The Influence of Abutment Angulation on Micromotion Level for Immediately Loaded Dental Implants: A 3-D Finite Element Analysis

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Purpose: *To investigate the micromotion between the implant and surrounding bone caused by the implementation of an angled abutment for an immediately loaded single dental implant located in the anterior maxilla.* ***Materials and Methods:*** *A simplified half premaxillary bone model was fabricated. The dimension of the alveolar ridge was adopted from a dry human skull. Based on Brånemark protocol for Mk IV implants in type-3 bone, an immediate loading model was developed by press-fitting a 4-mm-diameter cylinder implant into a 3.15-mm osteotomy site in a numeric model. Material properties were assigned to the simulated model, and the model was meshed. A bite force of 89 N was applied to the tops of the 0-degree, 15-degree, and 25-degree angled abutments at a 120-degree angle to the abutment long axis. The micromotion between the bone-implant interfaces was calculated using ANSYS 9.0 software featuring a nonlinear contact algorithm.* ***Results:*** *The micromotion values for 15-degree and 25-degree angled abutments were 119% and 134%, respectively, compared to the corresponding values for straight abutments. Compared to straight abutments, the 25-degree abutments resulted in increased maximum von Mises stresses to a level of 18%. Most of the stresses were concentrated within the cortical bone around the neck of the implants.* ***Conclusion:*** *Within the limits of the present finite element analysis study, abutment angulation up to 25 degrees can increase the stress in the peri-implant bone by 18% and the micromotion level by 30%.* INT J ORAL MAXILLOFAC IMPLANTS 2008;23:623–630

Key words: *angled abutment, finite element analysis, immediate loading, micromotion*

Since Brånemark introduced the concept of osseointegration and the possibility of anchoring dental prostheses by intraosseous implantation in 1969,[1] the rehabilitation of edentulous alveolar ridges by implant treatment has revealed consistent and reliable results.[2,3] The traditional Brånemark protocol suggested an undisturbed 3- to 6-month healing period subsequent to implant placement to obtain firm osseointegration. However, recent progress in implant dentistry has demonstrated that loading implants immediately after placement is possible without sacrificing implant success.[4–7]

Implant primary stability has been described as one of the most important variables affecting the success of immediately loaded dental implants.[6,8–11] It has also been reported that it is not the loading per se that is a threat to osseointegration, but rather excessive micromotion at the implant-bone interface.[12] The threshold of deleterious micromotion level has been asserted, by various researchers, to lie within the range of 50 to 150 µm.[12–14] Beyond that level of micromotion, fibrous encapsulation may occur around inserted dental implants.

In the anterior maxilla, bone resorption is a frequent consequence of tooth extraction.[15] Angled abutments are often necessary to compensate for such situations. For nonimmediate loading situa-

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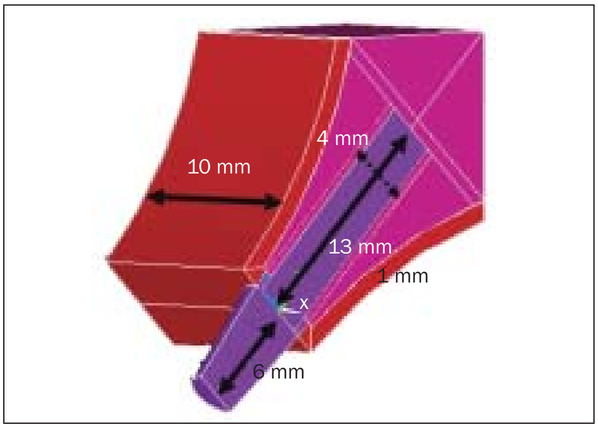


Fig 1 Demonstration of the constructed model, here with a 0-degree abutment 4 × 13 mm in dimension.

Table 1 Material Properties Used in the Present Study

	Modulus of elasticity (GPa)	Poisson ratio
Abutment and implant	102	0.3
Cortical bone	13	0.3
Type 3 cancellous bone	1.6	0.3

tions, it has been reported by the authors of several clinical studies that an angled abutment can be successfully employed to restore implant-retained prostheses.[16–19] For immediate loading situations in which osseointegration between bone and implant interface has not taken place, the influence of angled abutments under such situations appears to be unknown, especially with respect to the primary stability of an involved implant.

