Influence of Rigid Bar and Nonrigid Double Crown Attachments on Maxillary Implant Overdentures: An In Vitro Study with Differential Bone Quality

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Purpose: To evaluate the bending strain exerted on a maxillary implant overdenture supported by rigid bar and nonrigid double crown connectors in models of high- and low-quality bone. Materials and Methods: Four implants were embedded in acrylic resin models of an edentulous maxilla simulating good- and poor-quality bone at the canine and second premolar regions bilaterally. A bar (cross-section dimension: 5 × 5 mm; bilateral distal extension: 10 mm) and double crown connectors with a metal framework (same morphology as the bar) were attached to these implants and placed under a constant 49 N vertical load at the anterior and cantilever regions of both superstructures. The bending strain on the implants was measured by strain gauges attached to the implant surfaces. Results: In good-quality bone with cantilever loading, the strain—which was highest near the load for both attachment systems—was highly concentrated in the rigid bar system but dissipated through the double crown connector. The directionality of the bending moment was homogenous on the two attachments. In poor-quality bone, strains were significantly lower and more variable, especially for double crown connectors, and there was heterogeneity in the directions of the bending moment. Conclusion: Within the limitations of this study, bar and double crown connectors have identical biomechanical features in good-quality edentulous maxillary bone, but have divergent properties in poor-quality bone. Int J Oral Maxillofac Implants 2018;33:764–769. doi: 10.11607/jomi.6128

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In addition to providing sufficient support, retention, and stability, a maxillary implant overdenture (IOD) can offer superior phonetics, esthetics, and hygiene.1 Several attachments have been developed to retain IODs, and these are mainly classified as either splinted (eg, bar type) or unsplinted (eg, ball type) anchorage systems.2 These variants offer different biomechanical features.3,4

In the edentulous mandible, rigid splinted attachments and nonrigid double crown connectors for IOD anchoring have been evaluated for their effects on implant survival/success, marginal bone resorption, pocket depth, Gingival Index, calculus accumulation, and prosthodontic maintenance efforts during the follow-up period.5–10 There was no significant difference between the two attachments in terms of implant loss and implant marginal bone loss, although double crown connectors did appear to promote a healthier gingival structure.

While the use of double crown connectors to retain IODs in the mandible is an established treatment modality, their use in the edentulous maxilla remains contentious.11,12 The bone quality and quantity are often inferior in the edentulous maxilla, which influences its capacity to endure physiologic mechanical loads and the clinical effectiveness of maxillary IODs.2,13 From a biomechanical perspective, strain has both positive and negative consequences for bone tissue.14,15 High-quality bone has greater capacity to resist whole bone deformation during physiologic loading,16 implying that low-quality bone is more at risk from strain transference during loading. Therefore, it is important to understand the magnitude and direction of bone strain experienced at the bone-implant interface in bone of poor quality during treatment with maxillary
Implant treatment in the edentulous maxilla is challenging and may result in further reduction of bone quality and volume. Advanced atrophy of the alveolar crest calls for prosthesis stabilization, which is best achieved using bar or double coping connectors with a parallel-walled design. The working hypothesis of the present study was that—in different conditions of bone quality—the rigid splinted and nonrigid unsplinted anchorage attachments would have a differential influence on the force/strain imparted on an implant in the edentulous maxillary ridge. In the present study, the bending strain on a rigid milled bar and nonrigid double crown attachments used to attach maxillary four-implant overdentures was evaluated in an in vitro model.

MATERIALS AND METHODS

This study employed acrylic resin maxillary edentulous models (Palapress Vario, Heraeus Kulzer) designed to simulate good-quality and poor-quality bone with high and low capacity, respectively, to resist excess deformation (Fig 1). In the poor-quality bone model, a sagittal slit (width: 1 mm; depth: 33 mm) at the midline and two bilateral cavities at the posterior tooth-bearing regions were designed to simulate features that contribute to the capacity of the maxilla as a whole to undergo deformation (Fig 1b). Four implants (3.75 × 10 mm, Brånemark MK III Groovy, Nobel Biocare) were embedded bilaterally in the maxillary model at the canine and second premolar regions (Fig 1).

