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MECHANICAL ANALYSIS OF THE EFFECTS OF IMPLANT POSITION AND ABUTMENT HEIGHT ON IMPLANT-ASSISTED REMOVABLE PARTIAL DENTURES

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Abstract
Purpose: Dental implants are being used as abutments in implant-assisted removable partial dentures (IARPD) in an increasing number of clinical findings. We evaluated IARPD as a unilateral mandibular distal extension denture using three-dimensional in nature finite element analysis. In particular, the abutment tooth, denture, and tissue supporting the denture were evaluated for mechanical impacts of implant position and abutment height. Methods: The models used for analysis were prosthetically restored first and second molars, as well as the second premolar, on the left side of the mouth. One implant was used for each tooth position. There were two abutment heights: one that was the same as the mucosa and the other that was 2 mm higher. Six different models were built.

Results-Mobility of the abutment tooth was less for implants positioned distally to the abutment tooth than for those positioned medially to the abutment tooth for mucosal-level abutments. The displacement of the abutment tooth was less for implants placed medially to the abutment tooth than for those placed distally to the abutment tooth with raised abutments.

Conclusions: In relation to implant abutment height, the mechanical effects on abutment teeth at the same implant site varied.

Introduction

The practical use of dental implants as abutments for implant-assisted removable partial dentures (IARPD) is being documented in an increasing number of papers [1–5]. IARPD are less invasive and more affordable than fixed implant bridges because fewer implants are needed for the edentulous region [3,4]. IARPD improve implant support and diversify the fulcrum line, which also reduce denture movement [1–5]. Increased im- plant support was found to reduce denture movement in prior studies [6–8], but a few investigations have employed finite element analysis to assess the efficiency of IARPD with regard to mechanical properties. Particularly, it is not well understood how the biomechanical effects of implant position and the bracing affect on the tissues around the implant in free-end dentures. In this work, we evaluated the prosthetic treatment with IARPD as a unilateral mandibular distal extension denture using a three-dimensional finite element modelling. We specifically evaluated the mechanical effects of implant location and abutment height on abutment teeth, dentures, and denture-supporting tissue to better understand criteria for selection of implant location and appropriate abutment height in patients needing IARPD.

Methodology

Models of prosthetic therapy with IARPD employing a single implant were examined for defects in the left mandibular second premolars and first and second molars (Fig. 1). The teeth (dentin), cancellous bone, cortical bone, mucosa, periodontal ligament, metal crown, denture base, metal flame, implant, and abutment were the parts of the analytical model. At the location of the first or second molars, or the second premolar, one implant was placed. Three models (5-0, 6-0, and 7-0) used mucosal-level abutments that were higher than the mucosal-level abutments (H abutments) in the analysis of six models (Fig. 2). The analytical model was created by processing computed tomography (CT) images of a replicative skull model with CAD software (Rhinoceros Ver. 1.0, Robert McNeel & Associates, Seattle, WA, USA), 3D direct modeller and finite element software (ANSYS Rel. 18.2, ANSYS Inc. According on previously published information, models for cortical bone, cancellous bone, and mucosa were created.[9–11]. The implant body was a screw-type . The proposed occlusal plane and the implant were positioned perpendicularly. The implant platform height was adjusted so that it matched the top of the cortical bone, and the central axis of the implant and abutment were aligned. The implant and cortical bone made 100% of bone contact.
An RPI clasp for the left first premolar, a mesial rest for the right primary premolar, and an Akers clasp for the right first molar made up the framework of the retainer. A lingual bar served as the main connector. The frontal plane is represented by the XY plane, the sagittal plane by the YZ plane, and the horizontal plane by the XZ plane in a rectangular system of coordinates. The occlusal plane and the XZ plane were parallel.

Table 1-Properties of materials used.

