve the quality of life of patients regardless of the attachment system used.[2,3]

Generally, in the edentulous mandible, a treatment concept using two or four implants to retain a mandibular overdenture has been proposed.[1,4] The number and distribution of implants affect the loading implants and supporting bone.[5] Several investigators studied this treatment modality and found no difference in the clinical and radiographical state of patients treated with either two or four implants retaining a mandibular overdenture.[6-8] However, it is widely thought that if load is distributed on an increasing number of implants, the magnitude of the stresses in the bone decreases.[9,10] The contact amount of bone/implant interface is believed to be a defining factor for load-bearing capacity.[4]

Another factor to consider for rehabilitation with implant-supported overdentures is the selection of attachments. Retention should not be the only factor to consider when designing an implant-retained overdenture. As the patient functions with an implant-retained overdenture, loads are transmitted to alveolar bone surrounding the implants, as well as to the abutments and residual ridges. When selecting an attachment system, the clinician should know that the design of overdenture attachments should provide optimum force distribution around supporting implants to allow bone loading within physiologic levels, because it is important not to cause unfavorable loads on implant abutments, as these loads can be detrimental to implants.[11] From the standpoint of bone preservation, the systems that provide the most equitable transfer of occlusal forces are preferred.[12]

Various 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 bar-clip attachments when the model was subjected to a posterior vertical load.[13] 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 a bar-clip overdenture.[14] Similar results were observed by Barao et al, who compared the stress distribution on complete dentures and implant-retained overdentures with different attachments in finite element models (FEMs).[15] Menicucci et al compared the stresses on the mandible with either a bar-clip or ball attachments for two-implant-retained overdentures using a 3D FEM.[16] They found that the stress distribution with the ball and socket attachment systems was more favorable. On the contrary, Tabata et al[17] compared the stress distribution of bar-clip and O-ring retained mandibular overdentures over two implants and concluded that the O-ring attachment showed higher stress concentrations than the 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.[18] Machado et al compared O-rings, bar-clips, and their association with a photoelastic stress analysis.[19] They concluded that the use of bar-clip is a better alternative, because it showed more uniform stress distribution than the ball system.

In general, implant-supported overdenture attachments can be classified as single anchors, magnets, bars, and telescopic copings.[20,21] Generally, bars or independent connectors are used to connect the overdentures to the underlying implants, each featuring different biomechanical characteristics.[22-24] 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.[25]

Photoelastic stress analysis is based on the property of some transparent materials to exhibit colorful patterns when viewed with polarized light. With this method, internal mechanical pressure and stresses occurring inside of the complex structures are converted to visible light sketches. When photoelastic material is exposed to a load, passed through the nicol prism, and observed by polarized light, colored structures directly comparable with stresses and strains can be observed. When a ray of polarized light passes through the loaded photoelastic model, it turns into vertical vibrations, which pass through the material in different velocities. This is called the photoelastic effect. This effect can be observed with a polarized filter or polariscope.[26]

The authors of this report used the same testing methods in their previous study[27] to compare the stress dstribution of various attachments and implant inclination on three-implant-retained mandibular overdentures; however, the current study evaluated the effect of the number of supporting implants and different attachments on stress distribution. The tested attachments were also different from the previous study.[27] The aim of the study was to compare the load transfer characteristics of various attachment systems on two- and four-implant-supported mandibular overdentures photoelastically.

Materials and methods

Photoelastic resin (PL-2; Vishay Intertechnology, Malvern, PA) was used to fabricate two photoelastic models of an edentulous mandible. The configuration of the arch was replicated from a mandibular cast of an edentulous patient. A silicone mold (Speedex; Coltene/Whaledent, Alstatten, Switzerland) was obtained to duplicate the cast in wax models (Poliwax; Bilkim Kimya, Izmir, Turkey). Cylindrical implants (Calcitek, 4 × 13 mm; Zimmer Dental Inc., Carlsbad, CA) were embedded into the parasymphyseal area of each wax model by means of a surveyor (Ney Surveyor; Dentsply Intl, York, PA). The first model included two implants; the second included four implants parallel to each other and the midline. The crestal exit of the implants was at the top of the ridge crest.

