

Load Transfer Characteristics of Various Designs of Three-Implant-Retained Mandibular Overdentures

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Purpose: Many different attachment systems (eg, bars, studs, magnets, telescopic copings) have been used to retain overdentures. The current study aimed to investigate the load transfer characteristics and to compare the stress levels of four attachment designs for mandibular overdentures retained by one central implant and two inclined distal implants. **Materials and Methods:** Photoelastic mandibular models fabricated with three screw-type implants (Tapered Screw-Vent, 3.75 × 13 mm) were placed in the parasymphiseal area. The center implant was vertically oriented to the midline, and the other implants were embedded in the canine areas with a 20-degree angulation relative to the center implant. Four overdentures with different attachment designs (bar, bar/ball, bar/distally placed Rk-1s, and Locators) were studied in the context of this model. Vertical loads (100 N) were applied to the central fossa of the right first molar area of each overdenture. Stress levels that developed in the denture-bearing areas and around the implants were observed photoelastically and evaluated visually. **Results:** The studied attachment designs showed low and moderate stress levels. The greatest stress was found with the bar/ball design, while the lowest stress levels were observed with the Locator attachment design. **Conclusion:** Stresses were concentrated on the loaded side for each design. All tested designs experienced moderate stress around the posterior edentulous area. None of the designs experienced more than moderate stress. The lowest stress was noted with the Locator attachments, which transmitted little discernible stress around the implants. INT J ORAL MAXILLOFAC IMPLANTS 2015;30:1061–1067. doi: 10.11607/jomi.4013

Key words: implant-retained overdenture, photoelastic stress analysis, precision attachment

Proper rehabilitation of edentulous patients improves general health and enhances quality of life.¹ Implant-retained overdentures are recommended as the first choice of treatment for edentulous jaws, especially in the mandible.^{2–4} Proper function, esthetics, design, retention, and stability of the denture, as well as good quality of the denture-bearing area, are required to satisfy the needs of mandibular overdenture patients. Additionally, patient personality and expectations play roles in the efficacy of implant-retained overdentures.⁵

A mandibular overdenture supported by two to four interforaminal implants has been proven to be a successful treatment modality for edentulous patients.^{6–8} The use of two implants, which some researchers have reported is sufficient for overdenture support and retention, is a more cost-effective approach.^{9–11} However, the use of more than two implants increases retention of the mandibular overdenture and can be offered to patients with high muscle attachment, prominent mylohyoid ridges, or an extreme gagging reflex.¹² In addition, the placement of only two implants in the interforaminal region creates a straight-line relationship, whereas the use of three or more implants might produce an angular relationship. The most anteriorly positioned implant ensures indirect retention for an overdenture supported by three or more implants by preventing anteroposterior rotation of the overdenture in the sagittal plane.^{12,13} However, four interforaminal implants for mandibular overdentures are generally not recommended because the retaining bars may become too short, leading to loosening of the overdenture.¹²

Myriad attachment systems are available to retain an implant overdenture.^{14,15} Implants can be splinted with bars or stud attachments (eg, balls, Locators, or

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magnets), while clinicians might also use telescopic copings to attach the overdenture to the implants.^{7,16–23} Planning of bar attachments and bar units, which are manufactured in both resilient and rigid designs, has led to their widespread acceptance.^{5,17,23} However, retention should not be the only factor to consider when planning an implant-supported overdenture.⁷ Masticatory forces are an additional important factor, with loads being transmitted to alveolar bone surrounding the implants and to the edentulous alveolar crests via the overdenture.² Excessive loads may induce bone microdamage, which would lead to resorption of bone around the implants.^{24,25} Therefore, it is important to prevent the distribution of excessive loads to the implants.¹⁵

Planning of an implant-retained overdenture, including the number,^{6,8,19} diameters,^{26,27} lengths,^{27,28} inclinations,^{7,29} and locations of the implants,^{30,31} as well as the types^{14,17,32–35} and means of retention^{8,30,31,36} of the attachments, must be considered before treatment. These factors might also affect the load that is transferred to the implants and denture-bearing areas.