Model	**Young's modulus (MPa)**	**Poisson's ratio**
Teeth (dentin)	1.37×10^{4}	0.3
Cancellous bone	7.80×10^{3}	0.3
Cortical bone	2.28×10^{4}	0.3
Mucosa	4.50×10^{-2}	0.49
Periodontal ligament (1st load)	4.90×10^{-2}	0.49
Periodontal ligament (2nd load)	0.30×10^{1}	0.49
Metal crown (gold-silver-palladium alloy)	8.13×10^{4}	0.3
Denture base (acrylic resin)	2.38×10^{3}	0.3
Flame work (Co-Cr alloy)	2.18×10^{5}	0.3
Implant, abutment (titanium)	1.17×10^{5}	0.3

The properties of the periodontal ligament and mucosa approximate previously reported pressure-displacement values. To reproduce biphasic tooth movement, two types of periodontal ligament (with differing properties) were used.

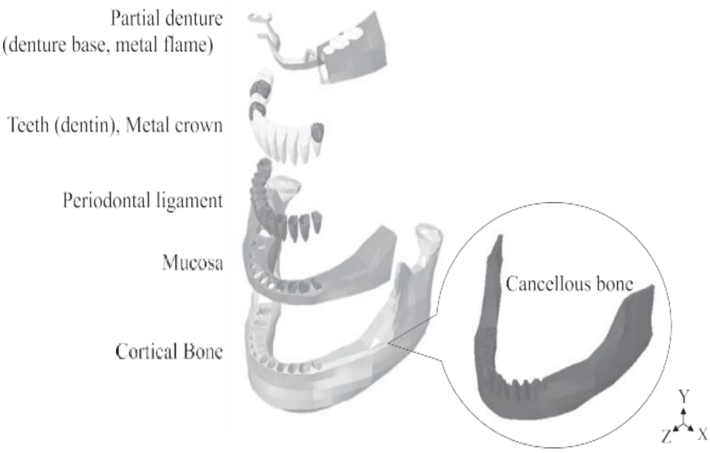


***Fig. 1.** Analytic model (Base model). The analytic model comprised defects of the left mandibular second premolar and first and second molars, which were prosthetically treated with IARPD. The implant is not positioned in this basic model*

Material properties

In Table 1 [12–21], the materials' qualities are displayed. The periodontal ligament and mucosa's material characteristics are close to previously reported pressure-displacement values [12,14,16]. Two distinct kinds of periodontal ligament were applied in an effort to mimic the biphasic movement of teeth. Occlusal contact and the stress placed on of the mandible by the masticatory muscles during biting in the intercuspal position limit loading and boundary conditions, meaning that the load characterises muscular activity as a contraction component associated with every muscle. [22].
The muscles engaged include the masseter muscles (shallow and deep), middle pterygoid muscles, temporalis muscles (anterior, middle, and posterior), lateral pterygoid muscles (upper and lower), and anterior belly of the digastric muscles (Table 2) [22].

With the use of finite element analysis software, mechanical evaluation was carried out utilising isotropic structural non-linear static analysis. Between the metal frame and teeth, between two teeth, and between the denture base and abutment, contact devices that replicated discontinuities between model components were also used.

The mesh tool in the ANSYS software programme was used to create tetrahedral meshes for the analytical models. The 5-0 model had 278.792 elements and 506.036 nodes, the 6-0 model had 278,654 elements and 505.986 nodes, the 7-0 model had 277.007 elements and 503.768 nodes, the 5-2 model had 279,283 elements and 507,106 nodes, the 6-2 model had 280.144 components and 508.162 nodes, and the 7-2 model had 280.144 elements and 508.162 nodes. The displacement of the left mandibular first premolar and denture base, as well as the minimal primary stress on the cortical bone surrounding the implant neck, were the factors assessed.

Right mandibular first premolar and denture base distance and direction of movement from cortical bone of the tooth and denture base were measured. The buccal cusp tip and root apex were used to measure the right mandibular first premolar (fig. 3). In addition, 16 places on the denture base's inner surface were examined (fig. 3). Utilising contouring scans of the minimal principal stress distribution and minimum principal stress values, the stress on the cortical bone surrounding the implant was assessed.

