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Effects of Vertical Interarch Space and Abutment Height on Stress Distributions: A 3d Finite Element Analysis

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Abstract - *This three dimensional Finite Element Analysis study investigated stress distribution and intensity in implants restored with cemented or screwed crown. Two parameters varied: interarch space and abutment height. Highest stresses occurred at the cervical area in all models. Stresses increased mainly with vertical interarch space highness, and secondarily with abutments shortness. From a mechanical point of view, bone and prosthetics components supporting cemented crowns were not as solicited as with screwed crowns.*

KEY WORDS: biomechanics, dental implant, abutment, interarch space, stress, finite element analysis.

INTRODUCTION

The single dental replacement by an implant is a successful clinical treatment, which has a high survival rate and requires strict surgical and prosthodontics procedures[1]. Implant primary stability is one of the main requests[2], especially with immediate loading. After implant placing, the practitioner has to choose an abutment as a function of clinical and mechanical conditions. Stress intensity and distribution increase in the crown, implant components and surrounding bone[3, 4] without passive fit between prosthetic parts.

The quantitative evaluation of vertical interarch space is one of the guiding parameters for choosing an abutment and optimizing biomechanical conditions of success[5-7]. Another one could be the abutment design (for cemented or screwed crowns), but no evidence was found about a special role of the luting agent in resisting deflection from applied forces[8].

Finite element analysis (FEA) is a computer-based method used to calculate and visually represent stresses and strains in complex structures, which are subjected to simulated loads. The calculations require knowledge of the mechanical properties of the materials, such as Young's modulus (E) and Poisson's ratio (ν). This numerical stress analysis technique is widely used today in studying biomechanical problems in dental implantology[9]. Most mechanical FEA looked at the forces distribution in peri-implant bone as a function of implants geometry. Unfortunately none among them analyzed the relationship between the vertical interarch space and the type of abutment[5, 9].

This three-dimensional FEA is used to determine the stress levels and distributions in all-ceramic crown restored implants as a function of different extents of interarch space and abutment height. The purpose is therefore to guide the clinician in his abutment's choice, in order to limit stresses and protect implant primary stability.

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MATERIAL AND METHODS

The software package used in this study was CADSAP® (CADLM, France), French version of SUPERSAP (ALGOR® Interactive Systems, USA), and ran on a compatible PC. A 3D modelling assuming linear elasticity was carried out. The material data (Young's modulus, E; and Poisson's ratio, ν) used in the calculations are presented in Table 1. Each structure was modelled with elements and is considered isotropic.

The crown restored implant aimed here to replace a single missing premolar tooth, with antagonistic teeth determining a vertical interarch space. The bone geometry was defined by a 3-D model. The cortical thickness was assumed to be 0.5 mm. The cortical bone was made of 1032 brick elements and the cancellous one of 2600 elements. Implants (2016 elements) with 4.1 mm diameter and 10 mm length were built. The geometrical configuration of the implant has been chosen arbitrarily. The implant was positioned in the centre of the bony structure. The implant was assumed to be embedded at its base (Fig.1a), completely integrated. Each implant was fitted with a different titanium abutment (900 elements) and a premolar ceramic crown (1128 elements) (Fig.1b). The all-ceramic crowns were modelled in a realistic way, with the occlusal thickness allowed by the abutment height. The screwed crowns had a 2 mm hole on their occlusal surface, authorizing the placement of a titanium screw. Abutments for cemented crown had the following heights: 4, 5.5 and 7 mm. Abutments for screwed crown were 2.5 mm high. The screwed pieces were considered to be in their definitive position. Between the crown and the abutment, the cement thickness was assumed to be 50 µm. Zinc phosphate luting cement (264 elements) was used. Crowns were mechanically loaded at their occlusal surface with a defined force of 30 N inclined

Table 1. *Materials' Elasticity Modulus (E, Young's modulus in GPa) and Poisson Proportions (ν, Poisson's ratio)*[25 26].

