Theoretical study of the effects of tooth and implant mobility differences on occlusal force transmission in tooth/implant-supported partial prostheses

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Statement of problem. Despite their mobility differences under occlusal loads, a natural tooth and an implant are often used together to support fixed prostheses. In some situations, tooth/implant-supported partial prostheses include cantilever extensions, especially in the posterior region where the bone is inadequate for placement of an additional implant.
Purpose. In this study, engineering beam theory was used to study the effects of the mobility differences between the implant and the tooth on the force and moment distribution, due to occlusal loads in tooth/implant-supported prostheses.
Methods. The prosthesis was treated as a linear elastic beam and the supports were modeled as springs with (vertical) translational and rotational stiffness. The bending moments and forces on the supports were calculated as functions of the parameters that describe the geometry, position of the occlusal load, and stiffness ratios (namely, implant or tooth) of the springs.
Results. Bending moments on the supports were more sensitive to the relative rotational mobility between the supports and their individual values than to the relative translational mobility. The moment at the implant was minimized when the supports had similar mobilities. A preliminary design concept was introduced and eliminated the moment at the implant without significantly increasing the magnitude of the moment at the tooth. Cantilevering the prosthesis resulted in moderately increased bending moments and considerable tensile forces on the supports for a broad range of the parameters that describe the geometry and loading.
Conclusions. From this simulation, it is suggest that cantilever extensions should be avoided or supported by a short implant, which will only restrain the vertical movement of the cantilever end. (J Prosthet Dent 1997;78:391-99.)

CLINICAL IMPLICATIONS

The theoretical model developed in this study demonstrated that, in a simulated tooth/implant-supported partial prosthesis, the detrimental forces and moments on the tooth and implant are sensitive to differences in rotational mobility between the tooth and implant (more than to differences in vertical mobility). Because it is practically impossible in clinical applications to match the rotational mobilities of the tooth and the implant, it is recommended that, if such prostheses are used, the connection between the prosthesis and the implant be designed to be practically free to rotate, thus eliminating the moment on the implant. Moreover, it is recommended that cantilevered extensions not be used in such situations, as they are associated with either increased moments or detrimental pull-out forces on the supports. If their use is essential, they should be supported by short implants that restrain vertical movement of the cantilever end.

In some clinical situations, it may be necessary for a natural tooth and an implant function together as abutments to support a fixed prosthesis (Fig. 1). Moreover, these prostheses sometimes include cantilever extensions in situations where the bone is inadequate for a second implant to be placed. However, there is a conflict in the literature on the use of mixed tooth/implant supported prostheses. Problems reported in previous studies include bone resorption around the implant neck,[1-6] bone fracture,[7] loss of osseointegration,[5,7,8] implant fracture,[7,9,10] fracture of attachment screw,[7] loosening of attachment screws,[9-11] and cement failure.[9,10,12,13] These problems are attributed primarily to mobility differences between the natural tooth and the implant.[1-13]

As a result, several implant systems have been designed to lessen the relative translational and rotational movements at the supports. The IMZ system incorporates an intramobile element (IME) made of relatively compliant polyoxymethlene, and the Brånemark screw joint system

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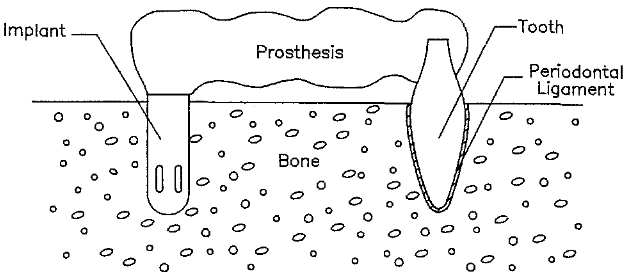


Fig. 1. Schematic of typical tooth-implant supported prosthesis.

does not use an IME. To date, several in vivo, in vitro, and theoretical studies have been conducted to assess the effectiveness of both implant systems in transmitting occlusal forces nondestructively in tooth/implant-supported prostheses. Some authors[4,5,14-16] who studied the IMZ implant concluded that the resilient IME provides enough vertical and rotational flexibility of the prosthesis on the implant to accommodate the mobility of the prosthesis on the supporting tooth. However, Hertel and Kalk[3] claimed that the IME, as used in the IMZ implant system, does not neutralize the effects of mobility differences, whereas McGlumphy et al.[17] claim that it is actually the bending of the titanium superstructure screw that provides the required flexibility. Studies on the Brånemark implant concluded that its screw joint design is associated with sufficient bending flexibility for equal distribution of the load on the supports, and thus there is no need for an IME.[11,18-20] All the investigators agree that, to achieve optimal distribution of the occlusal load in tooth/implant-supported prostheses, it is essential to provide sufficient flexibility at the implant. This leads to the question: what is the relative importance of (vertical) translational flexibility, rotational flexibility and length, moment of inertia, and modulus of elasticity of the prosthesis?

