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BASIC RESEARCH

Outlook of short finned implants in the posterior maxilla: the role of cortical bone thickness

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Abstract

Short finned implants are often applied in critical cases of edentulous posterior maxilla with no available bone for subcrestal implant placement. Resulting higher stresses in crestal cortical bone lead to its overload and subsequent implant failure. Finite element (FE) method provides biomechanical evaluation of bone-implant structures and influence of bone quality and implant parameters on bone stresses.

The aim of the study was to evaluate the impact of crestal placement of short finned implants on stress magnitudes in atrophic posterior maxilla under oblique functional loading to predict bone overload and implant failure.

Four Bicon Integra-CP™ implants with 4.5, 6.0 mm diameter and 5.0, 8.0 mm length were selected for this evaluation. Their 3D models were placed in 12 posterior maxilla segment models with type IV bone, 1.5, 1.0 and 0.5 mm crestal cortical bone thickness. These models were designed using CT images in Solidworks 2016 software. Implant and bone were assumed as linearly elastic and isotropic. Elasticity modulus of cortical bone was 13.7 GPa, cancellous bone – 0.69 GPa. Bone-implant assemblies were analyzed in FE software Solidworks Simulation. 4-node 3D FEs were generated with a total number of up to 2,820,000. 120.92 N mean maximal oblique load (molar area) was applied to the center of 7 Series Low 0° abutment. Von Mises equivalent stress (MES) distributions in surrounding bone were studied to determine the areas of bone overload with magnitude >100 MPa in cortical bone.

Maximal magnitudes of MESs were found in crestal cortical bone. The spectrum of maximal MESs was between 14.0 and 47.0 MPa. The highest MESs were found for 4.5×5.0 mm implant, while the smallest magnitudes were determined for 6.0×8.0 mm implant. For tested implants, maximal MES magnitudes were significantly influenced by cortical bone thickness and implant dimensions: for 0.5, 1.0 and 1.5 mm cortical bone thickness and diameter increase from 4.5 to 6.0 mm, MES drop was 48, 47, 43% for 5.0 mm length implants, while for 8.0 mm length implants it was 48, 48, 46%. In 0.5 mm cortical bone thickness, maximal MESs varied within 15-17% range. For 4.5/6.0 mm diameter implants, bone thickness increase from 0.5 to 1.5 mm corresponded to 43/35% MES drop for 5.0 mm length implants and 33/30% - for 8.0 mm length implants, while two-fold bone thickness increase from 0.5 to 1.0 mm corresponded to 21/19% MES drop for 5.0 mm length implants and 15/15% - for 8.0 mm length implants.

The study enhances perception of bone stress issues in the posterior maxilla relative to cortical bone thickness. Evaluated finned implants have not exceeded 100 MPa ultimate cortical bone strength. For 1.5 mm cortical bone thickness, no sensitivity to implant length was found. This FE study approves the finned implants clinical success in posterior maxilla due to their low susceptibility to poor bone quality. It provides a rationale for appropriate implant selection.

Background and Aim

Endosseous dental implants have been proven as a reliable way to renew lost teeth[1]. The success rate of dental implants is mainly associated with bone quality and quantity, so higher amount of implant failure occurs in the posterior maxillary region with insufficient bone height and poor bone quality[2]. At the same time, occlusal loads are significantly higher comparing to the frontal area. Other factors that may cause failure and difficulty in implant placement in the posterior maxilla are limited visibility, reduced interarch space, and sinus pneumatization due to post-extraction bone loss[3]. Surgical procedure, such as sinus augmentation, is used to improve bone quantity and allows conventional implant placement[3-6]. However, this procedure is associated with increased postoperative morbidity, higher costs and risks of complications[4-7], e.g. sinus membrane perforation, maxillary sinusitis, etc.[8,9]. But even after sinus lifting, bone quality and quantity is not predictable, and it influences the implant load-carrying capacity.

In posterior maxilla with insufficient bone height, placement of short implants provides a successful alternative[10]. Advantages of short implants include avoidance of additional surgery such as augmentation, easier treatment planning, shorter treatment period, reduced chance of complications, lower cost, less bone overheating[11-13]. Moreover, studies have revealed that the failure rate of short implants was not higher than that of long implants[9,14].