Fig. 2. *Analytic model (implant-positioned model). The implant was positioned at the site of the second premolar or first or second molar. Six models were constructed: three (5-0, 6-0, 7-0) with the abutment at the height of the mucosa and three with the abutment extending 2 mm above the mucosa (5-2, 6-2, 7-2).*

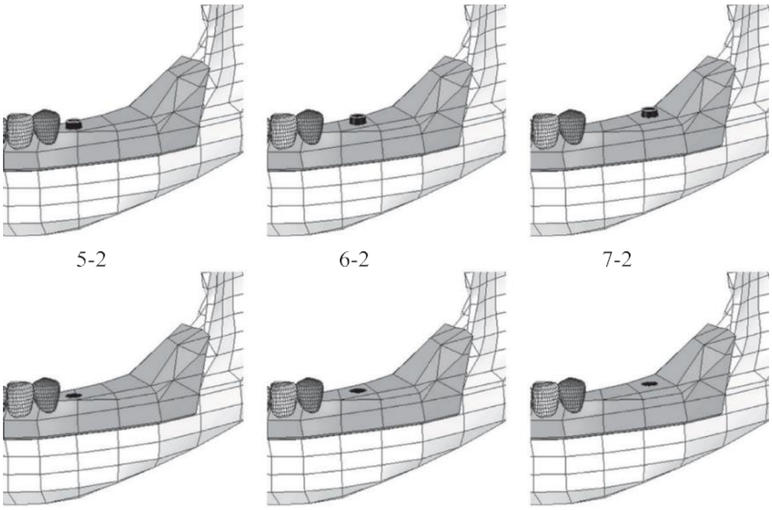


Table 2*- Mechanical analysis at the intercuspal position was possible because, by constraining the occlusal contact point and loading the putative muscles of the mandible, the models were able to closely simulate the forces in the human body.*

		Node numbers	**Loading force (*N*)**
Masseter muscle	Shallow part	14	190.4
	Deep part	5	81.6
Medial pterygoid muscle		11	132.8
Temporal muscle	Anterior part	9	154.8
	Middle part	12	91.8
	Posterior part	9	72.6
Lateral pterygoid muscle	Superior head	3	16.9
	Inferior head	3	18.1
Digastric muscle	Anterior belly	1	11.2

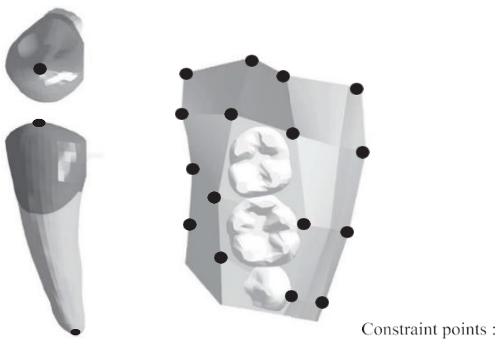


Fig. 3 *Measurement points. The measurement points were the tip of the buccal cusp and root apex of the right mandibular first premolar and 16 points on the inner surface of the denture base*

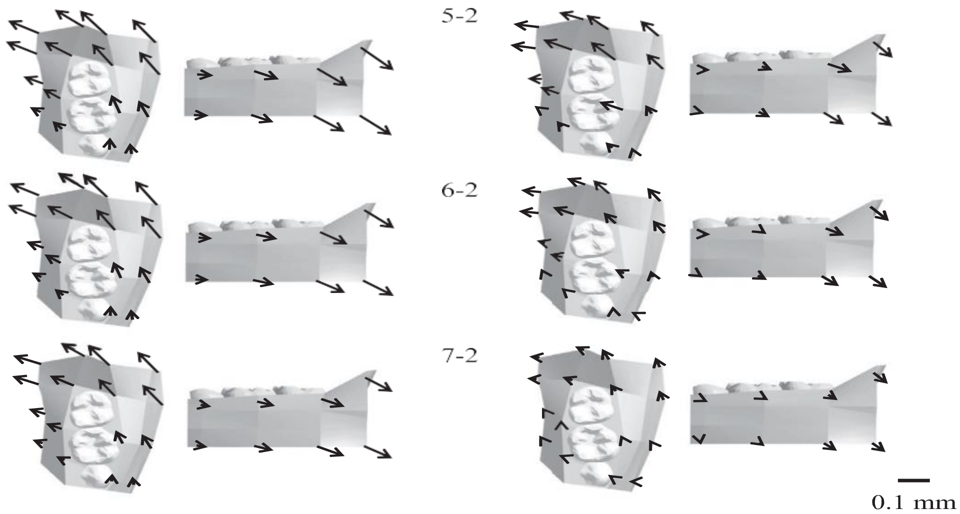


Fig. 4. *Displacement and direction vectors. The displacement and direction vectors for each measurement point are shown in occlusal and labial views of the denture base*