Several beam theory models have been proposed to answer this question. Brunski[16] conceived models for predicting axial loads on the abutments, including one where both abutments are represented by vertical linear springs attached to a rigid prosthesis and rigid bone, and another where both abutments are viscoelastic and represented by linear elastic springs and dashpots attached to deformable prosthesis and bone. In an article of high pedagogical value, Richter[1] suggested a model in which the supports are approximated as linear translational springs attached to a deformable prosthesis whose rotation is unconstrained at the tooth and totally constrained at the implant. By using these limiting values of rotational flexibility at the supports and by varying the values of translational stiffness of the tooth and implant, Richter quantified the potential benefits of a relatively resilient element, such as IME.[1] The limitation of Richter's model, which is a degenerate case of the generalized model presented in this article, is that by assuming limiting values for rotational flexibility, it cannot be used to quantify the

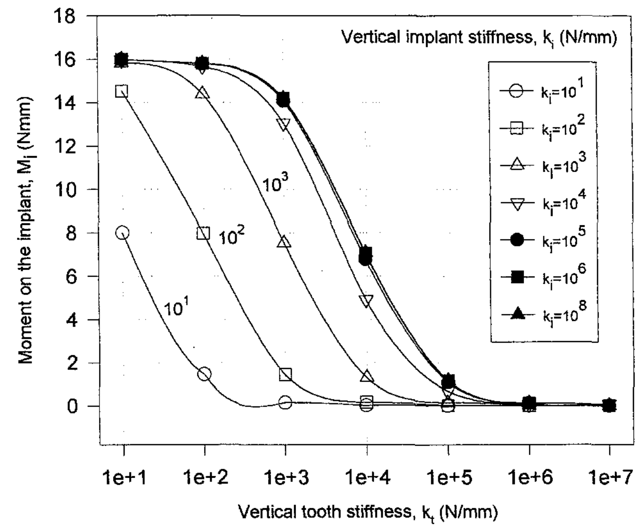


Fig. 2. Implant bending moment as functions of tooth and implant vertical translational stiffness for Richter's[1] model (length of prosthesis, 16 mm; cross-section, 6 × 6 mm; elastic modulus, 10^5 N/mm^2; load on tooth, 1 N).

significant effects of finite values of more realistic relative rotational flexibility on transmission of occlusal loads. The generalized model presented in this article, which quantifies the effects of relative translational and rotational mobilities, as well as length, inertia, and modulus of elasticity of the prosthesis, shows that errors in the calculations reported in Figure 8 of Richter's article[1] could potentially result in too much importance being attributed to relative translational mobility.

The purpose of this study was to study the effects of the mobility differences between the implant and the tooth on the force and moment distribution, due to occlusal loads in tooth/implant-supported prostheses. This study recalculates the results for Richter's model (Fig. 2) and discusses them because they provide a springboard for quantifying the effects of the aforementioned parameters. This information will provide guidelines to develop, in Richter's words "...an advantageous technical construction..." that minimizes the bending moment on the implant. The model used to calculate Figure 2 is also presented. This figure shows that for values of translational tooth stiffness and implant stiffness equal to $k_t \cong 10^3$ N/mm and $k_i \cong 10^4$ N/mm, respectively (with free rotation at the tooth and no rotation at the implant), the implant is overloaded by a bending moment equal to $M_i \cong 13$ Nmm, which is close to the 16 Nmm value associated with a cantilevered prosthesis supported by a free-standing implant, and in agreement with the aforementioned consensus. Figure 8 from Richter's article[1] shows that for this situation the implant experiences a much smaller moment M_i (0.6 Nmm) and contrary to the consensus, is not overloaded.

MATERIAL AND METHODS

Two models (Fig. 3), denoted "a" and "b", were created for the prosthesis shown in Figure 1. For both models, there were no cantilever extensions ($cl_t = 0$ and $cl_i = 0$). In model "a", the prosthesis was treated as a straight linear elastic beam with flexural rigidity EI, where *E* was the modulus of elasticity and *I* was the moment of inertia of the cross-section about its centroidal axis. The beam was supported by linear (vertical) translational and linear rotational springs. These springs represent the resistance provided by the supports of the prosthesis, which included the connection to the abutment and the material that surrounds the abutment (namely, the periodontal ligament and bone for the natural tooth, and bone for the implant) to vertical and rotational movement of the prosthesis on the supports. The force and moment reactions acting on the implant (tooth) were, respectively, F_i and M_i (F_t and M_t). This model made it possible to study the mobility differences of the two supports by varying the stiffness of the springs. The prosthesis was assumed to be rigidly connected to the tooth. Model "b", which was derived from model "a", represents a preliminary design concept that eliminates the rotational spring (moment) and allows free rotation of the prosthesis on the implant. The effect of this modification on the reactions on the tooth were quantified as part of this study. A unit occlusal load (P) was applied vertically at different positions of the prosthesis in both models.

