

# Mandibular Implant-Supported Overdenture: An In Vitro Comparison of Ball, Bar, and Magnetic Attachments

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In an implant-supported overdenture, the optimal stress distribution on the implants and least denture displacement is desirable. This study compares the load transfer characteristics to the implant and the movement of overdenture among 3 different types of attachments (ball-ring, bar-clip, and magnetic). Stress on the implant surface was measured using the strain-gauge technique and denture displacement by dial gauge. The ball/O-ring produces the optimal stress on the implant body and promotes denture stability.

**Key Words:** *overdenture, ball and ring, bar and clip, magnetic attachment*

## INTRODUCTION

**T**raditional mandibular dentures have limited retention and stability as they rest on the moving foundation provided by the mandible and its associated musculature. In the maxilla, the ability to cover a broader foundation presents the opportunity to fabricate a more retentive and stable denture.

Implant-supported overdentures are mainly useful for mandibular ridges, as they have undergone resorption and offer better retention than traditional dentures. However, the cost of implants is quite high; hence, the use of fewer implants (2 instead of 4) offers a less expensive option for an edentulous patient.<sup>1</sup> Nevertheless, stability cannot be compromised and should be given equal consideration.

Placement of the implants for overdentures in the mandible should be planned explicitly, as masticatory load transmission in mandibular implant-supported overdentures differs substantially from that of implant-supported fixed restorations.<sup>2</sup> In general, an implant should be loaded through axial forces. Importance should also be given to location and the number of implants being placed

in the dental arch, as well as the chewing function as horizontal forces and even moments can cause implant failure if these are ignored.

Mandibular implant-supported overdentures are generally retained by at least 2 implants, which are placed in, or slightly medial to, the canine area.<sup>3</sup> The commonly used forms of anchorage include ball attachments,<sup>4</sup> clips on a bar connecting the implants,<sup>5</sup> and magnetic attachments.<sup>6</sup>

Overdenture stability is a key factor for patient satisfaction<sup>7</sup> and is dependent on the ability of the implants to withstand occlusal loads. It is hence important to ascertain whether implants need to be splinted together or whether freestanding implants alone can withstand the loads.

The present in vitro study compared the load transfer characteristics to the implant and the movement of implant-supported overdentures among the 3 different types of attachments (ball and ring, clips on a bar, and magnetic).

The objectives of the study were to compare the following:

- Strain around the implant at the loading side and the nonloading side
- Bending moment transferred from the implant into the bone
- Denture displacement in mediolateral, upward-downward, and backward-forward directions

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## MATERIALS AND METHODS

### *Implants and attachments*

A castable bar of length 22 mm and clip length 16 mm were used for the bar and clip attachment. A metallic housing with a rubber O-ring component was used for the ball and ring attachment. Intraoral magnets (Alnico; power 600 g) were used for magnetic attachment. The length (14 mm) and diameter (4.3 mm) of the fixtures used were the same in all 3 types of attachments.

### *Edentulous mandibular model and overdenture*

Edentulous mandibular models were made from heat-cured polymethylmethacrylate resin. The surface of the acrylic resin was scraped and covered by a 2- to 3-mm thickness of polyvinyl siloxane impression material, to simulate resilient edentulous ridge mucosa.<sup>2</sup> Implants were placed in the canine region and retained with resin cement. Overdenture was fabricated in the conventional manner.

### *Strain-gauge installation*

The stress on the implant surface was measured using the strain-gauge technique. Strain gauges from the AP-2 series (Hytech micromerements), which have a specially treated constantan alloy as the basic material for the grid, was used. It has an adequately high level of strain sensitivity, which is relatively independent of temperature.

### *Surface treatment*

Before placing the strain gauge, surface treatment of the acrylic edentulous model was done using M Prep conditioner A (water-based acidic surface cleaner), M prep neutralizer 5A (water-based alkaline cleaner), and catalyst C for use with certified M bond adhesive.

### *Bonding cement*

For quick installation of gauges, and when long-term bond integrity is not important, cyanoacrylate adhesive is advocated and was used.

### *Testing procedure*

#### *Strain Around Implant*

Stress measured directly on the implant surface using the strain-gauge technique could be representative of stress that is introduced into the bone.

Four strain gauges were attached around each implant mesiodistally and buccolingually to measure the strain on the implant (Figures 1 and 2). The electrical signals from the 8 strain gauges were amplified and recorded using a switch and balance unit and a strain indicator. In the present study, a total of 24 strain gauges were used for the three attachments evaluated.

