Effect of Tilted and Short Distal Implants on Axial Forces and Bending Moments in Implants Supporting Fixed Dental Prostheses: An In Vitro Study

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Purpose: The aim of this study was to evaluate the axial forces (AFs) and bending moments (BMs) on implants supporting a fixed dental prosthesis (FDP) with a distal cantilever (10 mm) compared to an FDP supported by a tilted or short (7 mm instead of 13 mm) posterior implant by means of in vitro strain gauge measurements. ***Materials and Methods:*** Nine titanium Brånemark implants were placed in an edentulous composite mandible. The mechanical loading conditions were evaluated for the following three situations: *(1)* short distal implants supporting a cantilever, *(2)* long tilted distal implants, and *(3)* no distal implants supporting a cantilever. A vertical load of 50 N was applied at the first molar position, and the resultant AFs and BMs were measured for the three different situations, three different numbers of supporting implants (three, four, or five), and three different prosthesis materials (titanium, acrylic, and fiber-reinforced acrylic). ***Results:*** The mean BMs, as well as the maximum AFs and BMs, were significantly higher in the model with a cantilever compared to that having the tilted or short distal implants ($P < .001$). There was no significant difference between the models with a distally tilted implant versus a short distal implant. ***Conclusion:*** The use of posterior implants reduced the AFs and BMs on implants supporting an FDP compared to that with a distal cantilever. No difference in mechanical loading was observed between short tilted distal implants. *Int J Prosthodont 2010;23:566–573.*

Since the introduction of the principle of osseointegration several decades ago, implant-supported prostheses have been considered a reliable treatment option to restore the dentition of edentulous patients.[1–4]

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The presence of the anterior wall of the maxillary sinus or the inferior alveolar nerve and the mental foramen often precludes the insertion of long implants (> 10 mm) in the posterior portion of the mouth, especially in patients with advanced bone resorption. When bone grafting is not an option, several nonsurgical treatment alternatives could be considered, including adding a distal cantilever of one or two units, tilting a long implant to support the posterior portion of the prosthesis, or placing a short implant to support the posterior portion of the prosthesis.

In the edentulous maxilla, the presence of large sinus cavities may require the placement of tilted implants parallel to the anterior sinus walls. The apex of these implants and the rotation fulcrum are located in the canine region, while the implant platforms emerge in the area of the first or second premolar. Likewise, in the edentulous mandible, an implant may be placed anterior to the mental foramina with a distal inclination to provide adequate posterior support for a fixed prosthesis. The farther away the mental foramen is from the alveolar crest, the more tilted the distal implant can be, allowing the implant platform to be positioned more posteriorly. Tilted implants have been used increasingly, with studies showing short- and medium-term clinical success.[5–7] The placement of a short distal implant is another option when posterior support is needed. Despite unfavorable biomechanics,[8–10] some clinical studies have reported high success rates.[11,12] The biomechanical rationale for using these distally tilted or short implants is based on the premise to reduce the cantilever length and to increase the spread of the implants, aiming at decreasing the bending moments (BMs).

Despite favorable results with osseointegrated oral implants, failures do occur as a result of peri-implant tissue infection, adverse loading of the implants, the patient's medical and oral health status, or a combination of these factors.[13–17]

There is no consensus on the issue of whether a distal cantilever compromises the implant or prosthetic treatment outcome. Several animal experimental studies failed to demonstrate marginal bone resorption induced by static or occlusal load.[18–22] Few human studies have been performed to determine the potential influence of cantilever extensions on the peri-implant bone stability.[23] In full-arch reconstructions, neither implant location nor cantilever length were associated with a difference in marginal bone loss.[24] Several clinical studies did not find a difference in implant survival rate or peri-implant bone level change between implants supporting fixed dental prostheses (FDPs) with or without cantilevers.[25–27] Other studies, however, indicate that occlusal overload may contribute to peri-implant bone loss and eventually lead to loss of integration.[28–31] Clear evidence was provided by Isidor,[28,29] who reported that peri-implant bone loss resulting in a high risk of implant failure was associated with excessive occlusal loading in a monkey model. These and several other reports indicate that unfavorable mechanical loading could be associated with bone loss and implant failure.[32,33] The jaw bone can be challenged biomechanically when placing implants in the edentulous posterior area, where the available bone volume and quality is often limited. Cantilevered FDPs also reveal a higher incidence of technical complications, such as screw loosening or fracture.[34,35] Such problems may be directly related to the unfavorable biomechanical condition. Therefore, it is important to evaluate the biomechanical consequences of these distal implants.