The forces and moments at the supports, due to the vertical occlusal load on the prosthesis, were determined by solving the differential equation[21]:

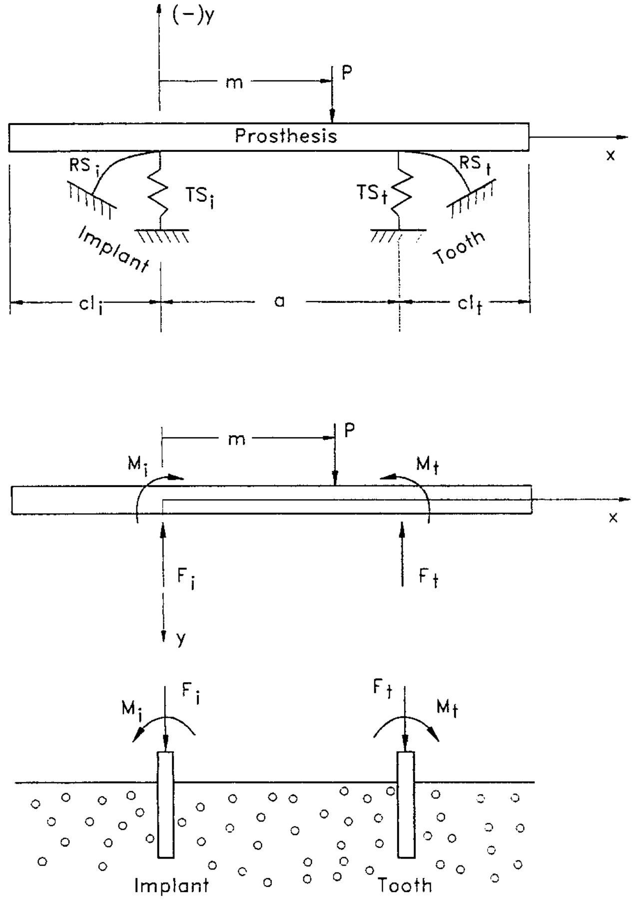
$$EI\frac{d^2y}{dx^2} = -M \tag{1}$$

where *x* is the distance from the left support, *y* is the deflection of the beam, and *M* is the internal moment at any section in the beam (Fig. 3). The boundary conditions applicable to model "a" and model "b" in Figure 3 were as follows, respectively:

$$y_{(x=0)} = \frac{F_i}{k_i}\quad \left(\frac{dy}{dx}\right)_{(x=0)} = \frac{-M_i}{\mu_i}\quad y_{(x=a)} = \frac{F_t}{k_t}\quad \left(\frac{dy}{dx}\right)_{x=a} = \frac{M_t}{\mu_t} \tag{2}$$

$$y_{(x=0)} = \frac{F_i}{k_i}\quad y_{(x=a)} = \frac{F_t}{k_t}\quad \left(\frac{dy}{dx}\right)_{x=a} = \frac{M_t}{\mu_t} \tag{3}$$

where k_i (k_t) and μ_i (μ_t) are, respectively, the vertical translational and rotational stiffness values of the implant (tooth), and *a* is the length of the beam. The aim of this study is to generalize the results for a reasonable range for all tooth/implant-supported partial protheses by calculating the force and moment reactions on both supports for unit P as functions of the flexural rigidity of the beam (EI), the stiffness values of the springs representing the tooth (k_t and μ_t), the stiffness ratios of the springs (k_i/k_t and μ_i/μ_t), the position of the occlusal load (m/a), and the prosthesis length (a). The estimation of the vertical translational and the rotational stiffness values used to model the tooth and the implant supports is crucial to this study.



Model "a": $cl_t=0$, $cl_i=0$; Model "b": $cl_t=0$, $cl_i=0$ and $\mu_i=0$
Model "cis": $cl_t=0$ and $cl_i>0$; Model "cts": $cl_t>0$ and $cl_i=0$

Fig. 3. Beam theory models and their free-body diagrams showing applied load and support reactions. *TS*: Translational spring; *RS*: rotational spring; *cl*: cantilever length; *a*: prosthesis length with cantilever extension; *m*: position of load from origin; *P*: load; *M*: bending moment; *F*: force; subscript *i*: implant; subscript *t*: tooth.

Estimation of vertical translational support stiffness

The vertical translational stiffness was estimated with the measured relationships of tooth and osseointegrated implant mobilities with vertical loadings previously reported[1,6]; their typical values are listed in Table I. In this study, the tooth stiffness associated with the second stage was used because the first stage corresponds to a small fraction of typical occlusal loads.

Estimation of rotational support stiffness for tooth

The estimation of the rotational tooth stiffness was more uncertain, as no significant data about tooth rota-

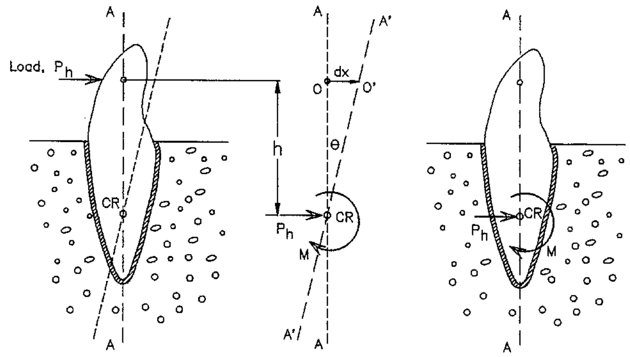


Fig. 4. Transition from horizontal mobility versus horizontal load relationship to rotational mobility versus bending moment relationship for tooth.[26] *CR*: Center of rotation; *A-A*: longitudinal axis before rotation; *A´-A´*: longitudinal axis after rotation; *θ*: angle of rotation; P_h: horizontal load; *h*: vertical distance between loading point and CR; *dx*: horizontal mobility at point O; *M*: bending moment about CR; and *O*: displacement measurement point.