Two silicone molds (Speedex) were obtained from wax models with implants. Photoelastic resin was poured into the silicone molds according to the manufacturer's recommendations. Four retention mechanisms were evaluated for each model (Fig 1). The first design was a single anchor attachment (ERA; Sterngold Dental, Attleboro, MA); the second design was round bar-clip (Bredent; Senden, Germany); the third design was a bar with two distally placed ball attachments (Bredent) and an anterior clip (Bredent); the final design was a bar incorporating two distally placed extracoronal rigid attachments (Easy Slot; Servo-Dental, Hagen-Halden, Germany) (*Easy Slot is very similar to, but not the same as the SD-Snap Riegel, SD- Snap-in latch.*) and an anterior clip (Bredent).

Group 1 included two implant-retained overdentures varying the retention systems as follows: ERA, bar-clip, bar-clip with distal ball attachments, and bar-clip with distal extracoronal rigid attachments. Group 2 included four implant-retained overdentures varying the retention systems as follows: ERA, bar-clip, bar-clip with distal ball attachments, and bar-clip with distal extracoronal rigid attachments.

To represent the thickness of the soft tissue, baseplate wax (Cavex Dental Base Plates; Cavex Holland B.V., Haarlem, The Netherlands), was adapted to the posterior edentulous areas of both photoelastic models.[16,28,29] This created a standard thickness of approximately 3 mm for vinylpolysiloxane impression material (Oranwash L; Zhermack S.p.a., Badia Polesine, Italy) that would be added to the intaglio surface of the denture.

For bar fabrication, shouldered abutments (Calcitek) and plastic castable copings (Calcitek) were placed on the implants. A plastic castable bar (Bredent) was sectioned and fixed between plastic castable copings. For bar-ball and bar with distally placed extracoronal rigid attachment (Easy Slot) designs, after the bar was fixed, ball and Easy Slot attachments were placed on the distal side of the copings using a surveyor (Paraskop M; BEGO, Bremen, Germany). These bar designs, cast with a base metal alloy (Biosil-F; Degudent GmbH, Hanau,