Although it is well known that long cantilevers induce high strains and stresses in the peri-implant bone, implants, and prostheses,[36–39] there are only a few reports dealing with the biomechanical aspect when distally tilted and short implants are used to increase support of the prosthesis in the posterior area. In two- and three-dimensional finite element studies, distal tilting of the posterior implants did not result in different peri-implant bone stresses when compared to implants placed perpendicular to the occlusal plane.[40,41] Other papers concluded that limited implant length leads to unfavorable implant biomechanics.[8-10] Only one study[42] reported that use of a distal short implant contributed to a decrease in anterior peri-implant bone stress. Yet, no previous experimental study evaluated or compared the biomechanical effects of both distally tilted and short posterior implants together with influencing factors, such as the number and distribution of supporting implants and prostheses material.

Fig 1 Superior view of the edentulous composite human mandible.

The main purpose of this study was to investigate the axial forces (AFs) and BMs on implants supporting a full-arch fixed prosthesis with a 10-mm-long distal cantilever, tilted distal implant, or a short distal implant by means of in vitro strain gauge measurements. Additionally, the impact of the number of supporting implants (three, four, or five) and prosthesis substructure material (titanium, acrylic resin, and fiber-reinforced acrylic resin) on distal implant loading were investigated.

The primary hypothesis was that the presence of a distal implant reduces the AFs and BMs, while no difference was expected between tilted and short implants. Additional hypotheses were that the number of supporting implants and the prosthesis material would affect the AFs and BMs on the distal implants.

Materials and Methods

Model and Implant

An edentulous composite mandible with physical properties similar to real human bone[43] was used (Sawbones) (Fig 1). The exterior portion of the mandible consisted of a hard cortical shell (density: 1.7 g/cm^3), while the interior portion was cancellous (density: 0.25 g/cm^3).

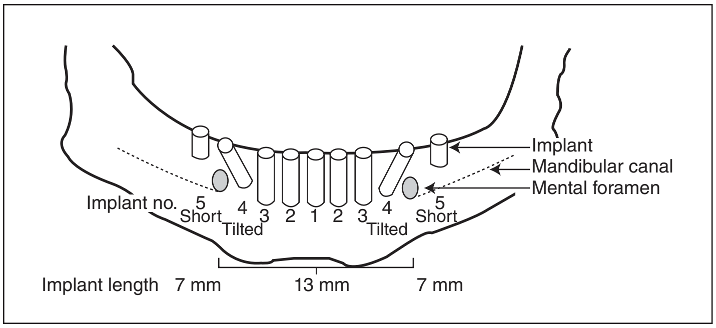


Fig 2a Schematic diagram of implant locations and angulations. Implants are labeled 1 to 5, with 1 being the most anterior (midline) and 5 the most distal implant.

Fig 2b Composite mandible containing the implants with 5-mm Multi-unit abutments.

Fig 3 Superior and inferior views of the **(left)** milled titanium, **(center)** acrylic resin, and **(right)** fiber-reinforced acrylic resin prostheses.

TiUnite regular platform dental implants (Brånemark System, Nobel Biocare) with a diameter of 3.75 mm and a length of 13 mm or 7 mm (short implant) were used. Nine implants were placed in the model. Five 13-mm-long implants were placed anterior to the mental foramen with an interimplant distance of 10 mm. An additional 13-mm implant was placed 7 mm distal to the last anterior implant and tilted approximately 30 degrees distally toward the long axes of the anterior implants. Furthermore, a 7-mm-long implant was placed distal to the mental foramina at the position of the first molar, hypothetically superior to the inferior alveolar canal. The OsseoCare (Nobel Biocare) drilling unit was used to place the implants and to measure the final insertion torque. All implants were self-tapping and were placed with a final insertion torque of 20 Ncm. Implants were labeled as 1, 2, 3, 4, or 5, with 1 being the most anterior (midline) and 5 being the most posterior implant (Fig 2a). Upon implant placement, 5-mm Multi-unit abutments (Brånemark System, Nobel Biocare) were placed and torqued to 35 Ncm (Fig 2b). The straight Multi-unit abutment was used even for the tilted implants because the strain gauges were attached to the abutment surface, with the intention to evaluate loading at the implant level. The direction of the implant and abutment axis therefore should have been in alignment.