A bar attachment designed by computer-aided design/computer-assisted manufacturing (CAD/CAM) (cobalt-chrome alloy; cross-sectional dimension: 5 × 5 mm) (Atlantis ISUS, Dentsply-Sankin) with a bilateral distal cantilever (extension length: 10 mm) was fabricated and connected to the implants on the model (Fig 2a). Attachment rigidity and resilience characteristics have been found to influence the lateral force imparted to the implant, which produces differential biomechanical features during loading. The double crown is typically fabricated from cast noble alloy with a vertical height of at least 4 mm. Recently, electroformed gold coping has been used to achieve a more precise fit and improve the wear resistance. Rinke et al reported on the successful function of double crown IODs composed of electroformed gold coping and titanium abutment cemented with zirconium coping. Based on these findings, for the unsplinted anchorage system in this study, four titanium abutments milled with a taper of 4 degrees (height: 4 mm; Nobel Biocare) were connected to the implants. Next, the outer crowns were fabricated with electroformed gold (AGC system, Wieland Dental) and secured into the metal framework with resin cement (ResiCem, Shofu) (Fig 2b). The metal framework for the double crown–retained overdenture (cobalt-chrome alloy; cross-sectional dimension: 5 × 5 mm; bilateral distal cantilever: 10 mm) was fabricated with the same dimensions as the bar attachment to allow direct comparison.
The model was positioned on a universal testing machine (Ito Engineering Corporation). Two miniature strain gauges (KFG-03-120-C1, Kyowa Electronic Industries) were attached 2 mm below the platform of each implant at its mesial and distal surfaces to simultaneously measure the bending strain around each implant under loading (Fig 1), in accordance with the Ogata et al study.23 The output from the strain gauges was transferred to an A/D converter through an amplifier (PCD-300A, Kyowa Electronic Industries) with proprietary software (PCD-30A, Kyowa Electronic Industries). Output from the strain gauges was calibrated for defined loads, and the linearity of the output indicated an error less than 5%. Before making test measurements, the validity of the model was confirmed by applying loads of 400, 800, 1,200, 1,600, and 2,000 gf perpendicular to the axis of the implant. The results from these calibrations replicated the findings of an in vivo study by Hotta,24 which measured implant displacements in the oral cavity (Fig 3).

Test measurements were collected from regions 1, 2, 3, and 4 indicated on the model in Fig 1. The formula for calculating the bending strain at each location was:

\[ \text{Bending strain} = \frac{\text{distal strain value} - \text{mesial strain value}}{2} \]

Negative and positive values represent a direction of bending moment toward the mesial and distal sides, respectively.

A vertical static load of 49 N simulating a masticatory force25 was applied five times to the superstructure directly at the bar and double crown attachments at anterior (center of the superstructure between the bilateral canine implants) and cantilever sites (5 mm distally away from the premolar implant) (Fig 1).

Statistical Analysis

Absolute values of the bending strain were used for comparison in the study. The results collected from the four locations were analyzed using one-way analysis of variance (ANOVA), with \( P < .05 \) considered to be statistically significant. The Bonferroni correction was used to adjust for multiple comparisons. Additionally, \( t \) tests were used to confirm the difference between the two different attachment systems at each location. All data were statistically analyzed using SPSS 20 software (IBM).

RESULTS

Strain Values in Attachments Mounted in Good-Quality Bone

Table 1 and Fig 4 show mean values of bending strain measured around the implants supporting the bar and double crown attachments in the model of high-quality bone. The highest bending strain values were found with cantilever loading (Fig 4b), and lower values upon anterior loading (Fig 4a). These findings were most pronounced for the nonrigid double crown connectors. With cantilever loading, the strain was concentrated almost entirely at region 4 in the bar configuration (with negligible strain in regions 1, 2, and 3), whereas the strain was dissipated through the double crown connector, with the highest strain again found at region 4 but with regions 3, 2, and 1 experiencing appreciable but decreasing strain (Fig 4b). With anterior loading, both systems experienced similar strain at regions 2 and 3, but the double crown system produced higher strain in regions 1 and 4 (Fig 4a). Evaluation of the bending moment showed that anterior and cantilever loading both produced a bending moment toward the loading point in both systems (Figs 4a and 4b).