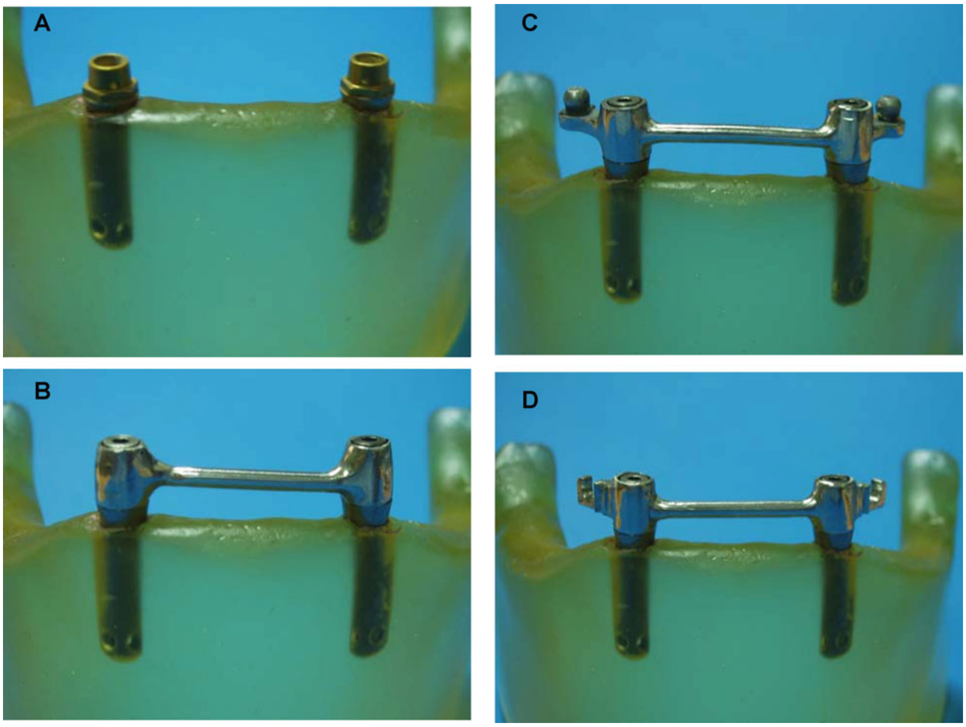

Figure 1 Attachment types tested in the study. A. ERA attachment. B. Bar framework. C. Bar with distally placed ball attachment. D. Bar with distally placed Easy Slot attachment.

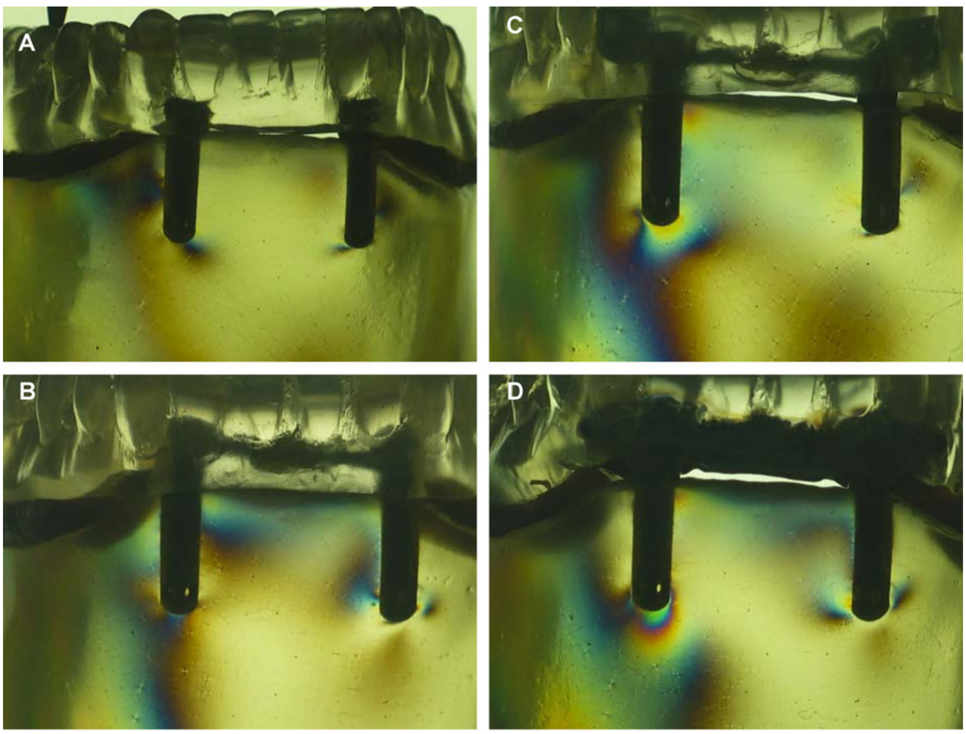

Figure 2 Stresses produced in two-implant-supported prostheses. A. ERA attachment. B. Bar attachment. C. Bar with distally placed ball attachment. D. Distally placed Easy Slot attachment.

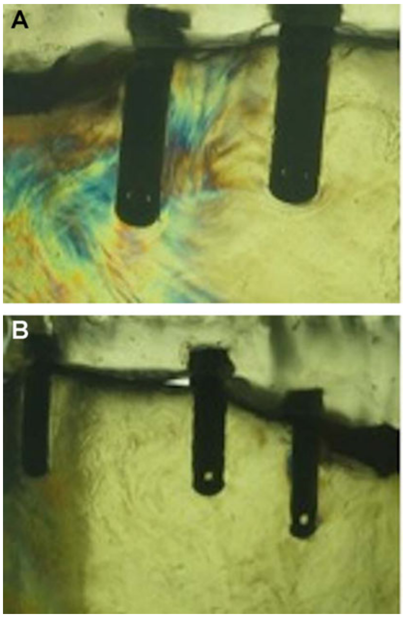

Figure 3 Stresses produced in four-implant-supported prostheses. A. Stresses produced by ERA attachment, load application side. B. Stresses produced by ERA attachment, contralateral side.