According to conventional laboratory procedures, three fixed prostheses with similar design and dimensions but different types of substructures were fabricated (titanium, acrylic resin, and fiber-reinforced acrylic resin) (Fig 3). The titanium prosthesis consisted of a milled commercially pure titanium framework (Procera, Nobel Biocare) veneered with acrylic resin teeth and a polymethyl methacrylate (PMMA) base. The acrylic resin prosthesis was fabricated using only PMMA, whereas the fiber-reinforced acrylic resin prosthesis consisted of PMMA reinforced with glass

Fig 4a Lateral view of the vertical loading (50 N).

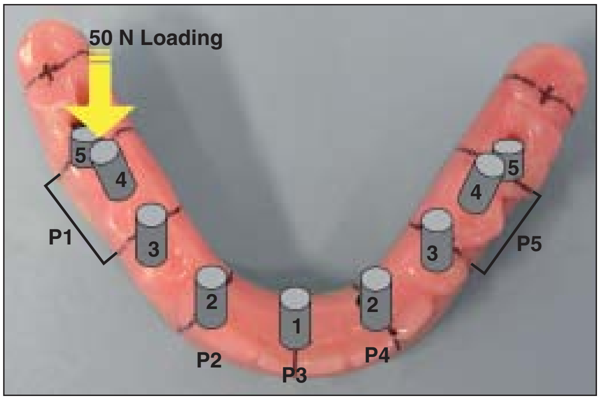


Fig 4b Definition of implant position as a basis for the loading position. P1 = ipsilateral distal implant; P2 = ipsilateral second implant; P3 = center implant; P4 = contralateral second implant; P5 = contralateral distal implant.

fibers (Stick, StickTech), which is fabricated as a continuous unidirectional E-glass fiber preimpregnated with PMMA monomer. Given the small interimplant distance, the fiber was weaved around the implants once in an "S" configuration. All prostheses had passive fit, which was verified using a microscope.

Strain Gauge Measurement

Three strain gauges (resistance: 120 ± 0.3 Ω; FLG-02-11, TML Tokyo Sokki Kenkyujo) were bonded to each of the 5-mm Multi-unit abutments placed on the nine implants. The strain gauges were bonded to the lateral abutment surface 120 degrees apart from one another, according to the manufacturer's instructions, and calibrated according to the procedures described elsewhere.[39,44] Fifty strain gauge signals were generated per second. A computer program was developed to process the data and to transform the recorded microstrain data into a numerical representation of AF and two BMs around the perpendicular axes. Through use of the BMs around both perpendicular axes, the total BM on the abutments could be calculated.[44]

Test Condition and Data Analysis

In this study, a total of 27 test conditions were investigated. Three main conditions were considered: *(1)* three different distal implant configurations (cantilever, tilted, and short implants), *(2)* three different numbers of supporting implants (three, four, or five), and *(3)* three different prosthesis materials (titanium, all-acrylic, and fiber-reinforced acrylic) (Table 1). The cantilever model had implant 3 as the most distal implant. In the models with the tilted and short implant configurations, implants 4 and 5 were used as the most distal implants, respectively.

Table 1 Placement of Implants Related to Distal Implant Configuration*

	No. of implants used		
Distal implant type	3	4	5
Cantilever	3,1,3	3,2,2,3	3,2,1,2,3
Tilted	4,1,4	4,2,2,4	4,2,1,2,4
Short	5,1,5	5,2,2,5	5,2,1,2,5

*See Fig 2a for implant placement (implants 1 to 5).