Strain Values in Attachments Mounted in Poor-Quality Bone

Table 2 and Fig 5 show the mean values of bending strain measured around the implants supporting the bar and double crown attachments in the model of poor-quality bone. The highest bending strain values were again measured following cantilever loading, but were markedly lower than in the high-quality bone (Fig 5b). Less strain was evident upon anterior loading, but there was more variability in the regional differences in measured strain (Fig 5a). Interestingly, there was no clear trend in which system and which region experienced the highest strain for any given loading. Additionally, evaluation of the bending moment showed a significant heterogeneity between the two attachment systems, irrespective of the loading point (Fig 5).
DISCUSSION

In good-quality bone, strain was concentrated in the bar configuration because of the rigidity of the connector and the high capacity of the bone to resist excessive deformation. Conversely, where the attachment system had some degree of circumferential “play” between the primary and secondary copings (ie, the double crown attachment), the high deformation resistance of the bone caused the strain to be transferred widely throughout the connector itself. Additionally, the biomechanical features and directionality of the bending moment (toward the loading site) were very similar in the bar and double crown attachment systems, suggesting a very predictable distribution of strain through this type of bone.

In contrast, strain values in poor-quality bone were generally lower with a less clear trend toward strain dissipation for both attachment systems, and divergent biomechanical features in relation to the direction(s) of the bending moment resulted. In the anterior loading case (Fig 5a), higher strain was concentrated at region 2 in both attachments, but lower strain was found at region 3 of the opposite site, which suggests less predictable and uniform distribution of strain through this type of bone. Therefore, bone quality appears to play a significant role in strain distribution: nonrigid attachments for maxillary IODs produced wide distribution of strain transference into poor-quality bone. However, whether the understanding of this wider force/strain distribution and increased bone deformation in the edentulous maxilla can lead to improved maxillary IODs with enhanced clinical effectiveness should be fully evaluated in an in vivo study.

The present study focused on the biomechanical effects of bar and double crown attachments in terms of the peri-implant strain distribution under loading. Implants with an external abutment connection were embedded in a homogenous acrylic model with features designed to simulate bone deformation in the maxilla; this simplification may have introduced limitations into this study. Different implant-abutment
connection designs have been shown to influence the stress distribution under loading. Clinically, a number of different double crown connectors with primary and secondary copings have been fabricated to retain overdentures, including 0 degrees of frictional parallel-wall telescopic design or 4 to 6 degrees taper of conical double crown type.

To prevent the results being influenced by different denture materials and morphologies, the loading was simplified for direct application on the bar and double crown superstructures. However, there are usually retentive devices connected on the bar attachment. Measurements on the framework with retentive devices on the bar would more closely match clinical conditions and should be evaluated to properly compare double crown connectors. Moreover, measurements were taken in dry conditions; however, saliva flow resistance enhances the retentive appearances of attachment systems, especially in electroformed double crown connectors. The results of the present study should be interpreted with caution, and further studies are needed to evaluate the detailed strain/stress distribution around the implants under clinical conditions.

**CONCLUSIONS**

Within the limitations of this study, the following conclusions were drawn. In the model of an edentulous maxilla with good-quality bone, IODs with rigid bar and nonrigid double crown attachments had similar biomechanical properties and effectiveness with regard to strain concentrations and bending moments. However, higher strain values were found in double crown attachments. Strain was concentrated close to the loading point in the bar configuration, but was distributed widely across double crown attachments. In the model of an edentulous maxilla with poor-quality bone, the highest strain values were found at cantilever loading of the bar and double crown attachments, but were markedly lower than in the high-quality bone. The biomechanical effectiveness of the two attachments was divergent. Less strain was exerted on the two systems, particularly in double crown connectors, suggesting more strain transference to the bone.
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REFERENCES