tions in the bone under applied moments is available in the literature. Therefore a range for the rotational stiffness of the tooth in the bone was estimated with available experimental data for horizontal mobilities of human teeth in lingual and labial (or buccal) directions under horizontal loads (≤ 500 gm-force).[22,23]

There is agreement in the literature that "normal horizontal mobility" of a tooth cannot be expressed by one single value, but rather should be defined by a range of physiologic mobility, which varies for different persons, at different days, or even at different hours.[22] Teeth exhibit two-stage mobility under horizontal loading.[23] The transition from the initial movement to the secondary movement occurs between 50 to 150 gm-force horizontal load, and the mode of the movement in both stages is described as linear. As in the vertical translational stiffness estimation, only the second stage of tooth mobility was used in this study, because the first stage corresponds to a small fraction of typical horizontal loads. Table I presents the results of Muhlemann's measurements[23] for the range of the most frequent mobility values in adults who are free of periodontal disease.

The following assumptions were made to estimate the physiologic range of the rotational stiffness by using Muhlemann's measurements[23]:

1. The slope of the horizontal mobility versus horizontal load curve for loads greater than 500 gm-force is the same as in the second stage of the horizontal loading.
2. The lingual mobility is equal to one half of the total mobility.
3. The second stage of mobility initiates at a load of 100 gm-force and at a displacement equal to 75% of the total lingual or labial (or buccal) mobility.
4. The center of rotation (CR) of the tooth is located in the middle third of the root, where tooth dimensions are taken from Wheeler.[24]

Table I. Horizontal tooth mobility values of different teeth for 500 gm-force horizontal loading[23]

Teeth	Horizontal mobility, mm/100
Incisors	10-12*
Canines	5-9*
Premolars	8-10*
Molars	4-8*

*The mobility values are the summation of the lingual and the labial (or buccal) values.

It was assumed that the horizontal movements (Table I and Fig. 4) were a result of a rigid body translation and rotation of the tooth about the CR. The horizontal load that was used in the experiment was replaced with a force and a moment at the CR. The rotational mobility of the tooth can be approximated, for small rotations, as

$$\theta_t \cong \tan \theta_t = (dx)/h \qquad (4)$$

where θ_t is the rotational mobility of the tooth about the CR in the labiolingual (or buccolingual) plane, *dx* is the horizontal mobility of the tooth at the loading point O, and *h* is the distance from the CR to the loading point.

The bending moment that results from the transfer of the horizontal load to the CR is given by the following formula:

$$M_t = P_{ht} * h \qquad (5)$$

where *M* is the bending moment about the CR in the labiolingual (or buccolingual) plane and P_{ht} is the horizontal load in the labiolingual (or buccolingual) direction. The rotational stiffness of the tooth in the bone (μ_t) is obtained as:

$$\mu_t = M_t/\theta_t = (P_{ht} * h^2)/dx \qquad (6)$$

Substitution of the data listed in Table II into equation (6) provided a range $10^4 \le \mu_t \le 10^5$ Nmm/radian.

Estimation of rotational support stiffness for implant

McGlumphy at al.[17] measured the deflection of a cantilever beam connected to an IMZ implant in a block of PL-2 photoelastic resin under a 5 pound vertical load. Their results were used to estimate the rotational stiffness of the IMZ implant in the photoelastic resin as 8×10^3 Nmm/radian. Rangert et al.[11] measured the deflection of a cantilever beam connected to a Brånemark implant in a block of steel under various vertical loads up to 150 N and used these results to estimate the rotational stiffness of the screw joint as approximately 5×10^4 Nmm/radian. Komiyama[25] reported the results of the labiolingual and mesiodistal horizontal mobility measurements of osseointegrated implants on patients under 2000 gm-force horizontal loading. Kayacan at al.[26] used Komiyama's[25]