The oral cavity is a complex biomechanical system that can be investigated using various *in vitro* approaches, such as photoelastic stress analysis, two-dimensional (2D) modeling, and 3D and quasi-3D modeling, to evaluate the mechanical behavior of dentures, to allow the determination of the stress distribution within the material.^{37–39} Although the mandible comprises medullary and cortical bone, a photoelastic mandibular model constitutes a single type of resin²¹; this allows investigation of the stress points, biomechanics, and physical characteristics of dental implants and dentures.^{7,11,20,21,40}

The aim of this study was to evaluate the stress distribution of mandibular overdentures retained by three implants using four different attachment systems.

MATERIALS AND METHODS

A cast of an edentulous mandible with moderate residual ridge resorption was generated from a female patient who was 62 years old. Photoelastic resin (PL-2, Measurements Group, Vishay Intertechnology) was used to fabricate a photoelastic mandibular model with implants. The mandibular cast of the edentulous patient was used to adapt the configuration of the arch. To duplicate the mandibular cast in a wax model (Modelling Wax, Dentsply), an impression was made with an elastomeric material (Zetaplus, Zhermack).

Three screw-type implants (Tapered Screw-Vent, 3.75 × 13 mm; Zimmer Dental) were placed into the interforaminal region of the wax model using a surveyor (Ney Surveyor, Dentsply). The center implant

was vertically oriented at the midline, and the distal implants were embedded in approximately the canine areas. The interimplant distance between each center and distal implant was set to 11 mm, and the distal implants were aligned at a 20-degree angle relative to the center implant.⁷ The orientation of the inclined implants was verified using prefabricated 20-degree angled abutments (Tapered Screw-Vent, Zimmer Dental). The divergence between the distal implants was ≤ 40 degrees, which was the maximum amount allowed by the locator attachments. Extended-range locator males (green, orange, red, and gray) can tolerate this divergence between the implants and provide adequate retention of overdentures.⁴¹

The implants were placed with their coronal end level with the top of the ridge. A silicone mold (Zetaplus, Zhermack) was obtained from the wax model with implants, and photoelastic resin (PL-2) was poured into the silicone mold according to the manufacturer's instructions.

Four attachment designs were compared on the model: (1) a Hader bar (Bredent); (2) a Hader bar (Bredent) and two distally placed ball attachments (Bredent); (3) a Hader bar (Bredent) and two distally placed Rk-1 attachments (Kargı Sağlık Hiz); and (4) Locator attachments (Zest Anchors LLC) with male combination (central Locator abutment with a clear male, lateral Locator abutments with green males) (Fig 1).

There is as yet no consensus regarding whether closed- or open-tray techniques provide the best accuracy for three or fewer implants.⁴² Therefore, in the present study, the master cast was generated from the mandibular photoelastic model using a single-tray impression technique with a closed tray.⁴³ Impression copings (Tapered Screw-Vent) were screwed into the implants, and an impression of the photoelastic model was made with an elastomeric impression material (Optosil, Xantopren, Heraeus Kulzer) using a stock tray (Teknik Diş). The impression copings were removed after polymerization of the impression. The impression copings were attached to implant analogs (Tapered Screw-Vent), and these assemblies were inserted into the impression. The master cast was poured with type IV dental stone (Begostone, Bego Dental). One layer of baseplate wax (Cavex Dental Base Plates, Cavex Holland) was adapted to the posterior edentulous ridge of the master cast to mimic the thickness of the soft tissue.^{11,21,22} This layer was approximately 3 mm thick and consisted of light-body elastomeric impression material (Xantopren, Heraeus Kulzer) that would be injected onto the bilateral tissue surfaces of the dentures.

To fabricate bar attachments, shouldered abutments (TAC2, Tapered Screw-Vent) and plastic castable copings (Tapered Screw-Vent) were screwed onto the implants, and the screws were tightened with a hex

Fig 1 Tested attachment designs on the photoelastic model. (a) Bar attachment. (b) Bar/ball attachment. (c) Bar with distally placed Rk-1 attachments. (d) Locator attachments.