The arrangement of channels around the implants was as given in the Table.

### *Load application*

Loads were applied to the occlusal surface of the right first molar region (Figure 2). We used the 1-point concentration load of the molar part, in which the denture mobility is high, as it is almost impossible to reproduce the chewing pattern by in vitro experiments. A moderate level of biting force on an implant-retained overdenture was simulated. Loads from 0 to 50 N were applied gradually and increased in 10-N steps. Three sessions, one for each attachment, were performed at suitable intervals. Five measurements at each load (0, 10, 20, 30, 40, and 50 N) were made under the same conditions, allowing at least 5 minutes for recovery.

### *Bending moment*

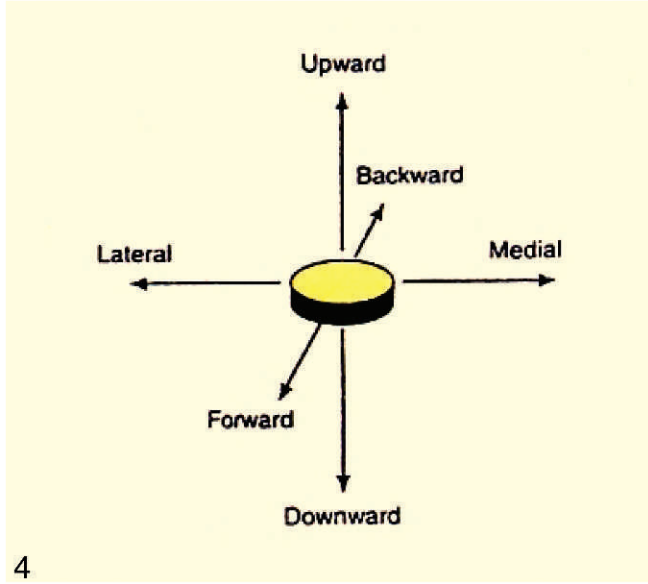
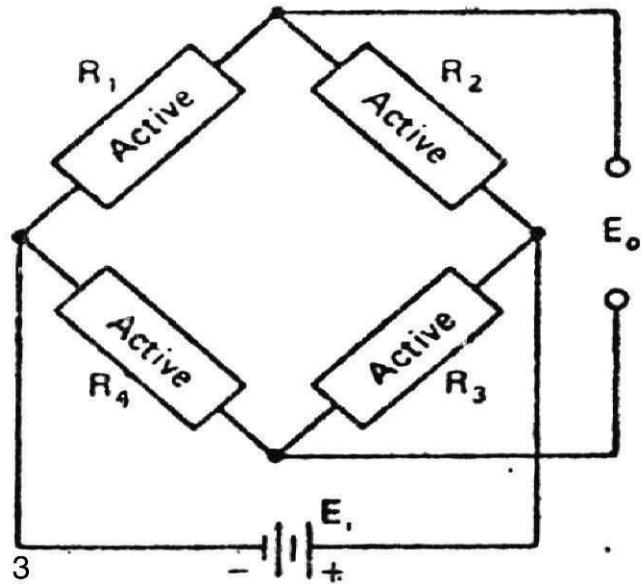
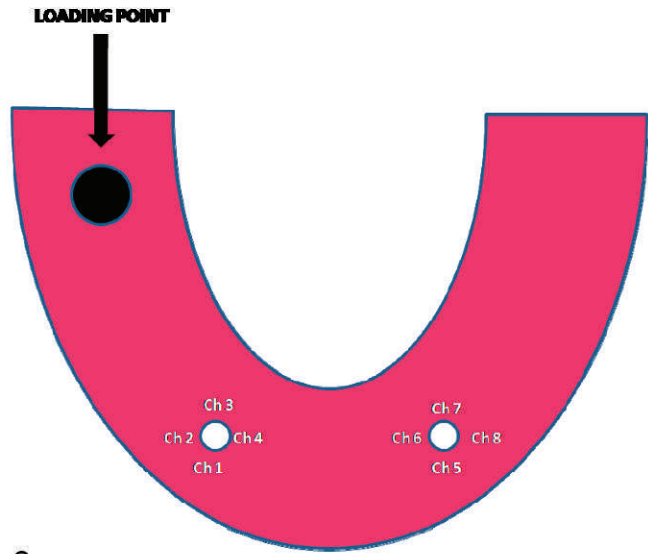
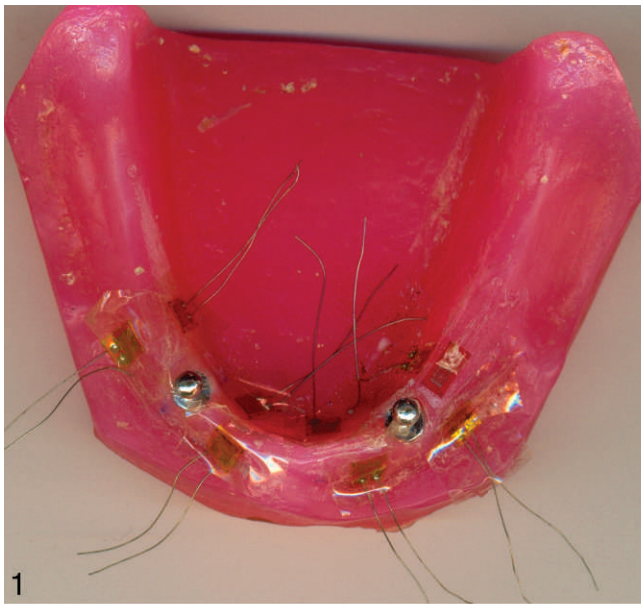
Each sequence of strain data was used to calculate the bending moment transmitted to the implant. A  $\frac{1}{4}$  Wheatstone bridge configuration was used to measure axial strains on the implant abutments. Pairs of opposing gauges were wired in a  $\frac{1}{2}$  Wheatstone bridge configuration, to double the sensitivity to bending in the buccolingual and mesiodistal plane.