Contrarily, short implants have smaller implant surface area leading to reduction of the bone contact area and increased stress and strain concentrations in crestal bone. Nowadays, this issue is overpassed through modification of implant shape and surface treatment[3]. Among various shapes of short implants, Bicon® finned design is one of the most widely used types[15,16]. In case of insufficient bone height, finned implants allow to increase the interface area and to improve stress distributions in the supporting bone[17], in particular, at the implant neck, which is considered the most critical area of the bone-implant interface from the biomechanical perspective[18]. Besides, these implants have indisputable advantages over threaded ones due to more favorable stress distribution in surrounding bone, though fin margins still cause local bone stress concentrations.

The finite element (FE) method is a contemporary tool to study dental system under functional loading[19] and to analyze stress fields around bone-implant contact area. Stress levels rely on surrounding bone quality/quantity and implant dimensions. If the latter are inadequate, following bone/implant loss becomes unavoidable because of peri-implant bone overload.

The aim of the study was to evaluate the impact of cortical bone thickness in atrophic posterior maxilla on stress magnitudes due to Bicon Integra-CP™ short finned implants under oblique functional loading to predict bone overload and implant failure.

Methods and Materials

Four Bicon Integra-CP™ implants with 4.5 (N), 6.0 (W) mm diameter and 5.0 (S), 8.0 (L) mm length were studied. Their 3D models were placed in 12 posterior maxilla segment models, which were designed in Solidworks 2016 software (Fig. 1). Their dimensions were selected to simulate the most critical scenario of minimal available bone to fit the specific implant with crestal placement as a necessary compromise. Bone segments with 1.5 (A), 1.0 (B) and 0.5 (C) mm crestal cortical bone thickness consisted of types III and IV bone. Implant apex was supported by sinus cortical bone (see Fig. 1). Implant and bone were assumed as homogeneous, linearly elastic and isotropic.

The size of maxilla segment was 30×9×11 mm (length × height × width). Implants and abutments were considered as a continuous unit and were assumed to be made of titanium alloy with the modulus of elasticity and Poisson's ratio of 114 GPa and 0.34, respectively[20]. The Poisson's ratio of bone tissues (both cortical and cancellous) was assumed to be 0.3[21]. Elasticity modulus of cortical bone was 13.7 GPa[21] and for types III and IV cancellous bone it was 1.37 (E_1) and 0.69 (E_2) GPa. Ultimate tension strength of cortical bone was 100 MPa[20]. With respect to boundary conditions, disto-mesial surfaces of the bone segment as well as upper cortical shell planes in all models were restrained (see Fig. 1).

Loading of implant was performed at the center of 7 Series Low 0° abutment, in 3D, by 120.9 N mean maximal functional load[22] applied obliquely at the angle of approximately 75° to the abutment top surface. Components of functional loading were determined as 116.3, 17.4 and 23.8 N in axial, lingual and disto-mesial directions. The last two components represent the resultant vector of 29.5 N horizontal functional load acting in the plane of critical bone-implant interface. All implants were assumed to be completely osseointegrated.

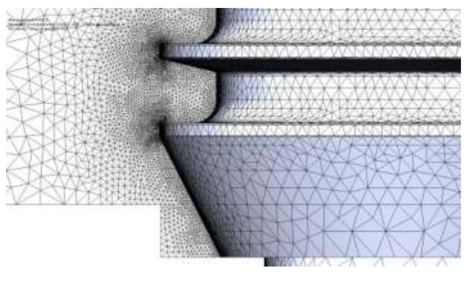


Fig. 2. FE meshing of maxillary bone segment with 1.0 mm crestal and sinus cortical bone and 4.5×5.0 mm implant with mapped meshing in the neck area of bone-implant contact. Minimal value of FE size is 0.025 mm.

Bone-implant assemblies were analyzed in FE software Solidworks Simulation. 4-node 3D FEs were generated with a total number of up to 2,820,000. Mapped meshing procedure was used to provide adequate accuracy of stress calculation in the critical bone-implant interface, i.e. in the plane of oblique functional loading (Fig. 2).

For implants success / failure analysis, von Mises equivalent stress (MES) was selected as the measure of bone failure risk. MES distributions in bone peri-implant area of 12 bone-implant assemblies were studied to calculate maximal MES values: (a) areas of bone overload with MES magnitude greater than 100 MPa in cortical bone were analyzed; (b) special extrapolation procedure was applied to predict actual stress magnitude in contacting bone.