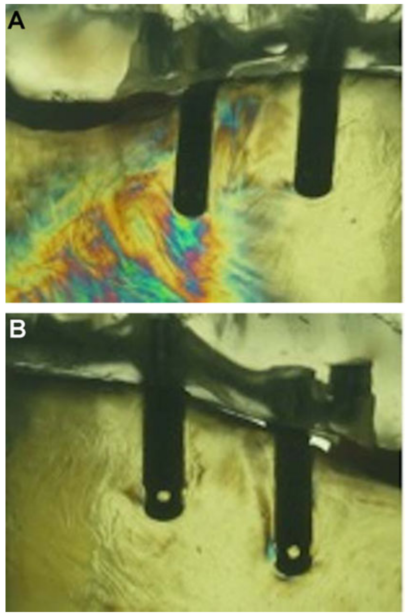

Figure 5 A. Stresses produced by bar with distally placed ball attachment, load application side. B. Stresses produced by bar with distally placed ball attachment, contralateral side.

Germany), were 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. Single anchor attachments (ERA) were also placed on the implants and tightened to 20 Ncm.

A metal framework extending to the distal sides of the bar with a 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).

Denture preparation was conducted in the same way as mentioned in our previous report:[27] One layer of baseplate wax

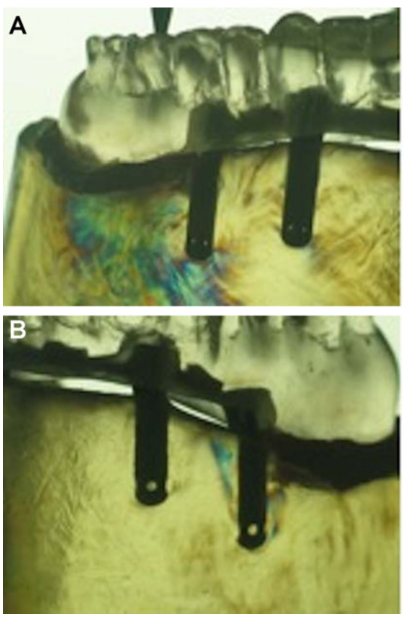

Figure 4 A. Stresses produced by bar attachment, load application side. B. Stresses produced by bar attachment, contralateral side.

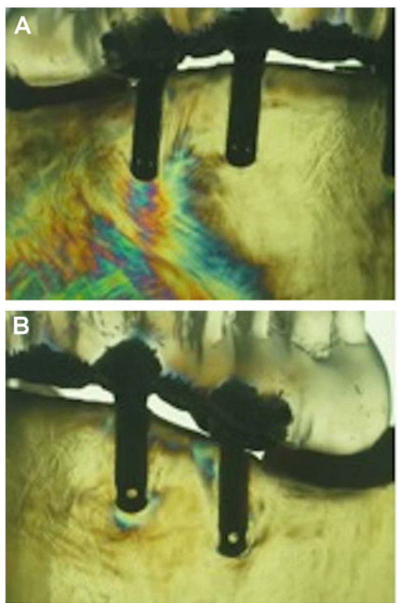

Figure 6 A. Stresses produced by bar with distally placed Easy Slot attachment, load application side. B. Stresses produced by bar with distally placed Easy Slot attachment, contralateral side.