Clinically it is virtually impossible to introduce any device into the implant-bone interface to attempt to investigate the level of micromotion between bone and implant under masticatory force. Several parameters have been used in past experimental and clinical studies to represent implant primary stability in experimental or clinical studies. These parameters include insertion torque,[20,21] removal torque,[22] cutting torque,[23] pull-out force,[22] Periotest data,[22,24] and implant stability quotient, as derived from resonance frequency analysis[25,26]; however, it would appear that most of these parameters are either low in sensitivity or that the correlation between these parameters is somewhat questionable.[23,27] Under such circumstances, finite element analysis (FEA) is an efficient technique for the evaluation of not only micromotion level but also stress distribution patterns. The purpose of the current study was to investigate the influence of abutment angulation upon the micromotion level and stress-distribution pattern for an immediate loading situation by means of FEA. The study area of interest was a single implant placed in anterior maxillary region.

MATERIALS AND METHODS

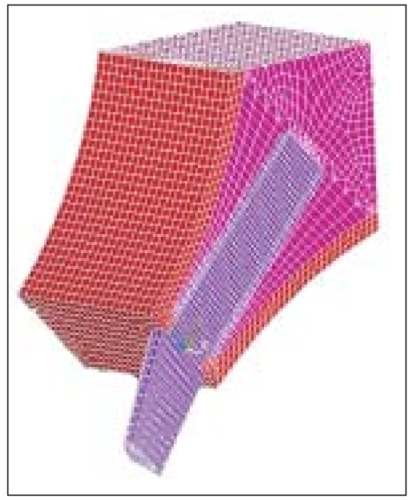
Model Geometry

A simplified premaxillary model was simulated using computer-aided design (CAD) software (SolidWorks 2004; Dassault Systemes, Suresnes, France). The cross-sectional dimension of the model was adopted from the approximate dimensions of a dry human skull. The alveolar ridge was 6.5 mm long labiolingually. The mesio-distal width of this bone model was set to 10 mm. A uniform 1-mm-thick layer of cortical bone was modeled on the outer surface of the cancellous core. Only half of the model was constructed, because the model was symmetric in the mesiodistal direction. A cylindric implant 4 mm in diameter and 13 mm in length was placed in the middle of the simulated alveolar ridge of this premaxillary bone block (Fig 1).

To simulate an immediate-loading situation at the bone-implant interface on the numeric model, the implant was assumed to feature a rough surface with a coefficient of friction of 0.68, a value which was adopted from Dammak et al's 1997 work.[28] Primary stability of the implant was obtained by press-fitting a 4-mm implant into a 3.15-mm diameter osteotomy site. This was based on the Brånemark implant placement surgical manual for an Mk IV implant in type 3 bone. No direct bone-implant bonding was modeled. The prestress applied on the implant surface was created by the interference of surrounding bone via press-fitting. The platform of the implant was modeled as being flush with the alveolar ridge surface to effectively mimic a real clinical situation. Three types of angled abutments were connected to the inserted implants individually. The angulations of the abutments, 0 degrees, 15 degrees, and 25 degrees, were adopted from the commonly used preangled abutments available on the market.

Material Properties

All of the materials in the current study were assumed to be homogenous, linearly elastic, and isotropic to simplify computation processes. Most of the data of the material properties were obtained from the relevant literature, and one report which appeared to have been frequently cited was that of Tada et al,[29] a summary of which appears in Table 1.



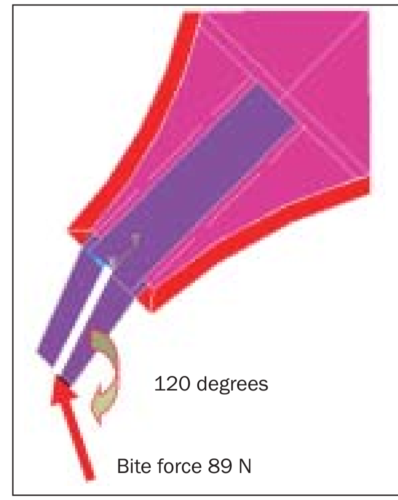


Fig 2 *(Left)* Meshed elements. Here a 15-degree abutment is used as an illustration.

Fig 3 *(Right)* Loading application for present analysis. A bite force of 89 N was applied at an angle of 120 degrees from the long axis of the abutment to the half-model (sagittal view). Here, a 15-degree abutment is used as an illustration.