A vertical load of 50 N was applied at the first molar region by means of a custom-made pneumatic loading device (Fig 4a). This loading position corresponds to the occlusal screw access hole of both the tilted and short implant, 10 mm from the most anterior implant (implant 3). Loading occurred consecutively at the left and right sides and was repeated three times. Figure 4b illustrates the positions of the implants and the location of load application.

Statistical Analysis

The AF and BM data were analyzed by three-factor analysis of variance (ANOVA), followed by the Scheffé test with the significance set at $P < .05$. All statistical analyses were performed using statistical software (SPSS v. 13.0, SPSS).

Results

The mean AF and BM of all implants in the different test conditions are shown in Fig 5. The greatest AF and BM values were observed at P1, which is closest to the site of load application. Negative AF values were

Fig 5 Mean AFs and BMs of all implants in each distal implant type for the different numbers of supporting implants and the different prosthesis materials: **(a)** AF for three implants, **(b)** AF for four implants, **(c)** AF for five implants, **(d)** BM for three implants, **(e)** BM for four implants, and **(f)** BM for five implants. Statistics were done for each number of implants separately (three, four, or five; ANOVA and Scheffé test). *P < .01; **P < .05; ***P < .001; NS = no significance; Ac = acrylic; Fb = fiber-reinforced acrylic; Ti = titanium.