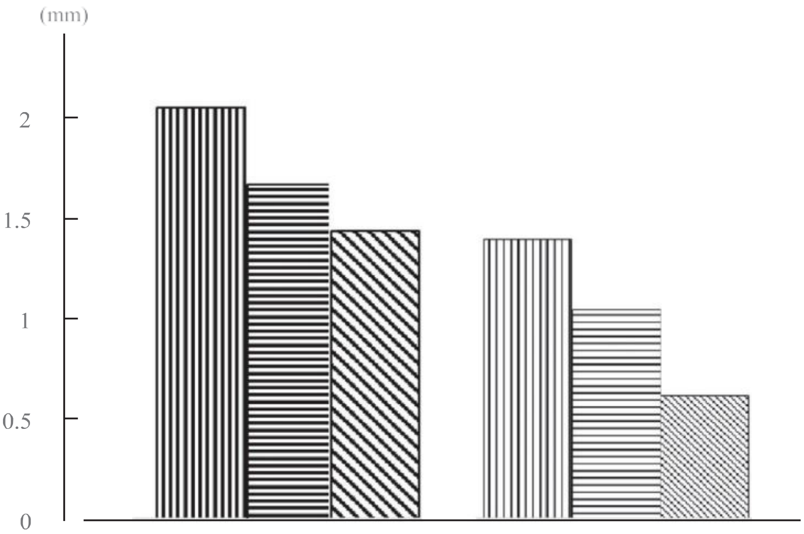


Fig. 5. *Displacement distance of denture base. The graph shows the sums of the displacement distances at the measurement points of the denture base.*

Results

Denture base

Figure 4 displays the displacement and direction vector for each measurement point in the denture base's occlusal and labial views. Figure 4 displays the totals of the displacement distances at the denture base's observation sites. All models showed distolingual sinking of the denture base. H abutments experienced larger displacement (5-2, 6-2, 7-2) than ML abutments (5-0, 6-0, 7-0).

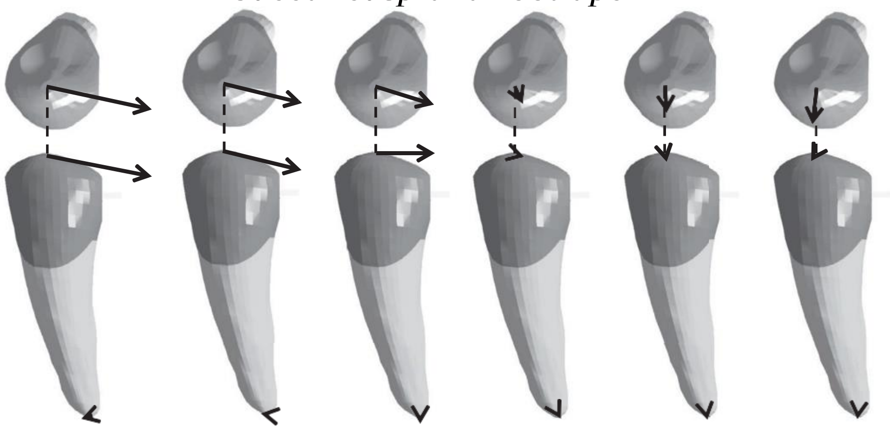
Abutment teeth

The root apex and tip of the buccal cusp are depicted in vector graphic occlusal and buccal perspectives in Figure 6. Figure 7 displays the totals of the displacement distances at the buccal cusp tip and root apex of the left mandibular first premolar. The tooth axes in models 5-2, 6-2, and 7-2 were noticeably distally inclined, while those in models 5-0, 6-0, and 7-0 were slightly buccally inclined. Models 5-2, 6-2, and 7-2 had shorter displacement distances than models 5-0, 6-0, and 7-0. In models 5-0, 6-0, and 7-0, displacement was lower when the implant was placed in the