	Titanium	*Ceramic*	*Cancellous bone*	*Cortical bone*
Young'modulus	117	96	7.9	13.7
Poisson's ratio	0.33	0.28	0.3	0.3

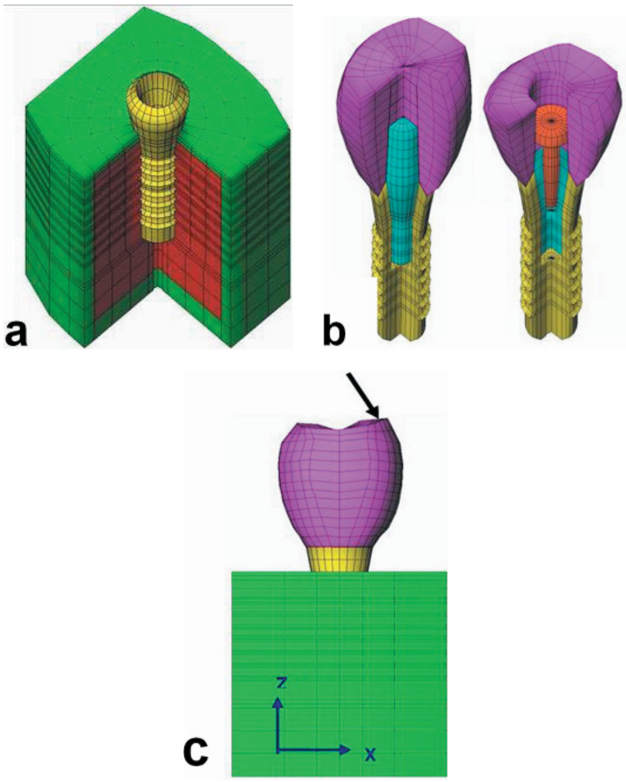

Figure 1. *Three dimensional models.*

a- Implants (yellow) were embedded in the bone structure (cortical bone: green, cancellous bone: red),
b- Two prosthetic configurations were evaluated: crown (violet) cemented on the abutment (blue) or screwed (red) within the abutment through an occlusal hole.
c- Assembled models were mechanically loaded with an inclined force.

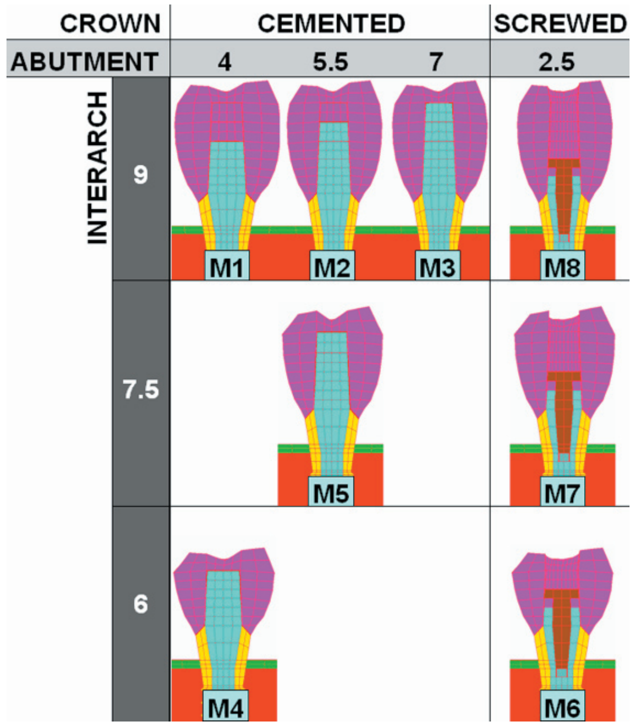

Figure 2. *Eight models compared. The two prosthetic configurations (cemented and screwed crowns) were confronted with different interarch space and/or abutment heights.*

at 30° with the bucco-lingual plane (Fig.1c). The intensity of strength applied to the occlusal surface, bone mechanical properties or geometrical configuration of the implant were chosen arbitrarily in this case of comparative study. It did not affect the outcome.

Eight models were compared (Fig.2). The first five had cemented crowns. Models M1, M2 and M3 had a 9 mm interarch space with different abutment heights (respectively 4, 5.5 and 7 mm). M4 had a 4 mm abutment with a 6 mm interarch space; M5 had a 5.5 mm abutment with a 7.5 mm interarch spaces. The last three models M6, M7 and M8 had screwed crowns with a 2.5 mm abutment and different interarch spaces (respectively 6, 7.5 and 9 mm).

Implant displacements in bone, stress distribution and intensity were calculated. It was hypothesized that compression was the most detrimental stress for bone tissue. They could potentially lead to bone resorption. Tensile stress was assumed to be critical for implant components failures. The distribution of compressive and tensile stresses was represented as iso areas showing mean stresses in MPa. Red and orange indicated areas subjected to high-intensity tensile stresses. Purple and blue indicate high-intensity compressive stresses.