Results

While analyzing the MES distributions, it was found that their maximal values are located on the outer surface of crestal bone along the line of critical bone-implant interface. Illustration of MES distributions for 12 tested bone-implant assemblies is shown on Fig. 3. Corresponding graphs of MES expanding along conical neck generatrix are presented on Fig. 4 for 1.5, 1.0 and 0.5 mm cortical bone thickness. The spectrum of maximal MESs was between 13.0 MPa (A,W,L,IV) and 47.0 MPa (C,N,S,IV) (see Fig. 5). The highest MESs were found on the surface of cortical bone for 4.5×5.0 mm implant and 0.5 mm bone thickness, while the smallest magnitudes were determined for 6.0×8.0 mm implant and 1.5 mm bone thickness. For tested implants, maximal MES magnitudes were significantly influenced by cortical bone thickness and implant dimensions: for 0.5, 1.0 and 1.5 mm cortical bone thickness and diameter increase from 4.5 to 6.0 mm, MES drop was 48, 47, 43% for 5.0 mm length implants, while for 8.0 mm length implants it was 48, 48, 46%. In 0.5 mm cortical bone thickness, maximal MESs varied within 15-17% range. For 4.5 and 6.0 mm diameter implants, bone thickness increase from 0.5 to 1.5 mm corresponded to 43 and 35% MES drop for 5.0 mm length implants, 33 and 30% - for 8.0 mm length implants, while two-fold bone thickness increase from 0.5 to 1.0 mm corresponded to 21 and 19% MES drop for 5.0 mm length implants, 15 and 15% - for 8.0 mm length implants.

Impact of cancellous bone quality on maximal MES magnitudes was analyzed comparing corresponding maximal MES magnitudes due to two-fold modulus of elasticity increase from E_2=0.69 MPa to E_1=1.37 MPa. For the 4.5×5.0, 4.5×8.0, 6.0×5.0, 6.0×8.0 mm implants, they resulted in the following MES drop: 17,7%, 20.3%, 13.6%, 12.8% for 0.5 mm cortical bone thickness; 16,0%, 20.6%, 9.7%, 9.6% for 1.0 mm cortical bone thickness; 14,6%, 21.8%, 6.9%, 5.7% for 1.5 mm cortical bone thickness.

4.5 mm diameter (N) and 5.0 mm length (S) implant | **6.0 mm diameter (W) and 8.0 mm length (L) implant**