Elements and Nodes

The numerical model was meshed in the ANSYS 9.0 software (Swanson Analysis Systems, Canonsburg, PA). For the angled abutments, press-fitted implants, cortical and trabecular bone, an 8-node solid element was used for meshing. To properly transfer stresses through nonbonded contact surfaces at the bone-implant interface, ANSYS surface contact element 174 and target 170 were used. Contact 174 features the same geometric characteristics as the solid element to which it was connected. This element type was automatically assigned by ANSYS software during the contact simulation process (Fig 2).

Boundary Constraints and Loading Condition

Immediate loading is a situation when dental implants have been inserted but have not become osseointegrated with bone subsequent to their placement. In other words, the contact between the implant surface and recipient bone is not bonded. Under such a scenario, sliding and separation between implant and surrounding bone are allowed. Such presumed behavior was achieved by assigning the implant and bone surface as, respectively, target and contact surfaces using ANSYS software. The micromotion status was obtained through the application of a nonlinear contact algorithm. The top and back surfaces of the pre-maxillary model were assumed to be fixed. The mid-sagittal surface of the simulated model was set to be a symmetrical boundary; thus, only one half of the premaxillary model was needed for the present study. A value of half of the maximum biting force of anterior teeth (ie 178 N)[30,31] was applied on the middle of the top surface of the angled abutment. This force was at a 120-degree angle to the abutment's long axis (Fig 3).

Calculation Process

Two load-steps were applied in the computer-calculation process. The first load-step was to simulate the situation where an implant (4 mm) was press-fitted into an osteotomy site of a slightly lesser dimension (3.15 mm). The second load-step was intended to simulate the application of biting force. The "large deflection" option of ANSYS software was turned on for this step.

Model Validation

From the finite-element model, the force needed to pull out the press-fitted implants was calculated. These data were then compared with the actual implant pull-out force from an experimental study reported in the literature.[22] If the data from the present numerical model appear to be readily comparable with the experimental pull-out forces described within the literature, the relative reliability of this simulation model for the derivation of immediate-loading data could be viewed as quite valid and relevant to the real-life situations.

RESULTS

Convergence Evaluation

Model convergence was evaluated by summing up the total strain energy of all elements present for the 15-degree numerical model. The mesh was gradually refined as regards the abutment, implant, cortical, and trabecular bone. When the model's element number reached 18,573, the calculation was deemed to have converged as shown in Fig 4.

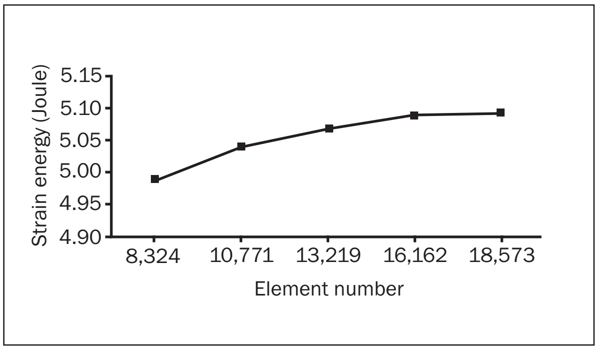


Fig 4 The convergence result was evaluated by strain energy and determined to be a model of 18,573 elements.

Table 2 Study Results for 3 Different Abutment Angulations

	0 degrees	15 degrees	25 degrees
Micromotion*	11.1 (100%)	13.3 (119%)	14.9 (134%)
Maximum cortical von Mises stress (MPa)	69.0 (100%)	77.3 (112%)	81.3 (118%)

*Relative interface sliding (μm).
Data in parentheses are percentage relative to 0-d data.

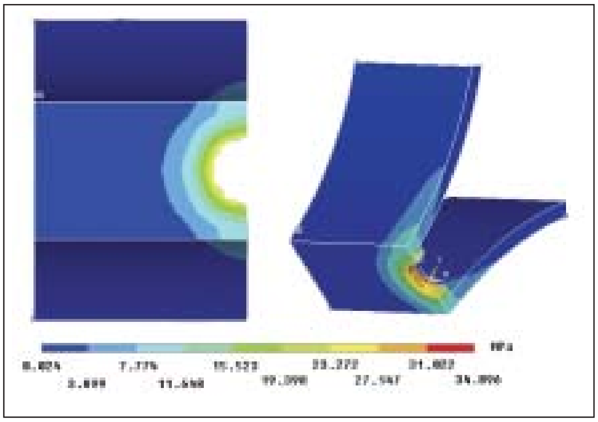


Fig 5 Von Mises stress (MPa) concentration on cortical bone when press-fitting an implant into the bone model: occlusal view *(left)* and isometric view *(right)*.