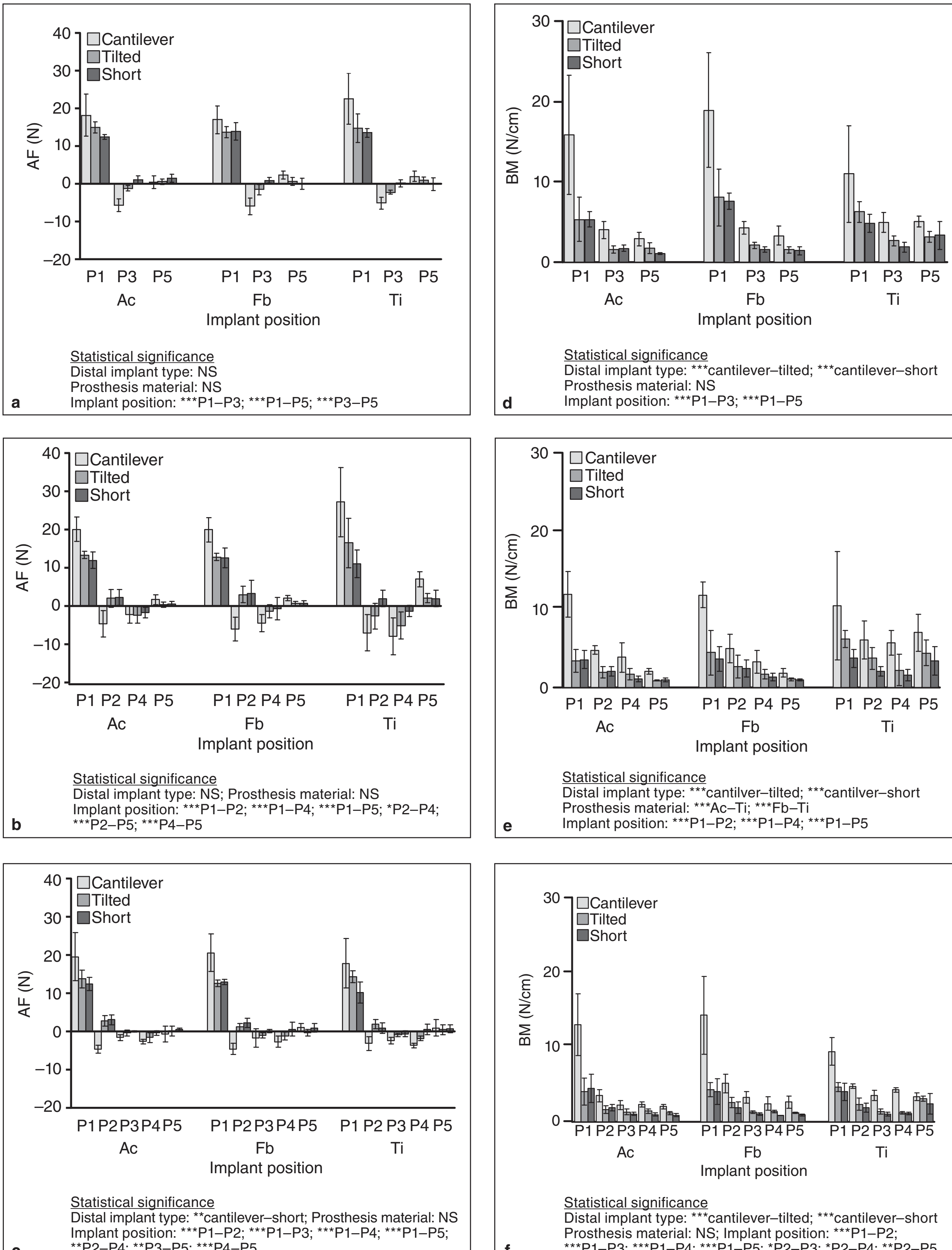
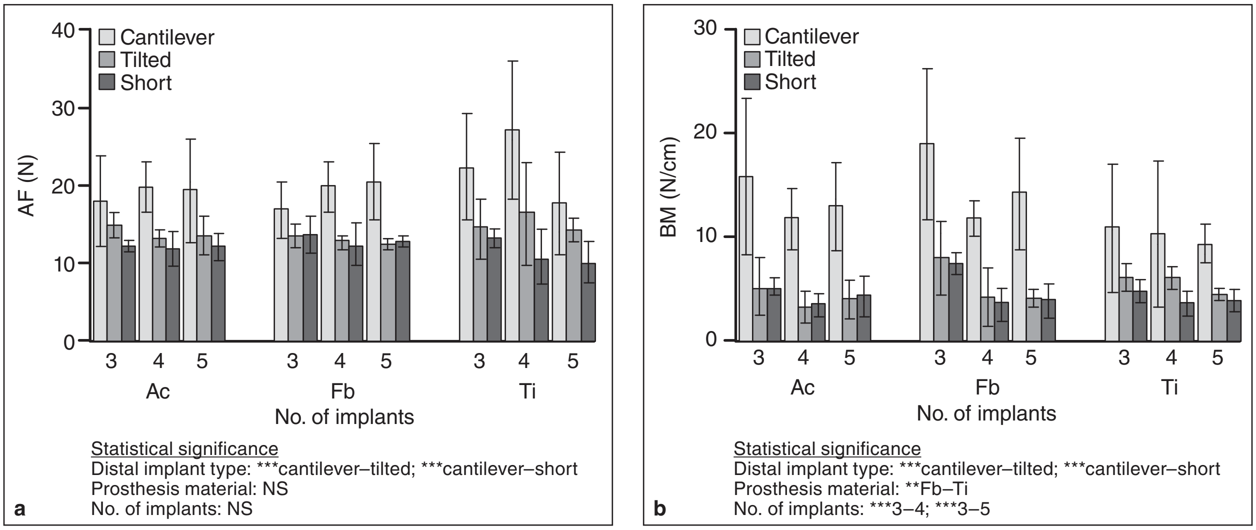


Fig 6 Mean maximum **(a)** AFs and **(b)** BMs (data from P1) for all test conditions (ANOVA and Scheffé test). *$P < .01$; **$P < .05$; ***$P < .001$; NS = no significance; Ac = acrylic; Fb= fiber-reinforced acrylic; Ti = titanium.



measured at P2, P3, and P4, especially in the cantilever model. Except for the model with five supporting implants, no significant differences in AFs were found between the different distal implant models, but there were significant differences in BM ($P < .001$). This was true regardless of the number of supporting implants. Significant differences were seen between the cantilever and tilted implant model ($P < .001$) and also between the cantilever and short distal implant model ($P < .001$). Significantly different BMs were found between the acrylic and titanium prostheses ($P < .001$) and also between the fiber-reinforced acrylic and titanium prostheses ($P < .001$), but only when the prostheses were supported by four implants.