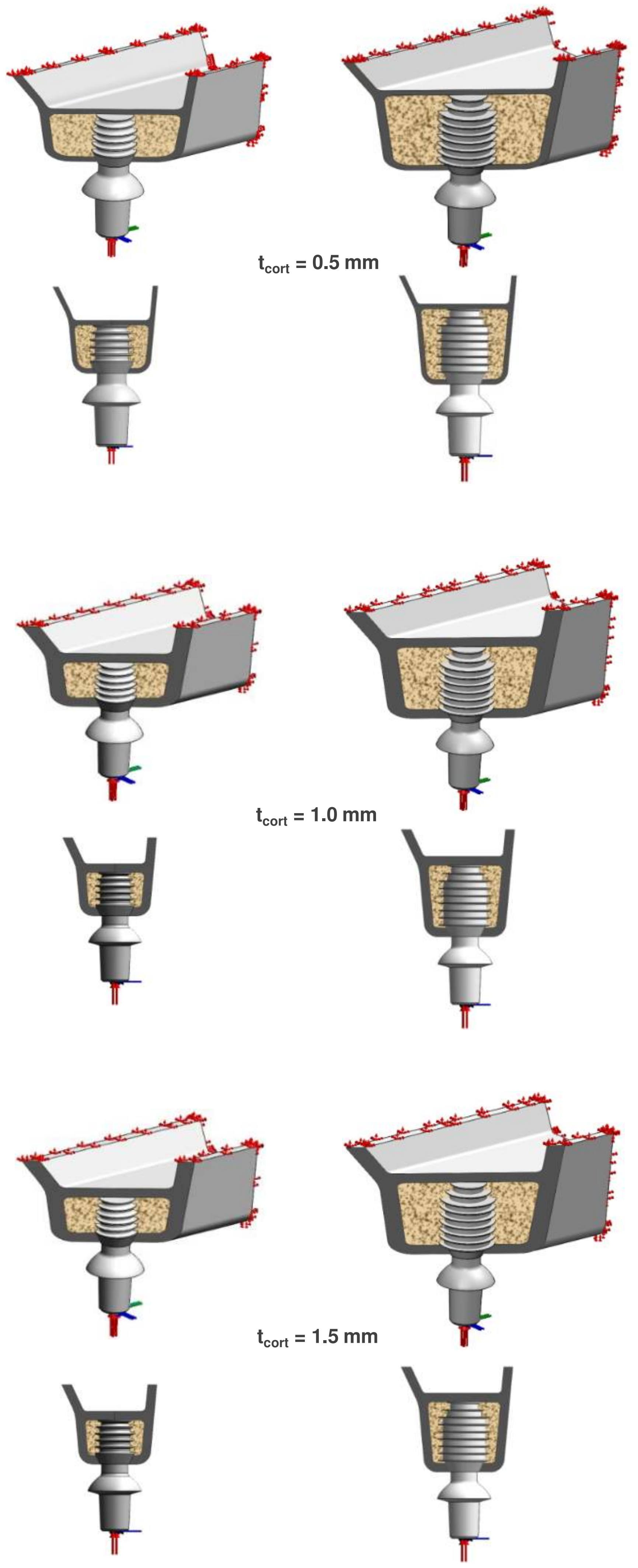


Fig. 1. Plane and 3D views of maxillary bone segments with 0.5, 1.0 and 1.5 mm crestal and sinus cortical bone thickness with inserted 4.5×5.0 and 6.0×8.0 mm implants. Oblique loading is applied at the center of 7 Series Low 0° abutment upper surface at 7.0 mm distance from the upper bone margin.

4.5 mm diameter (N) and 5.0 mm length (S) implant | **6.0 mm diameter (W) and 8.0 mm length (L) implant**

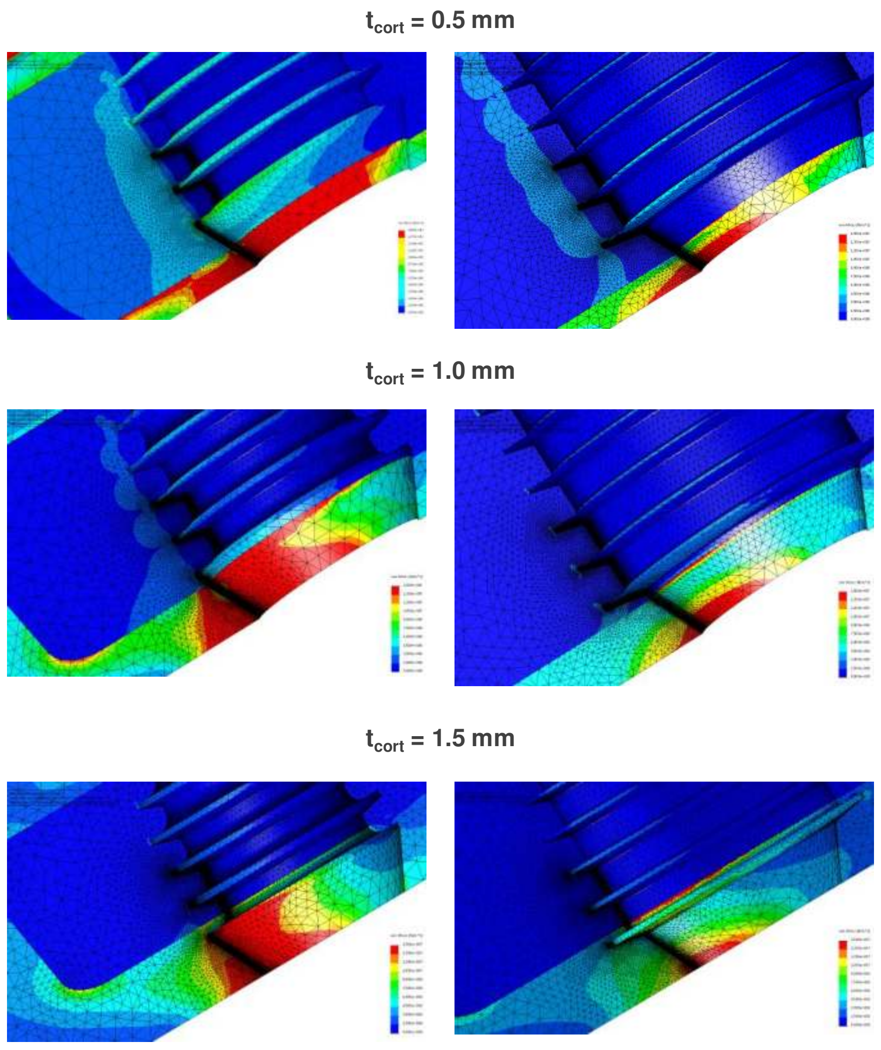
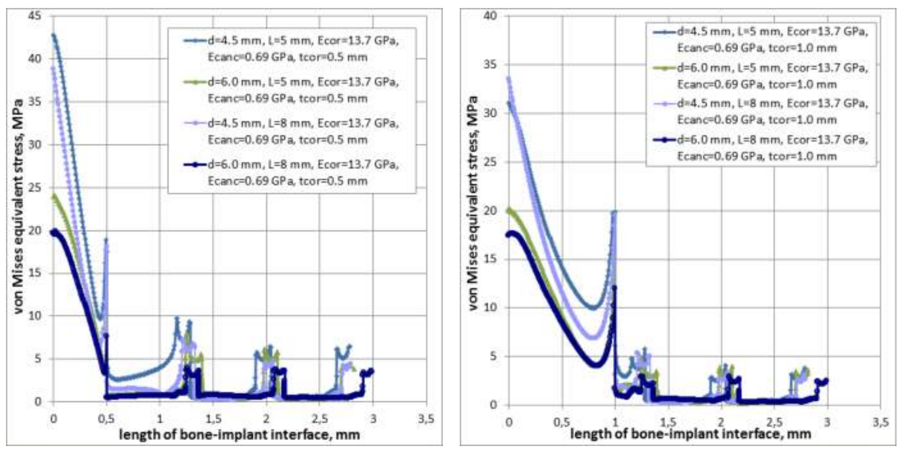