(Cavex Dental Base Plates) was applied to the stone cast. Artificial teeth (Major; Major Prodotti Dentari, Torino, Italy) were arranged. The cast with arranged teeth and finalized waxing was placed into the lower portion of an injection flask (SR-Ivocap; Ivoclar Vivadent, Schaan, Liechtenstein). Heavy-bodied elastomeric impression material (Speedex) was added to the upper portion of the flask. This provided the negative silicone mold to facilitate duplication of the wax denture to fabricate dentures for each model. After removing the waxed denture from the model, clear autopolymerizing acrylic resin (Futura Self; Schutz-Dental Group, Rosbach, Germany) was injected through the access openings of the injection flask into the space between the silicone mold and the master model for each attachment design on a stone cast. For the second stone cast, the acrylic was injected for each attachment design by using the same silicone mold. Eight dentures were fabricated in this manner. The use of clear material allowed light transmission through the model for stress pattern observation.

A light-body elastomeric impression material (Oranwash L) was applied to the intaglio surface of the extension base of the dentures to represent the soft tissue thickness. All dentures were sequentially placed on the models with the attachments engaged and then examined photoelastically. All photoelastic models exhibited negligible initial stresses in the polariscope field (Measurements Group, Instruments Division, Raleigh, NC) before force application.[30]

A 133 N vertical force was applied unilaterally to the central fossa of the right first molar.[28] This load level was selected as being within a range of normal occlusal mastication and near maximum loads for implant overdenture patients, depending on the dentition of the antagonist jaw.[31-33] Load was applied by a custom-made loading device (Gazi University, Technical Education Faculty, Mechanical Education Department, Ankara, Turkey). Mineral oil (Castrol, Istanbul, Turkey) was applied on the models to facilitate photoelastic observation. The resulting stresses of the models were observed and recorded photographically (Powershot G3; Canon, Tokyo, Japan) in the field of a circular polariscope. The views were oriented perpendicular to the vestibular area of the models. All photographs were evaluated visually for stress-induced fringes. Stress intensity (number of fringes) and locations were analyzed by the same evaluator. In the evaluation of these stress data, the following terminology was adopted:[5]

1. low stress—1 fringe or less,
2. moderate stress—2 or 3 fringes,
3. high stress—more than 3 fringes.

Results

On the two-implant-supported mandibular model, moderate stress was observed on the apical and distal side of the ipsilateral implant with the single anchor attachment (ERA) retained overdenture design. Little or no discernible stress was noted on the contralateral implant (Fig 2A). For the bar-clip design, moderate stress was recorded through the long axis and apical to the ipsilateral implant. Also, moderate stress was observed on the mesial side of the contralateral implant, showing that the load was transferred on both implants (Fig 2B). For the bar-ball design, symmetric moderate stress on the 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 (Fig 2C). 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 (Fig 2D).

For all designs on the two-implant-supported mandibular model, stress was concentrated on the ipsilateral implant. Although moderate stresses were observed, the resultant stress patterns were greater for the bar with the 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.

On the four-implant-supported mandibular model, for the single anchor attachment (ERA) retained overdenture design, moderate and low stress was observed on the apical and long axis of the ipsilateral implant. No discernible stress was noted on the contralateral implants (Figs 3A, 3B). For the bar-clip design, symmetric moderate stress was recorded apical to the ipsilateral implant. Also, moderate stress was observed on the mesial implant of the loaded side. Although no stress was observed on the mesial implant on the unloaded side, a minimum increase of stress on the distal implant shows that the load was transferred to the unloaded side of the model (Figs 4A, 4B). For the bar-ball design, there was moderate stress on the apical and mesial sides. Low stress on the distal side of the terminal implant was observed on the loaded side. Little or no discernible stress was noted on the other three implants (Figs 5A, 5B). For the bar with distally placed extracoronal rigid attachment (Easy Slot) design, moderate stress on the apical and low stress on the coronal region of the ipsilateral implant was recorded (Figs 6A, 6B).

For the four-implant-supported mandibular photoelastic model, the highest stresses were observed with bar-ball and bar-Easy Slot attachments. Stress distribution was observed only with the bar attachment. For other types of attachments, the stresses were concentrated around the terminal implant on the loaded side. For the splinted and unsplinted two- and four-implant-retained overdenture designs evaluated, moderate and low level stresses were observed with different attachment systems.