RESULTS

Stress distribution

In all the models, compressive stresses (Fig.3) were observed in the cervical area on the solicited cusp side, while tensile stresses were on the opposite side. Highest stresses occurred mainly around the neck implant. They decreased progressively through the bone, the abutment and finally in the crown cervical area. Titanium prosthetic screws (in M6, M7 and, M8) were relatively less solicited areas.

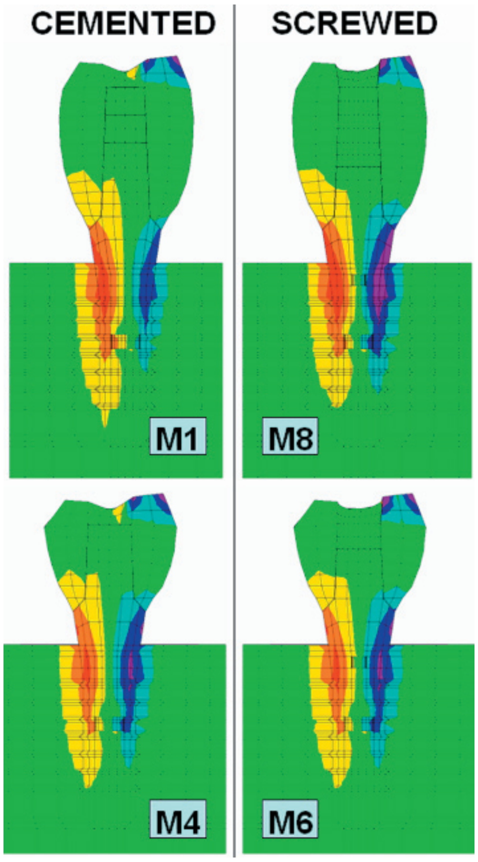

Figure 3. *Stresses distribution in selected extreme models. Bucco-lingual section of M1, M4, M8 and M6. Compressive stresses appeared in purple/blue, while tensile stresses were in red/orange. Stress distribution was mainly around the implant neck in all the models.*

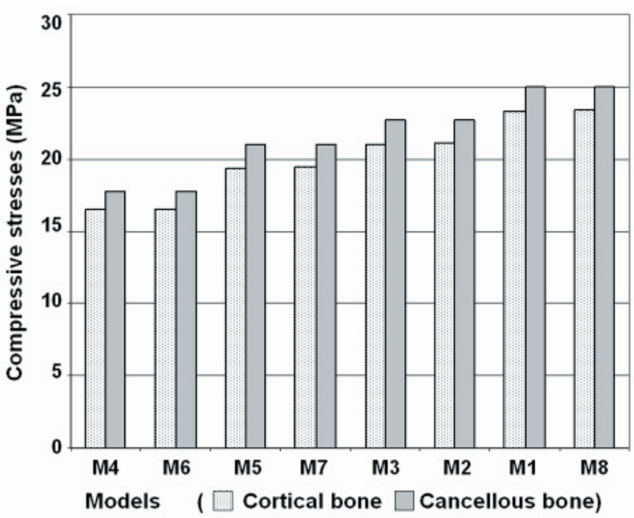

Figure 4. *Compressive stress intensity in bone at the implant cervical area (models put in increasing order). Cancellous (grey) bone stresses appeared slightly higher than cortical ones (white). Bone compressive stresses increased with vertical interarch space, and with short abutments.*

Bone stress intensity

Compressive stresses are clinically associated with bone resorption. Compressive stress intensities at the implant cervical area showed slightly higher levels in cancellous bone than in cortical one (Fig.4). Since FEA is a comparison method, relative percentages are preferred to theoric values. Bones of models M4 and M6, which correspond to short vertical interarch spaces, were the less solicited in the cervical area (mean of 17.15 MPa). M5 and M7 bones, corresponding to intermediate vertical interarch spaces, were significantly more solicited (+15%). M2 and M3, with abutments adapted to high vertical interarch spaces, were even more solicited (+21%). Finally, M1 and M9 bones were the more solicited (+29%) with their large vertical interarch space and their short abutments.