distal position; however, in models 5-2, 6-2, and 7-2, displacement was greater when the implant was placed in the distal position (figure 7)
Figure 8 displays contour photographs of the cortical bone's minimum primary stress. The graphics show the minimum principal stress levels, which were initially estimated as negative figures but are now shown as positive numbers (in MPa). Figure 9 displays the maximum and least primary stress levels in cortical bone. The distal end of the implant neck had the least primary stress in all models. In comparison to models 5-0, 6-0, and 7-0, stress levels were higher and more evenly distributed in models 5-2, 6-2, and 7-2. Models 5-2, 6-2, and 7-2 have lower minimum principal stress values than models 5-0, 6-0, and 7-0. Whenever the implant was situated distally in models 5-0, 6-0, and 7-0, the minimum primary stress values were higher; nevertheless, in models 5-2, 6-2, and 7-2, the minimum principal stress values were lower.

Discussion
Since earlier clinical reports [1–5] and mechanical analyses [6–8] indicated that denture movement was more constrained for partial implant overdentures than for ordinary partial dentures, the present investigation did not include conventional partial dentures without implants as negative controls. So, we decided to look into implant placement and implant abutment height. Accuracy in biomechanical analyses employing finite element analysis is significantly impacted by how closely the analytical model resembles the human body. Numerous mechanical investigations in dentistry that employ finite element modelling make use of loads coming from the direction of the occlusal surface and limitations at the bottom of the analytical model. [6–8]. Yet, as the mandible is raised by a number of muscles during occlusal contact, occlusal force occurs on the tooth. The models in this work were able to accurately reproduce the forces in the human body by restricting the occlusal contact point and loading the hypothesized muscles of the jaw. As a result, mechanical analysis at the inter-cuspal position was made feasible.[19].

Fig. 6. *Displacement and direction vectors for left mandibular first premolars. The figure shows occlusal and buccal vector graphical images of the tip of the buccal cusp and root apex*



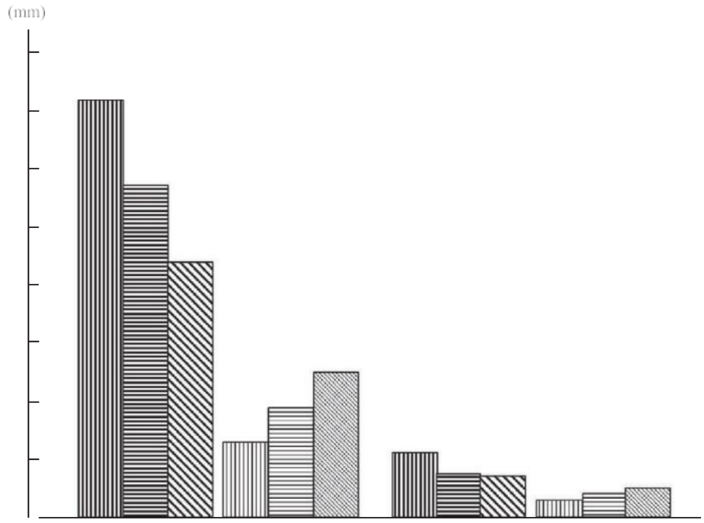


Fig. *7. Displacement distance for the left mandibular first premolar. The graph shows the sum of displacement distances at the tip of the buccal cusp and root apex of the left mandibular first premolar*

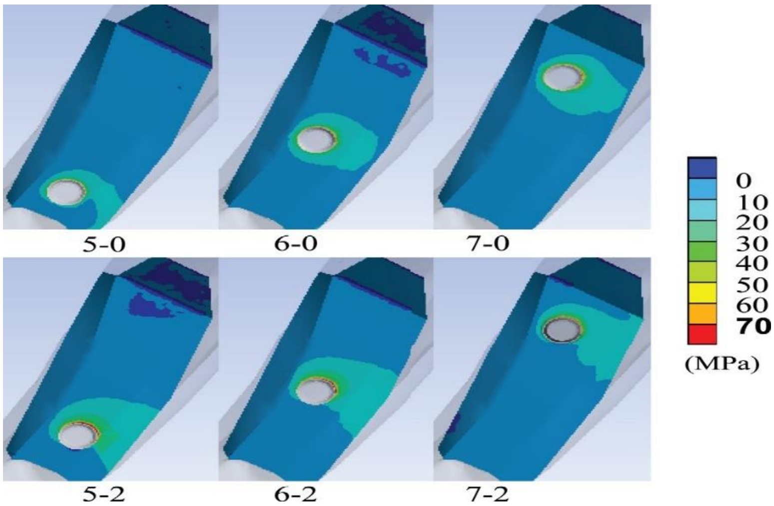


Fig. 8. *Contour images of minimum principal stress in cortical bone. Values for minimum principal stress were originally calculated as negative numbers but are presented as positive numbers (in MPa), after simple positive–negative conversion.*