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.[29] For bone preservation, the retention system that provides the most equitable transfer of occlusal forces is preferred.[12]

Various types of attachments are available, including bars, studs, magnets, and telescopic copings to connect a denture to the implants.[22] It was observed that the most commonly used attachments are studs, bars, and bars with different attachments. For this reason, ERA attachment (as a stud attachment), bar, bar-ball, and bar-Easy Slot designs were tested in the current study.

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.[11] Similarly, Federick and Caputo evaluated the effect of ERA, bar with distally placed ERA attachment, and bar attachments on load transfer characteristics on two photoelastic models with parallel and inclined implants, and concluded that ERA showed the most equitable stress transfer.[12] Unilateral loads were applied directly over the implant (at the first premolar), at the second premolar, and at the second molar. It was stated that posterior load application led to an increased proportion of load distribution to the denture base and a reduction of the stresses at the implant. According to the study, when the load was applied more posteriorly, the differences in load transfer characteristics of retention designs diminished. These results are parallel to the current study and explain the close stress levels occurring with different attachments. Also, similar to a previous study,[27] the highest stress level observed with all attachments was moderate, which may be related to the load application area.

Several studies have compared bar-clip and ball/O-ring attachments by means of stress distribution.[13-16] These stud attachments exhibited better stress distribution compared to bar attachments, in agreement with the current study. Although these studies compared bar-clip and O-ring systems, 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.[14]

Although minor differences in stress patterns were developed among the four attachment systems, the single anchor attachment (ERA) transferred less stress to the implants. This result was in agreement with previous studies.[11-13,34,35] The bar with the distally placed extracoronal rigid attachment (Easy Slot) design caused the highest stress patterns. The reason 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.[35] The lowest stress levels were observed with the single anchor attachment system (ERA), which seems to present the more favorable clinical conditions showing a better distribution of tensions when the loads were uniformly distributed in the ridge and also in the implants.

For all tested attachments on both models, the stress was mostly concentrated on the load application side for both models during unilateral loading. This is in accordance with previous studies.[19]

While only one implant is another option for mandibular implant-retained overdentures,[3] two to four implants are usually placed in the interforaminal region. This approach is well documented in the literature by means of high success rates.[4] In addition, an increased number of implants is suggested to support mandibular overdentures in clinical situations requiring increased retention. Therefore, four implants may be indicated for some clinical cases.

Although several investigators found no difference in the clinical and radiographical state of patients treated with either two or four implants retaining a mandibular overdenture,[6-8] studies comparing the load distribution with different attachments are limited. In our study, no difference was observed with the changing number of implants by means of stress concentration and magnitude; however, an increased number of implants is suggested to support mandibular overdentures in clinical situations requiring increased retention such as patients with high muscle attachments, prominent mylohyoid ridges, and atrophic ridges or extreme gaggers.[37] It may also be indicated for patients with mandibular soreness and pain, because the overdenture will be mainly supported by the implants, thus avoiding mucosal rubbing.[8]

Because the physiological strain thresholds of human jawbones and intraosseous strains around oral implants have not been measured by biosensors, the quality and quantity of strains leading to marginal bone loss around oral implants are unknown.[30] Currently, stress analysis studies are used to measure strains around implants. In the current study quasi-3D photoelastic stress analysis was chosen to evaluate the stress transfer because of the geometrical properties of models. The photoelastic modeling technique used in this study has limitations when predicting the response of biologic systems to applied loads, as do all modeling systems involving finite element analysis, mathematical models, or strain gauge studies; however, such modeling systems can indicate, under carefully controlled conditions, where potential stress-related differences may occur.[29,38]

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.

Conclusions

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

1. For all tested attachments on both models, the stress was concentrated on the ipsilateral implant. The bar-clip system allowed the distribution of load to all supporting implants in both models.
2. Although the highest stress level observed with all attachment systems was moderate, the bar-Easy Slot attachment showed the highest stresses. The lowest stress was observed with the single anchor attachment (ERA) design for both models.
3. No difference was observed with the changing number of implants by means of stress concentration and magnitude.

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