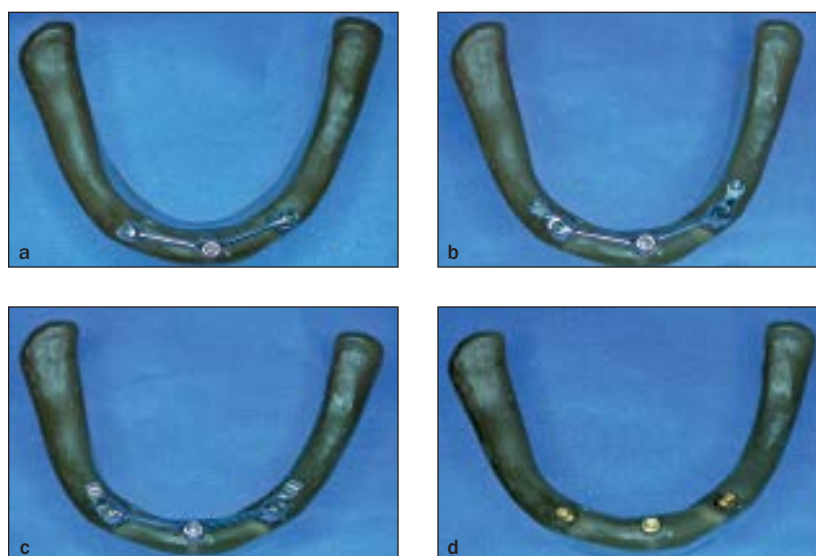
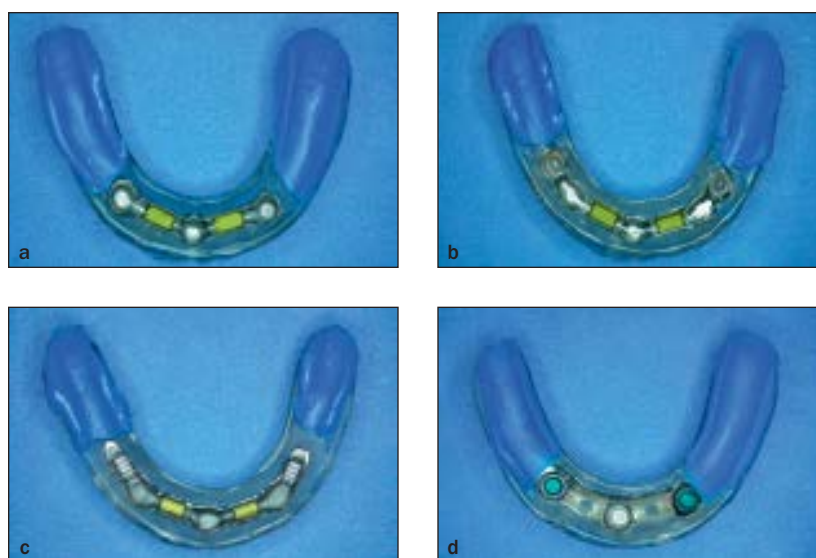


Fig 2 Internal view of the implant-retained overdentures with imitation soft tissue material. (a) Overdenture with bar attachment. (b) Overdenture with bar/ball attachment. (c) Overdenture with bar/Rk-1 attachments. (d) Overdenture with Locator attachments.



tool (Tapered Screw-Vent). Plastic castable Hader bars (Bredent) were placed between the plastic castable copings and attached with wax. For the designs that included a bar with distally placed attachments (bar/ball and bar/Rk-1), the ball (Bredent) and Rk-1 (Kargı Sağlık Hiz) attachments were fixed on the distal surface of the lateral copings using a surveyor (Paraskop M, BEGO). The bar, bar/ball, and bar/Rk-1 designs were cast in a base metal alloy (Biosil-F, Degudent). Passive fit of these designs was confirmed through the tightening of one of the screws and observation of complete seating at the other two implant-abutment interfaces.⁴⁰ If passive fit was not observed, the bar was sectioned, indexed, and soldered to acquire passivity. All of the bar

designs were screwed to the shouldered abutments by tightening them to 20 Ncm with a torque wrench (Tapered Screw-Vent). Direct abutments of the Locator attachments (Zest Anchors LLC) were screwed onto the implant analogs with an inserting core tool (Zest Anchors LLC). Metal frameworks were fabricated in base metal alloy (Biosil-F) for each design (bar, bar/ball, bar/Rk-1, and Locator).