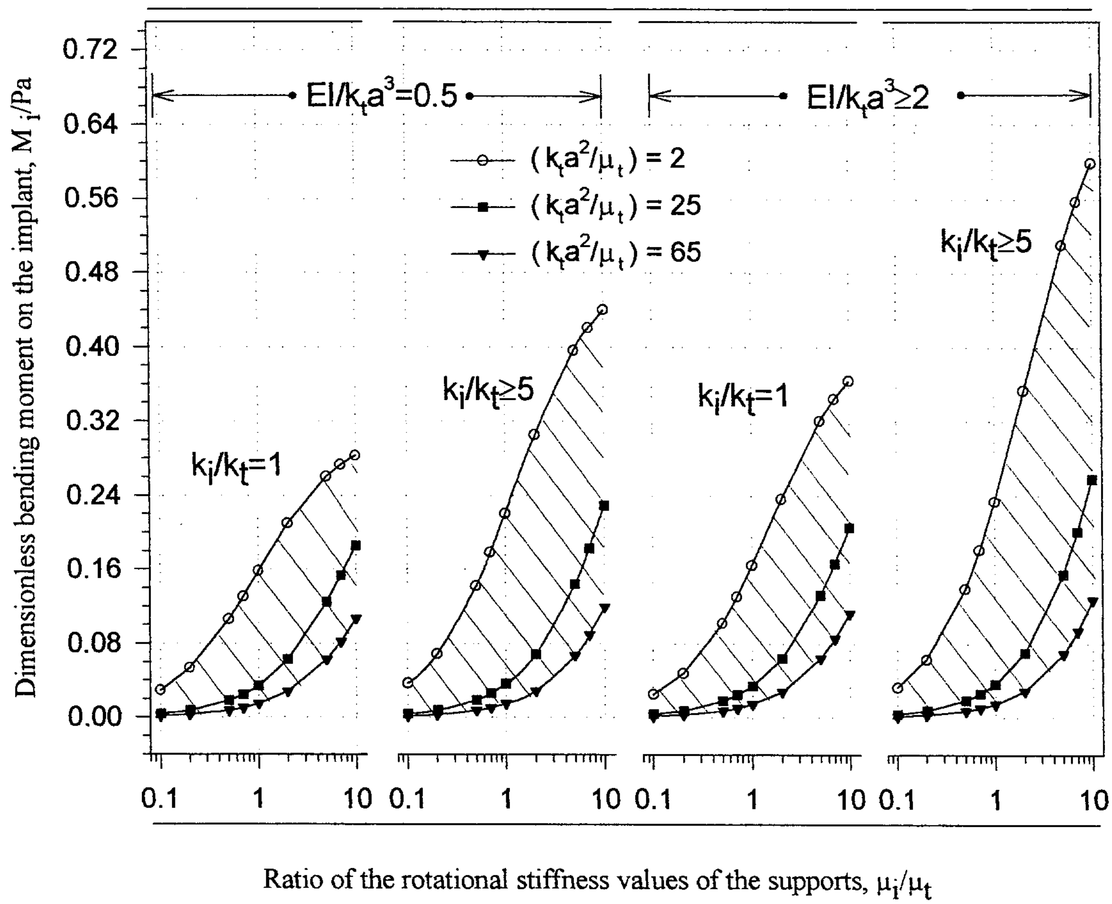


Fig. 5. Dimensionless bending moment on implant as functions of relative rotational (μ_i/μ_t) and vertical translational (k_i/k_t) stiffness of prosthesis' supports (load P on tooth, m/a = 1).

Table II. Numerical values of the parameters used in the engineering beam theory model

E_p (GPa)	I_p (mm^4)	k_i/k_t	k_t (N/mm)	μ_i/μ_t	μ_t (Nmm/radian)	cl_i and cl_t	a (mm)	k_ta^2/μ_t (mm)
90-120	90-300	1-10	10^3	0.1-10	10^4-10^5	0.25a, 0.5a	15-25	2-65

Subscripts *p*, *i*, and *t* represent prosthesis, implant, and tooth, respectively.

horizontal mobility experiment results and estimated the rotational stiffness of the osseointegrated implant as $3*10^4 \leq \mu_i \leq 4*10^5$ Nmm/radian.

In this study, the physiologic range of k_i/k_t and μ_i/μ_t was taken from 1 to 10 and from 0.1 to 10, respectively. The values approaching 10 were more likely to occur in a healthy tooth and a nonflexible osseointegrated implant combination. Values of k_i/k_t and μ_i/μ_t that were less than 10 illustrated the effects of any reduction in the mobility differences between the supports of the prosthesis because of more flexible implant-prosthesis connections or loosened implants. Table I lists the range of the values for all factors being used in the determination of the reactions on the supports, including the clinical range of the parameter k_ta^2/μ_t.

RESULTS

The bending moments at the implant as functions of relative stiffness of the supports are illustrated in Figure 5 for model "a" and Figure 6 for model "b". Figure 5 corresponds to the worst-case scenario for the implant support moment, which was associated with the occlusal load acting at the tooth supported end of the prosthesis (m/a = 1). The bending moment on the tooth support was not presented for model "a" because the mobility differences between the supports did not cause overloading of the tooth. However, it was presented for model "b" to show whether the preliminary design concept (free-rotation on the implant, $\mu_i = 0$) caused an increased bending moment on the tooth support.

Results for the vertical reaction forces on the supports were also excluded because their maximum values for both models were found to be less than what a single tooth is repeatedly subjected to during routine service or what a single implant is designed to withstand. Complete results for all the reactions on the supports can be obtained from the authors. The results herein are presented in the following nondimensional parameters:

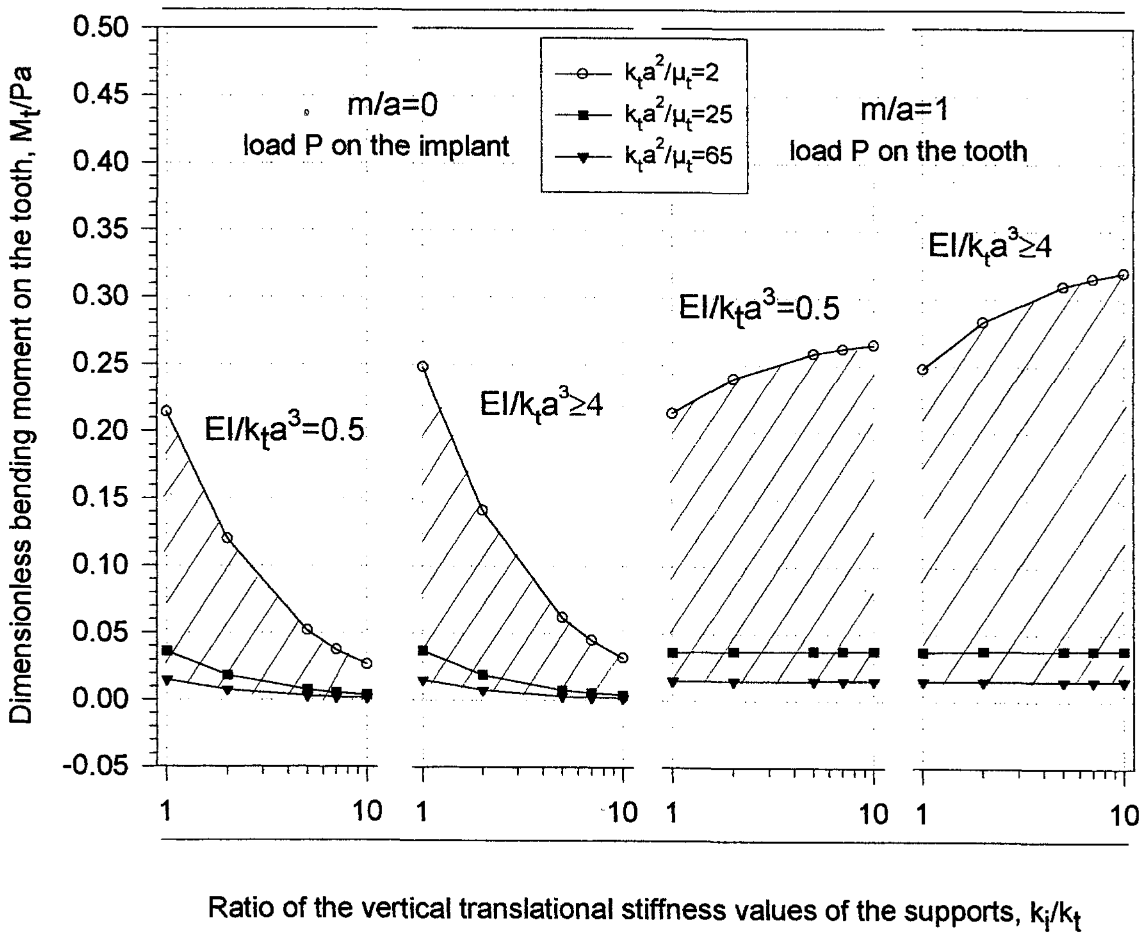


Fig. 6. Dimensionless bending moment on tooth as functions of relative vertical translational stiffness (k_i/k_t) of prosthesis' supports (free-rotation on implant, $\mu_i = 0$).

k_i/k_t (relative translational stiffness of implant to tooth), μ_i/μ_t (relative rotational stiffness of implant to tooth), k_ta^2/μ_t (the parameter that introduces the length of the prosthesis), EI/k_ta^3 (the parameter that introduces the flexural rigidity of the prosthesis). The moments are normalized with the quantity Pa, which corresponds to the moment reaction of a cantilever beam.

DISCUSSION

Model "a"

Figure 5 clearly illustrates that the moment on the implant was a strong increasing function of the rotational stiffness ratio of the supports (μ_i/μ_t). The effects of μ_i/μ_t were more pronounced for larger values of the vertical translational stiffness ratio of the supports (k_i/k_t) and rotational tooth stiffness (μ_t), and for smaller values of the prosthesis' flexural rigidity (EI) and length (a). Increasing values of k_i/k_t also lead to larger magnitudes of moments at the implant, especially for small values of the length (a) and for large values of the μ_t. When k_i/k_t and μ_i/μ_t become large, the magnitude of the moment at the implant will approach 1.0 as the implant acts as a cantilever support.

Model "b"

When the results shown in Figure 6 were compared with those for model "a" (which are not presented here because of space limitations), it was concluded that eliminating the moment at the implant does not significantly increase the moment on the tooth. For example, the maximum bending moment increased from approximately 0.16 for model "a" with $m/a = 1$, $k_i/k_t = 1$ and $\mu_i/\mu_t = 1$ to 0.25 for model "b" with $m/a = 1$, $k_i/k_t = 1$, and reached its maximum value 0.32 at $m/a = 1$ and $k_i/k_t = 10$. These results also demonstrated that the bending moment on the tooth was a relatively weak function of the vertical translational stiffness of the supports (k_i/k_t), especially when the load was on the tooth. Therefore the preliminary design concept (free-rotation on the implant support, $\mu_i = 0$) actually eliminated the need to reduce the difference between the vertical mobilities of the supports.

The following examples show how Figures 5 and 6 can be used to calculate results for specific values of the parameters that describe the tooth/implant supported prosthesis design.