Fig. 3. Typical von Mises stress distributions in the plane of critical bone-implant interface for selected implants and type IV bone segments.



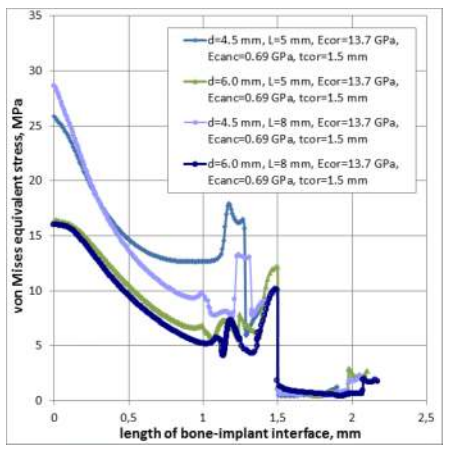


Fig. 4. Dependence of von Mises equivalent stress on the length of bone-implant interface for the spectrum of implants placed into bone segment with 0.5 (top left), 1.0 (top right), 1.5 (bottom left) mm cortical bone thickness for type IV bone (E_2=0.69 GPa).

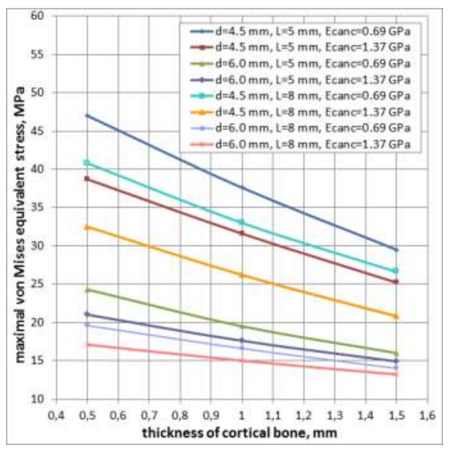


Fig. 5. Impact of cortical bone thickness and cancellous bone quality on maximal von Mises equivalent stress magnitudes for the spectrum of implants placed into bone segment with 0.5 mm, 1.0 mm, 1.5 mm cortical bone thickness for types III and IV bone (E_1=1.37 GPa, E_2=0.69 GPa).

Conclusion

Studied Bicon Integra-CP™ implants have not caused 100 MPa ultimate stresses in crestal bone under mean, and even 275 N maximum experimental load. Bone stresses were influenced by cortical bone thickness and mainly implant diameter, contrarily implant length increase only slightly influenced the von Mises equivalent stress reduction. We believe this study supports clinical success of finned implants in posterior maxilla due to their low susceptibility to poor bone quality and insufficient bone height. The outcomes of this study enhance understanding the biomechanics of the maxilla surrounding different-sized short finned implants and provide a rationale for selection of appropriate implant.

References

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