Stress intensity in implant components

Tensile stress was assumed to be clinically critical for implant components. In all the models, maximum tensile stresses were found within the implants in comparison with abutments (Fig.5). In the 3 specific models M6, M7 and M8, screws showed much lower stress intensity than the other implant components. When put in increasing stress order, models showed the same arrangement that previously observed for bone compressive stresses.

When the vertical interarch space was short, implants were less solicited (mean of 19.4 MPa for M4 and M6). The intermediate vertical interarch space involved slightly more intense implants solicitations (+10.6% for M5, +11.8% for M7). When the vertical interarch space was large, implants were much solicited (+11.8% for M2 and M3) and especially those with short abutments (+21.5% for M1 and +22.8% for M9).

Concerning abutments, intermediate vertical interarch space caused a stress increase of 9.5% (mean of 14.2 MPa for M4-M6, 15.7 MPa for M5-M7). When the vertical interarch space was large, abutments were solicited especially if they were short (+ 19.8%). The prosthetic screw was less solicited when the vertical interarch space was short (5.8 MPa for M6), and the solicitations increased with the height (+9% for M7 and 20.5% for M8).

Implant displacements in bone

Implants mobility evolution was similar with stress intensities. In comparison to M4 and M6 (3.6 µm), 7.5 mm vertical interarch space increased the implant displacement of 6.25% (M5 and M7), while 9 mm increased of 8.16% for intermediary abutments (M2 and M3) and 13.66% for short abutments (M1 and M9).

DISCUSSION

This 3D FEA showed the mechanical behaviour of different extents of interarch space and abutment designs, corresponding to cemented or screwed crowns. These two parameters affected the stress transfer conditions.

FEA has proved to be an accurate tool for evaluating the mechanical behaviour of implant layouts[9] and convenient as models can easily be modified to accommodate varying hypothesis. The program used in this investigation has

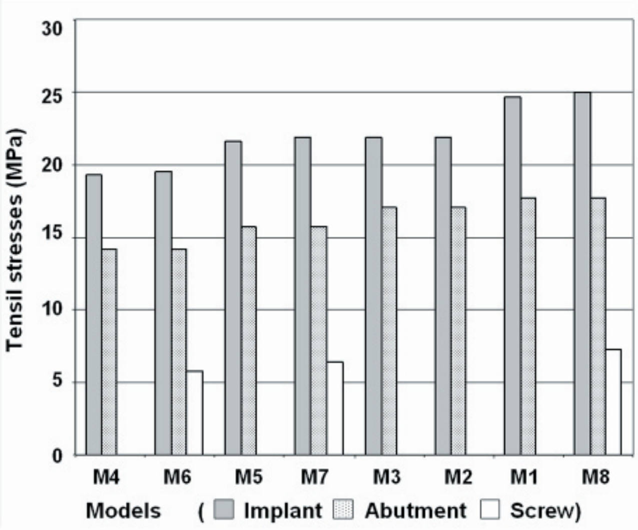

Figure 5. *Tensile stress intensity in implant components (models put in increasing order). Implants (dark grey) were more solicited than abutments (light grey) and screws (white). Tensile stresses in implant components increased with vertical interarch space, and with short abutments.*

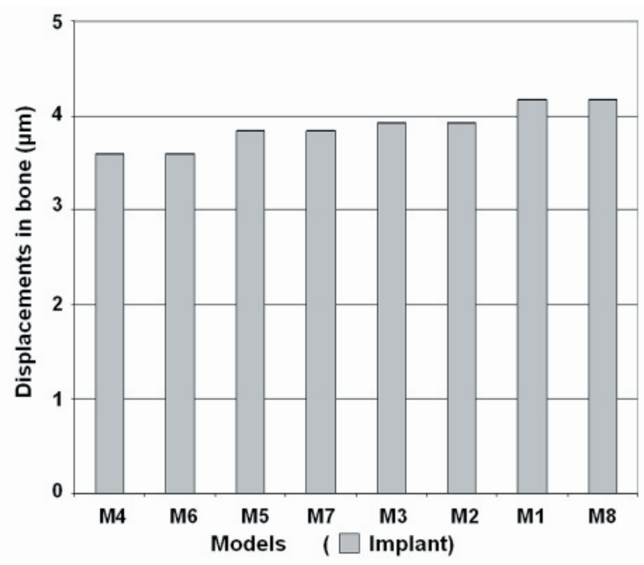

Figure 6. *Implant displacements in bone (models put in increasing order). Implants mobility increased with vertical interarch space, and with short abutments.*

several limitations considering the unrealistic simulation of material properties of the structures. This static study assumes that the bone, the tooth, and the periodontal ligament are homogeneous, linear-elastic, isotropic, and does not take into account materials fatigue due to the repeated loads and the complexity of masticatory forces.