Maxillary and mandibular stone casts were mounted to the articulator, and the denture tooth arrangement was completed using bony landmarks that were guided by the occlusal plane.²¹ Anatomic artificial teeth (Major, Major Prodotti Dentari) were used for denture setup. The mandibular cast with denture tooth

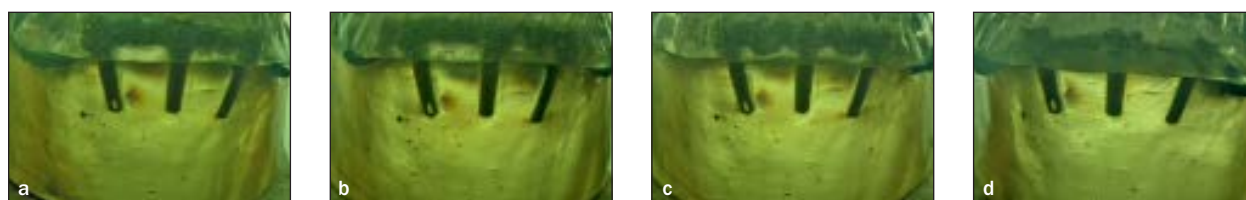


Fig 3 Evaluation of the model with overdentures before load application. (a) Bar attachment. (b) Bar/ball attachment. (c) Bar with distally placed Rk-1 attachments. (d) Locator attachments.

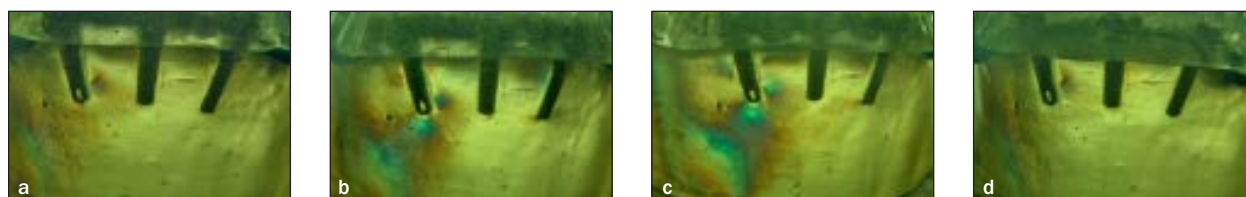


Fig 4 Frontal views of the stresses produced in the implant-retained overdentures. (a) Bar attachment. (b) Bar/ball attachment. (c) Bar with distally placed Rk-1 attachments. (d) Locator attachments.

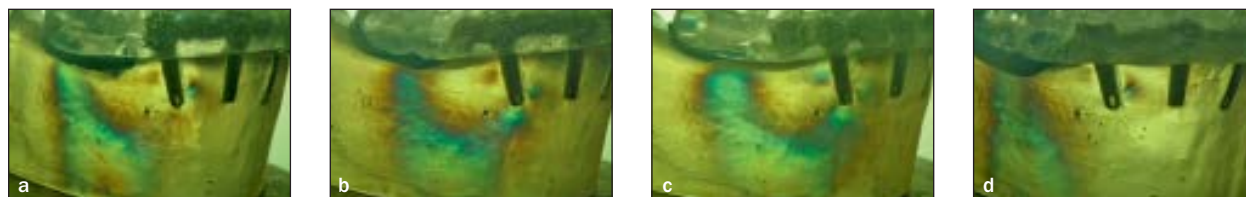


Fig 5 Lateral views of the stresses produced on the loaded side of the implant-retained overdentures. (a) Bar attachment. (b) Bar/ball attachments. (c) Bar with distally placed Rk-1 attachments. (d) Locator attachments.