Model Validation

For the present numeric model, the normal contact forces applied to the implant surface from every contact element were summed, revealing a total of 935 N. Frictional force was obtained by multiplying the normal contact forces by 0.68, which is the estimated coefficient of friction between a porous metal surface and bone.[28] The result obtained from this calculation was 635.7 N. These data represented the frictional force needed to pull out an implant press-fitted into the bone from the numerical simulation model.

The actual pull-out force was estimated by reference to a study conducted by Kido et al.[22] For Kido et al's study, a total of 36 screw-type implants with diameters of 3.25 mm and 4.5 mm and being 8 mm in length were inserted into five human-cadaver mandibles and were subsequently pulled out to test their primary stability. The resultant average pull-out forces were 543.2 ± 275.46 N and 624.3 ± 361.78 N for, respectively, implants featuring a diameter of 3.25 mm and 4.5 mm (Table 2). The estimated implant pull-out force from the numerical model (635.7 N) fall within the range of values provided by the experimental data, as a consequence of which, the numerical model was considered to have been validated and was deemed as being relevant to a real-life situation.

The Influence of Abutment Angulation upon Micromotion Level for Immediately Loaded implants

For type-III bone with implant-placement protocol proposed by Brånemark's implant system, increases in abutment angle generally increases micromotion level between implant/bone interfaces. The micromotion between implant and bone for 0-degree, 15-degree and 25-degree abutments was, respectively,11.1 μm, 13.3 μm and 14.9 μm. Cortical bone stress elicited by implant placement and stress loading also increased as abutment angle increased. Such data are listed below (Table 2). If the data of 15-degree and 25-degree abutments are presented in proportional format relative to that for the 0-degree abutment, the micromotion increased by 19.4% and 33.5% for, respectively, 15-degree and 25-degree abutments.

The Influence of Stress Concentration in Bone from Angled Abutments

Stress Distribution Associated with Press-fitting an Implant into Bone. The stress resulted was mainly concentrated in the cortical bone around the implants (Fig 5). Maximum von Mises stress was 34.9 MPa and appeared to be located in the interface between cortical and cancellous bone surrounding the implant neck. Stress level within the cancellous bone appeared to be relatively minor due to this type of bone's lower elastic property as compared to cortical bone.

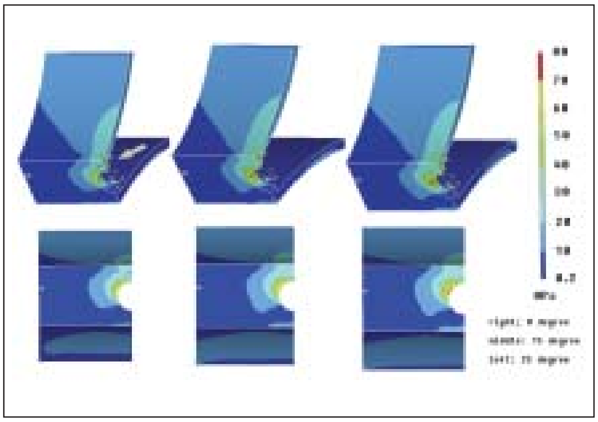


Fig 6 Occlusal *(bottom)* and isometric *(top)* view of stress distribution in cortical bone after bite force application. The stress indicated by the white arrow was ignored *(see text for explanation)*. The stresses on the top of the ridge at the junction between the labial and distal surfaces of the implant are the stresses concerned. As the abutment angle increased. (*left*, 0-degree; *middle*, 15-degree; *right*, 25-degree), the maximum stress also increased.

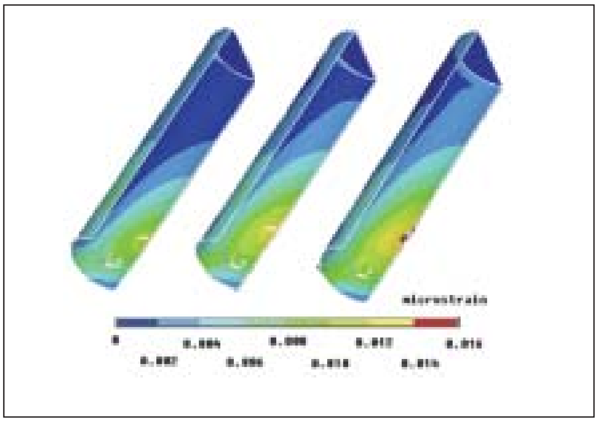


Fig 7 Location of maximum contact sliding (micromotion) for *(left)* 0 degrees, *(middle)* 15 degrees, *(right)* 25 degrees.