This method assumes futhermore that the bonding of the bone and the implant is perfect. All static mastication forces applied to Fixed Partial Dentures (FPDs) were loaded axially. The mastication forces are though dynamic and oblique relative to the occlusal surface of FPDs, and the interference between the implant and the bone is dynamic in reality. Consequently, it is usually impossible to reproduce all the details of natural behaviour. FEA can not determine criteria for acceptability of stress levels, but enables to compare different models and quantify their risk. More work on these models will be yet needed for matching the reality.

Our study suggests important bone compressive stresses around the implant neck. Since FEA is a comparison tool, stresses around the implants appeared to depend rather on implants geometry or bone structure than on implant mechanical characteristics. This results corroborate other in vitro studies using FEA or other method [4, 7, 10-12]. Moreover, in a number of radiologic long-term studies, loaded implants showed bone loss around the implant neck [13-18]. The cervical area is critical because of high-intensity stresses concentration, especially when implants are subjected to lateral forces. Repeated stresses imply fatigue of implant components, reduce their long-term resistance, and lead to a higher risk of biomechanical complications[10]. This FEA can unfortunately not take into account fatigue events but suggests clinical location of implant components fracture, bone resorption or crown unscrewing[19]. If Rangert [20, 21] compared success rate for implants of different heights, no up-to-date study has compared the long-term biomechanical performance of implant-supported prostheses and implant-assisted prostheses with abutments of different heights. Only the restoration is of influence, as our mechanical study compares implants supported prosthetics in strictly identical conditions (same height and diameter, bone volume and density). The main stress parameter appears to be the vertical interarch space, when associated with crown height. As a matter of fact, when abutment height is not a varying parameter (for cemented crowns: models M1 and M4; M2 and M5; for screwed crowns: M8, M7 and M6), stresses increase with the vertical interarch space. It increases likewise when abutment height adaptation is not a varying parameter (M4, M5 and M6). High vertical interarch space leads to stress transmissions in bone and implant components more significant than height or type of abutment. When the interarch space is not a varying parameter (M1, M2, and M3), stresses increase with the abutment shortness. Moreover, for cemented crowns, abutment adaptation (2mm less than the interarch space) decreases stresses intensities (comparing models M1 and M4; M2 and M5). Concerning abutment types, stresses appear to be higher in abutment designed for screwed crowns (comparing M3 and M8; M5 and M7; M4 and M6). Moreover, when comparing models with similar interarch space (M3, M2, M1 and M8), abutment shortness seems to be the linear influence parameter. Abutments designed for screwed crowns are 2.5mm high. Nevertheless, this abutment design is of less influence than vertical interarch space on stress intensities.

Implant displacements in bone are linked to those stress intensities. Concerning primary stability of implants, immediate loading raises the problems of micro movements. They induce fibrous tissue formation at the bone-implant interface when exceeding 100 µm[1, 22, 23]. Control of these micro movements is possible in long span prosthodontic designs [11, 17, 24] but is hazardous with single-tooth replacements[6]. Our study showed that initial stability of the implants depends on the vertical interarch space, but also on the height and type of abutment. Large vertical interarch space is an unfavourable parameter for immediate loading.

The FE method provides a means of testing assumptions that obviously must then be confirmed by clinical studies, where comparing the results of prostheses supported implants in strictly identical conditions would be impossible to organize (same patient, bone volume and density, type of restoration). Despite these difficulties, the interpretation and clinical consequences of the results must be submitted to the clinical reality.

CONCLUSION

Within the limits of this 3D-FE Analysis, the following can be concluded:

1. The most intense stresses appear in the cervical area within the implant and bone. Highest stresses occurred in the implants first at their neck, and progressively decrease towards the bone, the abutment, in the threaded part and the cervical area of the crown,
2. Stress levels increase with the vertical interarch space, which is the dominating factor. As a consequence, initial stability is easier with short vertical interarch spaces.
3. Abutment height adaptation to the vertical interarch space is an important parameter. In this mechanical context, the comparison allows preference to abutments designed for cemented crowns.

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