### *Wheatstone bridge configuration*

The constant voltage Wheatstone bridge consists of 3 parts, as shown in Figure 3. There are 4 resistors— $R_1$ ,  $R_2$ ,  $R_3$ , and  $R_4$ —arranged in a bridge configuration, and the readout circuit consists of loads resistance,  $R_m$ .

In the following equations, the value of  $R_m$  is assumed to be infinite so that no current is drawn from the bridge.

For the Wheatstone bridge, the output voltage  $E_0$  is given by



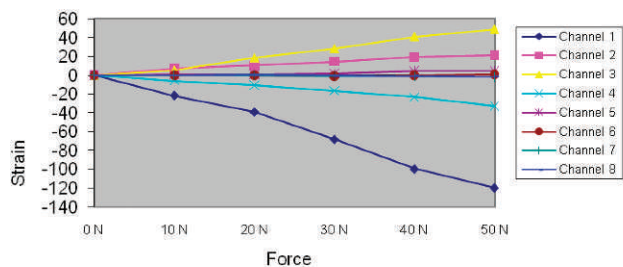
FIGURES 1-4. FIGURE 1. Strain gauge arrangement. FIGURE 2. Channels and loading point. FIGURE 3. Wheatstone bridge configuration. FIGURE 4. Denture displacement directions.

$$E_0 = \frac{R_1 R_3 - R_2 R_4}{(R_1 + R_2) R_3 + R_4} E_1$$

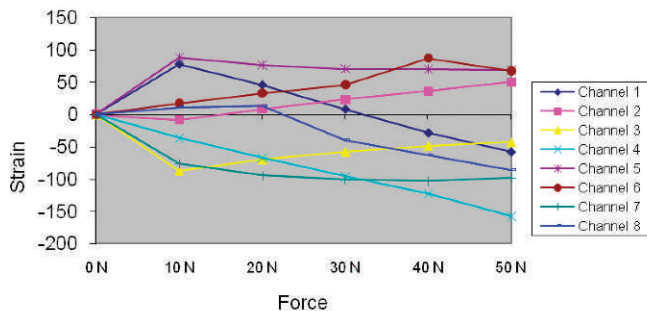
TABLE		
Arrangement of channels around implants		
Channel		Site
Loading	Nonloading	
1	5	Buccal
4	6	Mesial
3	7	Lingual
2	8	Distal