Stress Distribution Generated Through Loading on Angled Abutments. When a bite force was applied to an angled abutment, as abutment angle increased, the stress generated in bone increased and appeared to have been concentrated in certain areas. The maximum stress in the model was located at the junction of cortical and cancellous bone labial to the implant. Such data only exist in simulation because the model was simplified during its design; in a real-life situation there would not have been a distinct junction between cortical and trabecular bone (Fig 6). If such singular stress is ignored, the maximum von Mises stress was then concentrated in the cortical bone around implant neck and was at the junction of labial and distal surface on the crest of alveolar ridge (Fig 6). The stress associated with implant loading also increased with the increase in abutment angle. The resultant stress distribution patterns for the 3 abutment angulations appeared to be quite similar.

The Status of Micromotion at the Implant-Bone Interface

The relative movement between implant and bone (micromotion) as a consequence of implant loading for 3 different abutment angles is plotted in Fig 7. Such results constituted the focus of interest for the present study. Although the level of micromotion increased as abutment angulations increased, the pattern and location of maximum relative sliding between simulated implant and bone surface as a consequence of impact loading did not appear to change significantly along with the change of abutment angulation. Such sliding was typically located on the mid-palatal surface at the bone-implant interface.

DISCUSSION

In the present study, the resulting stresses were mainly concentrated within the cortical bone on the crest of the alveolar ridge. Compared to the stress transferred via a 0-degree abutment, the von Mises stress resultant from implant loading were 12% and 18% greater for abutment angles of 15 degrees and 25 degrees, respectively. Until recently, no published experimental study pertaining to immediately loaded implants featuring angled abutments appeared to have been available. For non-immediate loading situations, there does not exist any real consensus amongst researchers as to how abutment angle affects dental-implant stress level. Clelland[30,32,33] conducted a series of studies regarding angled abutments in which photoelastic, strain gauge, and finite element techniques were employed to study the effect of stress transfer. Their findings suggested that the compressive stresses measured from strain gauge readings for 15-degree and 20-degree abutments were 170% and 190%,[33] respectively, compared to the compressive stresses for a 0-degree abutment. Under a similar loading condition but with different material properties for bone and implant, the finite element study[30] revealed only an 11% increase in peak compressive stress when the abutment angulation was increased from 0 to 20 degrees. In 1998, Brosh et al[34] attached strain gauges to implant surfaces and embedded these implants in photoelastic acrylic resins to investigate stress transfer from angled abutments. When the color fringe change within the photoelastic acrylic resin was observed, only an 11% increase in shear stress detected when the abutment angulation was increased from 0 to 25 degrees.[34] In the same study, however, the strain-gauge data showed that for 15- and 25-degree abutments, respectively, the increase of strain were 3 and 4.4 times greater, respectively, than the control (0 degrees). The actual influence of such abutment angles upon implant loading appear to be related to a variety of factors such as loading condition (magnitude and direction), material properties, and how detecting devices such as strain gauges were located. This could possibly explain the wide variety of study results from various researchers. The same applies to the current study. The micromotion magnitudes that were obtained in this study may have been strongly influenced by the applied variables, such as the chosen coefficient of friction, the elastic modulus of the bone, and the osteotomy diameter.

The coefficient of friction used for the pull-out force estimation of the present numeric model was adopted from that proposed by Dammak et al.[28] The porous metal sample used for Dammak et al's study may not be identical to the TiUnite implant surface of the Brånemark implant system, which was used for the present study. The data adopted for coefficient of friction was applied to the 3 different abutment-angle groups. Therefore, the relative trends of the results between the 3 studied angulations should not be affected by the adoption of this coefficient. The coulomb-Amonton friction law also states that the coefficient of friction is independent of normal force and contact area,[35] which suggests that the adopted coefficient of friction of current study was applicable even though the normal force from press-fitting may not have been identical between the present study and that of Dammak et al in 1997.