Because the greatest AF and BM values were found at P1 in all models, the maximum value for each test condition was considered as well. Figure 6 shows the mean maximum AF and BM values for all test conditions. There were significant differences between the cantilever and tilted distal implant model ($P < .001$) and between the cantilever and short distal implant model ($P < .001$) for both AFs and BMs. Significantly different BMs were detected between fiber-reinforced acrylic and titanium framework prostheses ($P < .05$) in the models when three and four supporting implants were used ($P < .001$) and also between the models using three and five supporting implants ($P < .001$).

Discussion

This study evaluated and compared AFs and BMs in three different models comprising a 10-mm distal cantilever, a vertically placed short distal implant, and a 13-mm-long distally tilted posterior implant by means of in vitro strain gauge measurements under static loading conditions. The effect of these three conditions was evaluated using different numbers of supporting implants and different prosthesis materials.

The main hypothesis that an implant supporting a distal cantilever reduces the AFs and BMs was supported. However, no difference was found between the two distal implant types (tilted versus short) in terms of mechanical loading. The results of this study support the idea that distally tilted long implants reduce overall implant loading and therefore the risk of implant overload,[5–7] and similar findings were found when a short implant was used to reduce the distal extension span.[11,12]

In all models, maximum AFs and BMs were observed for the implant at position P1, closest to where the load was applied. This is in agreement with many other in vitro and in vivo studies.[37–39,45] Although it has been proven that overload can lead to marginal bone loss and eventual implant failure,[28,29,33] mechanical loading does not have to be detrimental. Mechanical loading may even affect bone healing positively and stimulate mineralization to a certain extent.[46–51] Bone loss as a result of mechanical overload will only occur when the mechanical loading exceeds the bone's load-bearing capacity, especially in patients with low bone quality, limited bone quantity, adverse functional habits, and compromised medical health (ie, uncontrolled diabetes).

The hypothesis that the number of implants would have an impact on the distal implant configuration was rejected since similar differences between the distal implant conditions were detected for the various numbers of supporting implants. This implies that distal prosthesis support plays a role in the resultant forces on the supporting implants, regardless of the number of implants placed. The number of supporting implants as such, however, had an impact on the AFs and BMs. The BMs in the three-implant model were higher compared to when four and five implants were used, which is in agreement with an in vivo load measurement study on this topic.[39] No significant differences were found, however, between either four or five supporting implants (Fig 6). This may be because distribution of the supporting implants is as important for the resultant forces as the actual number of supporting implants.

Currently, metal frameworks are considered the gold standard for implant superstructures because of their higher modulus of elasticity and their strength in comparison to acrylic resin.[3,52–54] The results of this study reject the hypothesis that the material composing full-arch fixed prostheses has an impact on the distal implant, whether it be a cantilever model or that with shorter or distally inclined implants. It was assumed that the prosthesis material would be of importance since a more elastic material is more likely to deform under loading, thereby transferring higher forces to the implant closest to the area of loading and distributing less forces to the other supporting implants. This might lead to a larger difference between the cantilever model and the model with a supporting distal implant (short or tilted) when an elastic prosthesis material is used, such as acrylic resins. Although such a difference was not observed, there was a biomechanical effect of the prosthesis material. The mean BMs showed a tendency to be greater for the titanium prosthesis in the model with four supporting implants, whereas the mean maximum BM with the titanium prosthesis was lower than that with the fiber-reinforced prosthesis. A reason for these lower maximum BMs with titanium could be explained by the stiffness of the material, which facilitates a more efficient distribution of the mechanical loading. A material with a high modulus of elasticity has a lower deformation under loading and therefore allows a more efficient load distribution.[54,55]

Conclusion

A distal cantilever developed higher BMs on the supporting implants compared to situations where a tilted or short distal implant was used. No differences between the tilted and short distal implant models were found for all test conditions. There were no clear effects resulting from the number of implants and prosthesis material on the impact of the distal implant condition for the AFs and BMs on the distal implant. These findings thereby confirm that the placement of a distal implant to create better posterior support for a prosthesis reduces loading on the supporting implants.

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