Example 1. Elastic modulus of the prosthesis $E = 10^5$

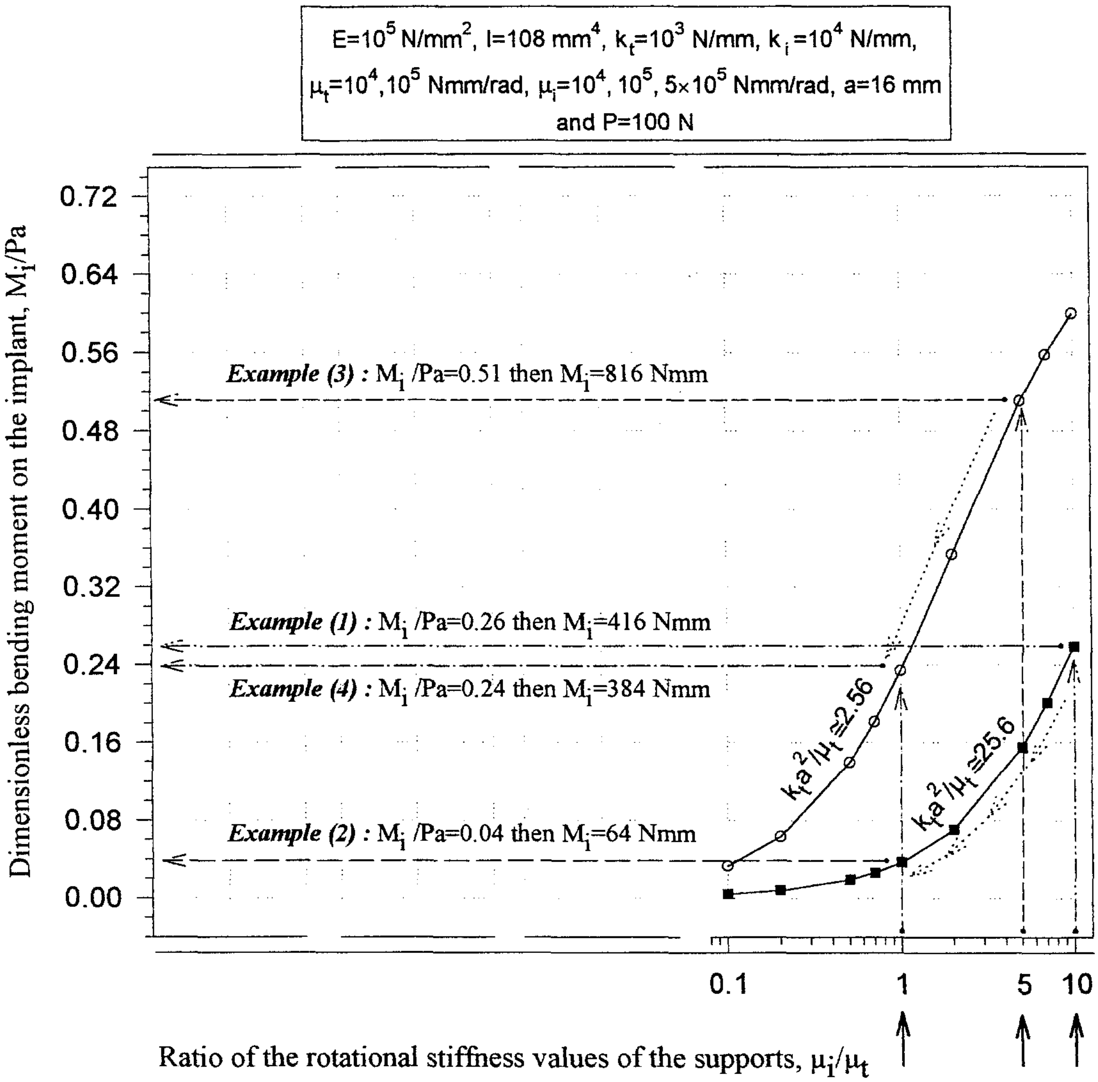


Fig. 7. Numerical examples showing influence of relative rotational mobilities and rotational tooth mobility on bending moment on implant (model "a", load P = 100 N on tooth, m/a = 1).

N/mm^2, moment of inertia of the prosthesis I = 108 mm^4, length of the prosthesis a = 16 mm, load P = 100N on the tooth (m/a = 1), vertical translational stiffness of the tooth $k_t = 10^3$ N/mm, vertical translational stiffness of the implant $k_i = 10^4$, rotational stiffness of the tooth $\mu_t = 10^4$ Nmm/radian and rotational stiffness of the implant $\mu_i = 10^5$ Nmm/radian. The dimensionless variables are calculated as $EI/k_t a^3 \cong 2.64$, $k_i/k_t = 10$, $\mu_i/\mu_t = 10$, and $k_t a^2/\mu_t = 25.6$. When these values of the nondimensional variables were marked on the graph of model "a" (Fig. 7), the nondimensional bending moment on the implant (M_i/Pa) obtained was 0.26, and the bending moment on the implant ($M_i = 0.26 \times$ Pa) was calculated as 416 Nmm, approximately a quarter of the maximum value for the cantilever beam with a single support ($M_{i\text{-cantilever}} = 1600$ Nmm).

Example 2. The only difference from Example 1 is that the rotational stiffness of the implant was reduced from $\mu_i = 10^5$ Nmm/radian to $\mu_i = 10^4$ Nmm/radian, so that both supports have similar rotational mobilities, and $EI/k_t a^3 \cong 2.64$, $k_i/k_t = 10$, $\mu_i/\mu_t = 1$, and $k_t a^2/\mu_t = 25.6$. The nondimensional bending moment on the implant (M_i/Pa) is 0.04, and the bending moment (M_i) becomes 64 Nmm, which is almost negligible compared with the maximum value for a cantilever beam.