The experimental variables specified in Kido's pull-out test[22] and those of the present study would not appear to be identical; they differed in various experimental variables, including extent of implant depth embedded within bone and implant diameter, implant type, bone quality at site of implant, and even surgical protocols adopted (Brånemark versus Steri-Oss). Due to the large standard deviation regarding implant pull-out force obtained in Kido's study, it would appear very difficult to pinpoint the exact force needed to pull out a nonosseointegrated implant of a certain dimension.[22] This is probably because the primary stability of an implant is a multifactorial issue. In a study such as that reported by Kido, it is not an easy task to control all factors, including bone quality and quantity, for all test specimens. As a consequence of the estimated pull-out resistance of the current numerical model being very close to the average data obtained in Kido's study, the model of immediate loading of an implant through press-fitting as adopted for the current study should be deemed valid. However, the actual bony fracture near thread was not simulated in this finite element analysis, since this screw model didn't consist of external threads, and the pull-out forces resisted were primarily shear forces between the implant and the bone.

Does micromotion affect implant osseointegration? The study from Cameron et al[14] revealed that bone cells are able to grow into certain porous metal surfaces under conditions of micromovement but not macromovement. A number of other clinical and experimental studies have also clearly demonstrated that effective osseointegration is possible under a certain level of micromotion.[14] It would appear that it is reasonably recognized that the early loading/immediate loading itself of a dental implant does not necessarily lead to fibrous encapsulation; an *excessive* level of micromotion leads to fibrous encapsulation.[36]

On the other hand, evidence has also been offered suggesting that under a certain level of controlled mechanical stimulation/micromotion, bone healing may be enhanced.[37] In a randomized clinical trial, Kenwright et al[38] applied a mechanical-stimulation regime of 1-mm axial movement at 5 Hz for 20 minutes every day upon human tibial fractures and reported that micromovement fixation was associated with a significantly shorter healing time than rigid fixation. Given such results, it is not unreasonable to assume that micromovement for immediately loaded implants may, in fact, produce a similar effect. Histologic examination of retrieved implants supports such observations.[39–42]

Thus, the question necessarily arises, how much micromotion is excessive? Some studies have suggested that 30 μm,[24] 50 to 150 μm,[36] or 100 μm[13] is excessive. Furthermore, evidence has also been presented to indicate that the threshold value of micromotion may be influenced by other factors, such as implant surface treatment.[35] Until now, there would not appear to have been available a commonly accepted data set germane to this threshold level. Even if the critical threshold stress level for the deleterious micromotion is determined, it would appear impossible to directly measure the existing level of micromotion in a clinical context. Hence, to immediately load a dental implant, clinicians should seek any measure to prevent or reduce micromotion. Essentially, this is the reason that the current study was undertaken (ie, to explore the effect of abutment angulation upon the level of micromotion).

For this study, a number of variables that may influence study results were controlled for, such as bone quality (type-3 bone), press-fit level (0.425 mm), the presence of sufficient bone quantity without implant-thread exposure or bone dehiscence, an abutment angle (less than 25 degrees), and bite force (less than 178 N). Under such circumstances, the micromotion level for angled abutments lay within the safety limit of osseointegration specified by various researchers. For situations beyond the limitations of the present study (reduced press-fit level, bruxers with nocturnal biting forces beyond 178 N[43] and of significant duration), current results may not apply. Further clinical and experimental studies are thus clearly needed to verify test values for such situations.

Within the limits of the present study, micromotion magnitudes may be strongly influenced by *(a)* the value chosen for coefficient of friction, *(b)* the local variations in the elastic modulus of the bone (ie, local bone quality), and *(c)* the osteotomy diameter. An implant with a diameter of 4 mm and a length of 13 mm placed into a type-3 bone osteotomy socket with a diameter of 3.15 mm, with an increase of abutment angle up to 25 degrees, could increase the micromotion level by up to 30% in comparison with a 0-degree abutment. This up-to-30% increase in micromotion as compared to the 0-degree option would still appear to lie within the safety threshold for osseointegration as previously asserted by various researchers. The primary stability of immediately loaded dental implants that require an angled abutment will thus not be endangered under the situation specified in the present study.

If the Brånemark surgical protocol is not strictly adhered to for implant placement, however, or when receiving bone quality is not optimal, a situation which might render the primary stability of inserted implants to a borderline level of fibrous encapsulation, then this 30% increase in micromotion for a 25-degree abutment may pose a threat to the relative stability and longevity of an immediately loaded implant. Under such circumstances, angled abutments should not be loaded immediately. Rather, the timing of loading should be deferred until 3 or 6 months subsequent to the achievement of clinically acceptable osseointegration.

CONCLUSION

Within the limits of the present study, for an implant placed under immediate loading in type-3 bone to support a single-tooth restoration, abutment angulations up to 25 degrees can increase the stress in the peri-implant bone by 18% and the micromotion level by 30%.

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