arrangement was inserted into the lower portion of the injection flask (SR-Ivocap, Ivoclar Vivadent). A negative silicone mold was fabricated by putting heavy-body elastomeric impression material (Optosil) into the upper portion of the flask. The silicone mold was facilitated to duplicate the wax denture for each design. For each attachment design, the waxed denture was removed from the cast, and clear autopolymerizing acrylic resin (Futura Self, Schutz-Dental Group) was injected through the access openings of the injection flask into the space between the silicone mold and the master cast.⁷ In all, four overdentures were fabricated using the same approach (Fig 2). The clear acrylic resin was used to allow light transmission through the photoelastic model for evaluation of the stresses (Fig 3).⁴⁰

The soft tissues on the bilateral distal crests were imitated with a 3-mm layer of light-body elastomeric impression material (Xantopren, Hereaus Kulzer) that was injected onto the intaglio surfaces of the denture at the distal ends (Fig 2). All overdentures were placed onto the photoelastic model. The photoelastic mandibular

model was determined to be under negligible initial stress in the circular polariscope (Measurements Group, Instruments Division) before load (Fig 3).⁴⁴

To enable photoelastic observation, mineral oil (Castrol) was applied to the model via a cotton pellet (Boz Tekstil). The layer of oil helped to evaluate fringe colors. A custom-made loading device (Gazi University, Technical Education Faculty, Mechanical Education Department, Ankara, Turkey) applied 100-N vertical loads to the central fossa of the right first molar of the overdentures.^{45,46} The stress distributions of each of the designs were recorded with a camera (Fujifilm HS10, Fujifilm) using the circular polariscope (Measurements Group) (Figs 4 and 5). The images of all loaded designs were evaluated visually for fringe orders by a single researcher.

The stress intensity and locations were compared subjectively. Stress data were described and the following terminology was adopted: low stress = one fringe or less; moderate stress = between one and three fringes; high stress = more than three fringes.²⁰

RESULTS

The three-implant-retained overdenture with a bar attachment experienced low stress levels (less than one fringe order) around the apex of the ipsilateral implant. Little to no discernible stress was noted on the other implants (Fig 4a).

For the overdenture with a bar/ball design, moderate stress (1.5+ fringe orders) was observed on the loaded side of the implant apically. No stress patterns were seen around the center and unloaded implants (Fig 4b).

For the overdenture with a bar/Rk-1 design, moderate stress (1+ fringe orders) was observed along the body of the ipsilateral implant. Little or no stress was noted on the center and unloaded implants (Fig 4c).

For the overdenture with Locator attachments, no notable stress patterns were observed around the implants (Fig 4d). The occlusal load was transmitted to the edentulous ridge of the loaded side.

All designs showed moderate stress levels (one or more fringe orders) on the right posterior edentulous area (Fig 5). The bar/ball design showed higher stress levels than the other designs. The Locator attachment design transmitted little to no discernible stress through the implants. The bar, bar/ball, and bar/Rk-1 designs transmitted low to moderate stress to the ipsilateral implant.

DISCUSSION

Biomechanical complications are typically caused by the transmission of excessive occlusal forces to implants via the superstructure, potentially leading to failure of the implants.^{24,25} Balanced occlusion and attachment systems that ensure the most equitable transfer of loads can minimize stresses and bone resorption.²⁹

Ideally, implants should be embedded parallel to each other and the placement path of the denture. However, this condition is frequently not achieved because of variations in bone morphology and interference from crucial structures (eg, mandibular canal, mental foramen, maxillary sinus).⁷ Therefore, in the current study, the distal implants were placed at a 20-degree angulation relative to the central implant, so that the total divergence between the distal implants was 40 degrees. Extended-range locator males (green, orange, red, and gray) can tolerate this divergence between implant axes.⁴¹

Many different types of attachments (eg, bar, stud, magnetic, and telescopic attachments) can be used to retain an overdenture on implants.^{13,15} In addition, combinations of these attachments (eg, bar/ball

or bar/Locator designs) are commonly used by clinicians.^{7,16,18–23} In this study, Locator, bar, and two combination designs (bar/ball and bar/Rk-1) were fabricated.