Example 3. Change the value of the rotational stiffness of the tooth from $\mu_t = 10^4$ Nmm/radian to $\mu_t = 10^5$ Nmm/radian and of the implant from $\mu_i = 10^4$ Nmm/radian to $\mu_i = 5 \times 10^5$ Nmm/radian. Then $EI/k_t a^3 \cong 2.6$, $k_i/k_t = 10$, $\mu_i/\mu_t = 5$, and $k_t a^2/\mu_t = 2.56$. The nondimensional bending moment on the implant is 0.51, and the bending moment is 816 Nmm, approximately half the maximum value for the cantilever beam.

Example 4. The only difference from Example 3 is that the rotational stiffness of the implant is reduced from $\mu_i = 5 \times 10^5$ Nmm/radian to $\mu_i = 10^5$ Nmm/radian, so that both supports have similar rotational mobilities. Then $EI/k_t a^3 \cong 2.6$, $k_i/k_t = 10$, $\mu_i/\mu_t = 1$, and $k_t a^2/\mu_t =$

2.56. The nondimensional bending moment on the implant is 0.24, and the bending is 384 Nmm, approximately a quarter of the maximum value for the cantilever beam.

The results of these examples suggest that differences in the rotational mobilities of the prosthesis' supports do not necessarily lead to excessive overloading of the implant as long as the rotational mobilities of the prosthesis on the supports are large. However, if the rotational mobilities of the prosthesis on the supports are small, then the difference in rotational mobilities of the prosthesis' supports significantly affects the bending moment on the implant. In short, one needs to consider the interaction among all parameters when considering the distribution of occlusal loads in tooth/implant supported partial prostheses.

Cantilevering tooth/implant supported fixed prostheses

In some clinical situations, tooth/implant supported fixed prostheses are also extended as cantilevers, especially in the posterior region, where the bone may be inadequate for placement of an additional abutment. As a final part of this study, calculations were performed for cantilever extensions in tooth/implant-supported fixed prostheses.

Two models, denoted *cis* and *cts*, were created for the cantilevered prostheses by adding the cantilever extensions to model "a" (Fig. 3). Model *cis* had a cantilever extension on the implant side (cantilever length on the tooth side, $cl_t = 0$); whereas model *cts* had a cantilever extension on the tooth side (cantilever length on the implant side, $cl_i = 0$). Two different lengths of cantilever extension were used for both models: one fourth ($cl = 0.25a$) and one half ($cl = 0.5a$) of the prosthesis length. A vertical unit occlusal load (P) was applied to the farthest point of the cantilever extension of the prosthesis for both models because the loading at that point was the most critical with respect to bending moments and forces on the supports, tooth, and implant.

The results for the moments and forces of the cantilevered prostheses were not graphically presented. It was found that for the assumed clinical range of the tooth stiffness and prosthesis length (Table I), these cantilevered configurations were associated (for a broad range of the parameters describing the prosthesis design and loading) with moderately increased moment relative to the noncantilevered system, and significant detrimental tensile (pull-out) forces on the tooth and the implant. In fact, the pull-out forces were as high as 40% of the applied vertical load. Consequently, a cantilevered tooth-implant supported fixed prosthesis should be avoided or kept as short as possible. If the cantilever is essential, a possible solution that has been suggested by some authors[27,28] for implant-supported cantilevered prostheses, consists of supporting the cantilever extension with a short implant that will only restrain the vertical movement of the cantilever end.

CONCLUSIONS

The following conclusions were drawn from this study.

1. The difference in rotational mobilities of the prosthesis on the implant and tooth was the most significant factor effecting the bending moments on the implant and tooth, especially for smaller values of rotational mobilities of the prosthesis on the supports. Higher rotational mobilities on both supports lead to lower bending moments. Therefore prosthesis/implant and prosthesis/tooth connections should be designed to be rotationally flexible.
2. Large differences in translational mobilities do not necessarily produce excessive overloading of the implant support if the rotational mobilities of the prosthesis on the supports are large.
3. Supports with similar mobilities, especially for smaller rotational mobilities of the supports, diminish the so-called cantilever effect for the noncantilevered prostheses and experience significantly smaller bending moment on the implant. This justifies the idea for the use of intramobile elements (IMEs), flexible screw joint, or any other prosthesis-implant-bone connection designs that will provide more flexibility on the implant.
4. When the prosthesis-implant connection was designed to release the rotational constraint, the bending moment on the implant was totally eliminated without significantly increasing the magnitude of the bending moment on the tooth. This design eliminates the need for predicting or controlling vertical and rotational mobility differences between the supports. Thus it is suggested that new design concepts be considered to release the rotational constraint of the prosthesis/implant connection.
5. Cantilevered tooth-implant supported prosthesis should be avoided or kept short because they are associated with either increased moments and/or detrimental pull-out forces at the abutments. If they are essential, cantilever extensions can be supported by short implants that restrain only vertical movement of the cantilever end.

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