*Denture Movement by Dial Gauge Technique*

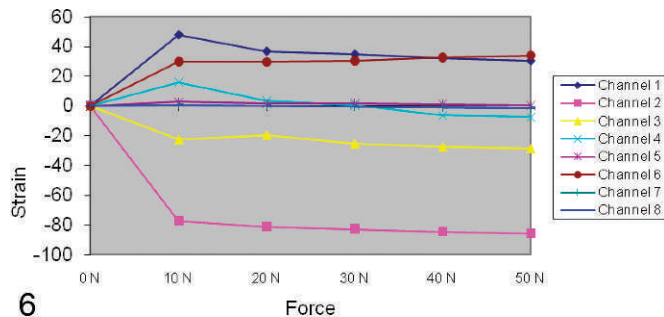
The digital counter-type dial gauges were used for measuring denture displacement. The important feature of this technique is easy and error-free reading, with both up and down digital counters as well as a dial. It is provided with a feed wheel for easy course feeding, and a heavy duty type is



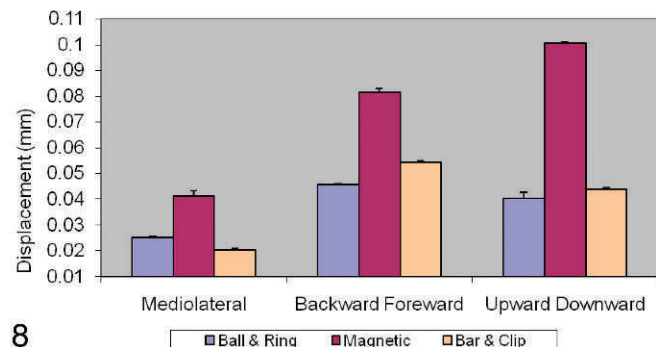
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7



6



8

**FIGURES 5–8.** **FIGURE 5.** Strain in the implant during load application in the ball and ring attachment. **FIGURE 6.** Strain in the implant during load application in the magnetic attachment. **FIGURE 7.** Strain in the implant during load application in the bar and clip attachment. **FIGURE 8.** Denture displacement noted across different attachments.

available with a long scribe. Denture displacement in mediolateral, backward-forward, and upward-downward directions can be detected with this technique (Figure 4).

**Statistical analysis**

The means and standard deviations were calculated, and statistical comparison was made using a 1-way analysis of variance (ANOVA) and Duncan’s calculation for post hoc comparisons.

**RESULTS**

**Strain measurements**

*Ball and Ring Attachment*

At the beginning of the load, the ball and ring transmitted a small strain in each channel (Figure 5). The strain increased linearly as the load was increased. In addition, the strain on the implant at the loading side was greater than at the non-loading side implant. The maximum compressive strain occurred in channel 1, the buccal site of the loading side implant. The maximum tensile strain was observed in channel 3, the lingual site of the loading side implant.

*Magnetic Attachment*

With the magnetic attachment, the strains in the 8 channels differed at the initial load; unlike the ball attachment, but beyond 5 N, the strains in each channel were almost constant (Figure 6). The maximum compressive strain was found in channel 2, the distal site of the loading side implant. The maximum tensile strain was found in channel 6, the mesial site of the non-loading side implant.

*Bar and Clip Attachment*

With the bar attachment, the strains in the 8 channels differed at the beginning of the load, and no clear trend in strain change was noted with load increase (Figure 7). While some of the channels changed from compressive strain to tensile strain, a few changed from tensile to compressive strain. The maximum compressive strain was found in channel 4, the mesial site of the loading side implant. The maximum tensile strain was detected in channel 6, the mesial site of the non-loading side implant.

**Bending moment**

Bending moment was calculated from strain at 50 N for different types of attachments at loading and

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nonloading sites. Duncan's post hoc analysis (1-way ANOVA test) showed that the bending moment (measured in microns,  $\mu$ ) for magnetic attachment was very less, whereas for ball and ring and bar and clip, it was not statistically significant. At the nonloading site, the bending moment was highly significant between the 3 attachments.

### **Denture displacement**

In the mediolateral direction, the denture displacement with the magnetic attachment was highly significant (Figure 8;  $P < .01$ ). The difference in denture displacement between ball and bar attachments was also significant. Least displacement occurred in the bar and clip attachment.

In the backward-forward direction, the ball attachment had significantly less displacement than the other attachments did ( $P < .01$ ), while maximum displacement was noted with magnetic attachment.

In the upward-downward direction, magnetic attachment had a significantly greater displacement ( $P < .01$ ). The difference between ball and bar attachments was also significant ( $P < .05$ ).