The three implants were placed in the interforaminal region of the photoelastic mandibular model. Although a single material was used to represent both cancellous and cortical bone, the locations of stress points would be the same as in a more realistic condition.²¹

The McGill¹⁰ and York⁹ consensus reports suggested that the placement of two implants should be the standard protocol in the edentulous mandible. In contrast, Mericske-Stern et al¹² claimed that three or four implants are most suitable for the edentulous mandible, especially in patients with large or V-shaped anterior ridges, to ensure accurate bar designs and favorable overdentures. The authors did not recommend four interforaminal implants because of problems associated with short bars and clips. For this reason, three implants were embedded in the anterior ridge of the photoelastic mandibular model in the current study.

Many *in vitro* studies have compared the stress distribution of bar/clip and stud (especially ball/O-ring) attachments. No consensus has been reached regarding the most suitable attachment design for implant-retained overdentures.^{28,32–36,46}

Takeshita et al³⁶ evaluated stress concentrations on two-implant-retained mandibular overdenture designs with either bar, bar/ball, or magnet attachments. They observed that the ball attachments experienced the highest strain, followed by the bar and magnet designs. In another study using the same attachments with a two-implant-retained mandibular model, the authors found that the ball/O-ring attachments provided a good distribution of forces and thus reduced stress levels.³³ Tokuhisa et al³⁵ investigated the stress distribution on a two-implant-retained mandibular overdenture with the same attachments. The researchers concluded that the ball attachments experience the lowest stress and that the bar/clip attachments transmit the highest stress values around the implants.

Meijer et al²⁸ suggested that the use of stud attachments, instead of splinted implants with bars, ensures a balanced distribution of stresses. Similarly, Menicucci et al³⁴ reported that ball attachments transmitted less stress to the implants than a bar/clip design.

Celik and Uludag⁷ evaluated Locator, ball, bar, and bar/ball designs using photoelastic models with three implants. The bar/ball attachment design showed the lowest stress levels. The same authors¹⁹ also investigated the effect of the number of supporting implants (two or four) on the mandible and compared the stress distribution of extracoronary resilient attachment (ERA), bar/clip, bar/ball, and bar designs with distally placed

Easy Slot attachments. A bar with distally placed Easy Slot attachments caused the greatest stress, followed by the bar/ball, bar, and ERA designs. These findings indicate that the number and inclination of the implants do not significantly affect stress levels and concentrations. Accordingly, in the current study, the effects of the attachments were determined by comparing the stress distributions on a mandibular photoelastic model with inclined implants. Similar to the research of Celik and Uludag,¹⁹ in the present study, the bar/ball design resulted in the greatest stress level, while the Locator design caused no stress around the implants.

Fanuscu and Caputo²⁰ observed that a bar/ERA design generated greater stress than a ball/O-ring attachment in a mandibular photoelastic model with two and three implants. When Federick and Caputo²⁹ compared the stress distribution patterns of ERA and bar/ERA attachments retained by two angled or parallel implants, they concluded that the stud/ERA design resulted in a more balanced stress dispersion than the bar/ERA design. Another study evaluated four-implant-retained mandibular overdentures with four different retention mechanisms and found that, compared to the bar designs, the ball/O-ring attachment design transmitted less stress to the denture-bearing areas and around the implants.²¹

In the present study, the stress was distributed to the implants on the unloaded side and to the denture-bearing area. Many other studies have reported a similar phenomenon.^{7,19,20,40} As previously noted, there is no general consensus among researchers about which overdenture attachment type causes the least stress. This is likely a result of the many additional factors that might affect the load transfer characteristics, including the number, diameters, lengths, inclinations, and locations of the implants; interimplant distances; and the types of precision attachment. Findings from further studies investigating these factors would be helpful for clinical planning of implant-supported overdenture cases.

CONCLUSIONS

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

- For all denture designs tested, the least stress was transferred to implants with the Locator attachment system. No stress concentrations were found around the implants.
- For all overdenture designs, the highest observed stress level was moderate.
- A moderate stress level was noted in the posterior edentulous area for each design.

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