Denture mobility in IARPD is influenced by the morphology of the implant abutment. When compared to ML abutments with the identical implant placements, H abutments showed no difference in the direction of denture movement, however the distance of denture movement was smaller. This observation, irrespective of the height of the implant abutment, is probably due to the restriction of denture movement in the sinking direction. On the other hand, H abutments were joined with minimal horizontal movement. Additionally, irrespective of the height of the abutment, placing the implant distal to the tooth abutment reduced denture movement. This may be because a wider gap between the abutment teeth and implant increases the stability of dental prosthetics.

Movement of abutment teeth

The form of the implant abutment in IARPD has an impact on how the abutment tooth moves. In particular, at the same implant site, abutment motion was less for H abutments than for ML abutments. If the implant was placed distal to the abutment tooth rather than medial to the abutment tooth, ML abutment teeth migrated less than when the implant was placed medial to the abutment tooth. But when the implant was placed medial to the abutment tooth, abutment teeth for H abutments migrated less. The movement of the denture and the abutment teeth in ML abutments were coordinated.. Nevertheless, with H abutments, when the implant abutment and abutment teeth were closer, bracing effectively reduced abutment tooth movement. Because an abutment tooth doesn't need to receive a retention arm, placing an implant adjacent to it is aesthetically pleasing [23]. Still, the current findings imply that, in order to brace with an implant's abutment, the implant should be positioned near to the abutment tooth because doing so is more aesthetically pleasing and protects the abutment tooth.

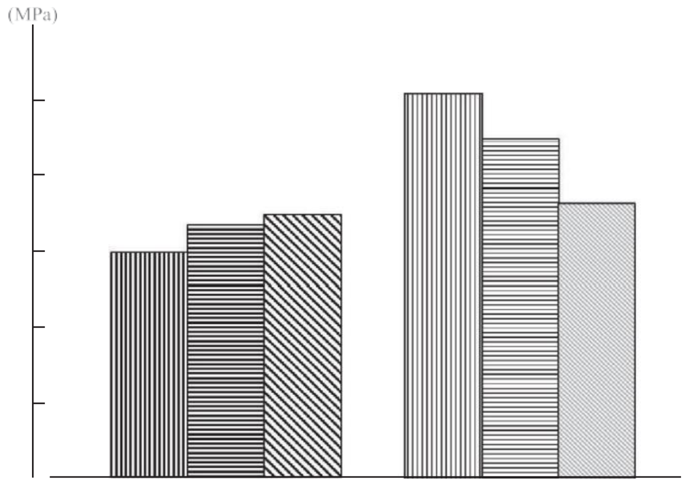


Fig. 9. *Minimum principal stress. The graph shows maximum values for minimum principal stress in cortical bone. Values for minimum principal stress were originally calculated as negative numbers but are presented as positive numbers (in MPa), after simple positive–negative conversion*

Conclusion

Implant abutment geometry influences the movement of the denture and abutment tooth as well as the distribution of the minimal primary stress on the cortical bone close to the implant neck when IARPD is used for prosthetic mandibular unilateral distal extension. For implants in the same position as well denture movement was more constrained for higher abutments than for mucosal-level abutments. Movement of the abutment tooth was less for implants medial to the abutment tooth than those that were distal to the abutment tooth for mucosal-level abutments. With respect to implant abutment height, the mechanical impacts on abutment teeth at the same implant site varied. When implants were positioned medial to abutment teeth compared to when they were placed distal to abutment teeth, abutment tooth motion was more constrained. Finally, minimum principal stress values were lower when the implant neck was located distally.

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