Based on Duncan's post hoc analysis for total displacement, the ball and ring and the bar and clip attachments did not show any statistically significant difference. On the contrary, the values obtained for magnetic attachment were highly significant.

### **DISCUSSION**

In an implant-supported overdenture, 2 basic factors are to be minimized. One is the stress on the implants and the other is the movement of the denture. Numerous methods have been followed to achieve this goal. The role of anchorage, which includes ball attachments,<sup>4</sup> clips on a bar connecting the implants,<sup>5</sup> and magnetic attachments<sup>6</sup> was reported to be quite important.

Cost is an important factor that determines the placement of implants. By reducing the number of implants required to support an overdenture, the cost can be considerably reduced. Two instead of 4 implants in the mandible can also offer an almost equal amount of stability to the denture. A multicentric study of overdentures supported by 2, 3, and 4 Branemark implants advocated the placement of 2 implants in the mandible (canine

region) for uniform load distribution and denture stability.<sup>1</sup>

The assumption that unfavorable loading of implants may lead to bone resorption has been neither confirmed nor rejected.<sup>8</sup> Therefore, it is necessary to learn more about naturally occurring forces in vivo.

Because of technical difficulties, in vivo measurements of forces with the transducers mounted directly on the implants are rare. In the present study, stress on the implant surface was measured using a strain-gauge technique and denture displacement by the dial gauge technique.

The strain-gauge device offers quite reliable measurements as noted by Duyck and Van,<sup>9</sup> who performed a methodological study to measure the 3-dimensional forces on oral implants using this technique. Digital counter-type dial gauges, on the other hand, are a comparatively newer and reliable method for measuring various linear displacements.

Various earlier studies have evaluated the different types of attachments used to stabilize the implants. When a photoelastic model was subjected to a posterior vertical load, the ball and O-ring attachment transferred less stress to the implant than the bar and clip attachment.<sup>10</sup> When ball and bar attachments were compared using 3-D finite element analysis methods, the peri-implant bone stress was greater with bar and clip attachments.<sup>11</sup> However, these studies<sup>10,11</sup> focused only on minimizing the stress on the implant and peri-implant tissue without considering the stability.

We found that with ball and magnetic attachments, the strain was concentrated on the loading-side implant. The stress on the loading side implant was small when the load was slight because of the secondary splinting that occurs with ball attachments. The bar attachment, on the contrary, produced higher stress on the non-loading side implant when compared with the ball and magnetic attachment because of the primary splinting effect even at low pressure.

Our result is consistent with a previous study that noted that the axial force on the loading-side implant was minimal with the ball attachment.<sup>12</sup> This may be the result of the stress-absorbing effect of the rubber O-ring component. Under our experimental condition, in which a ball attachment was used, the force was not transmitted to the implant body. The force may have been absorbed at

the rubber O-ring component and anchor head connection. Therefore, in the long term, prosthetic complications such as screw loosening or the need to replace O-ring matrices may occur.<sup>13</sup>

With single ball anchors, the forces in centric occlusion and on the ipsilateral implant, when using a bite plate, were slightly increased in the vertical and backward forward dimensions compared with the mediolateral direction.<sup>8</sup> On the contralateral side, equally low values were found. On the contrary, we found that a connection between 2 implants burdened the non-loading side implant from the viewpoint of bending moment.

Of the 3 attachments, the ball attachment resulted in the least denture displacement. This is thought to be due to the presence of the rubber O-ring and deformation of the denture. Our experimental conditions, such as the position and direction of the applied force, and the dial gauge position may also have contributed to this result.

Even though magnetic attachment induced the least bending moment, it resulted in greater denture movement. The main drawback of magnetic attachment, however, is its corrosive nature and power deterioration.<sup>14</sup> A high correlation exists between patient satisfaction and denture stability, and it was found that magnetic attachment would not significantly improve the patient's satisfaction.

### CONCLUSION

It is obvious that implants cannot be stress free in cases such as this experimental model. Since implant failure can result from excessive load on the implant, the practical goal for the clinician is to avoid excessive stress on the implants. Until future scientific studies provide insight into the biologic effects of interfacial stress transfer, one goal of the clinician should be to provide the most favorable delivery of forces to the implant through proper prosthesis design. We suggest that ball/O-ring attachments might provide an adequate system

with respect to reducing the stress on the implant and promoting denture stability.

### ABBREVIATION

ANOVA: analysis of variance

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