P-BR-105

BASIC RESEARCH

Prospect of Short Plateau Implants in Atrophic Posterior Maxilla: Biomechanical Study.

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Abstract

Poor bone quality and anatomic restrictions significantly influence implant success in posterior maxilla. Short implants were proposed as a reasonable choice. Implant prognosis is predetermined by stress magnitudes in bone-implant interface, which are sensitive to bone and implant parameters. Plateau implants are often preferred since they reduce bone stresses and improve implant prognosis. Precise analysis of complex biomechanical systems can only be performed by finite element (FE) method.

The aim of the study was to evaluate and compare the prospect of different short plateau implants placed in atrophic posterior maxilla under 120.92 N mean maximal functional load (Mericske-Stern & Zarb, 1996).

5.0 mm length and 4.0 (N), 5.0 (M), 6.0 (W) mm diameter Bicon SHORT ® implants were studied. Their 3D models were placed in eighteen posterior maxilla segment models with types III and IV bone. They were designed in Solidworks 2016 software and had three geometries: (A) 1.0/4.0 mm, (B) 0.75/4.25 mm and (C) 0.5/4.5 mm cortical/cancellous bone layer, their size was 30×9×11 mm (length × height × width). Implant and bone were assumed as linearly elastic and isotropic. Elasticity modulus of cortical bone was 13.7 GPa, cancellous bone – 1.37/0.69 (type III/IV). Bone-implant assemblies were simulated in FE software Solidworks Simulation. 4-node 3D FEs were generated with a total number of up to 5,064,000. 120.92 N mean maximal oblique load (molar area) was applied to the center of 7.0 mm abutment. Von Mises equivalent stress (MES) distributions were studied to determine areas of bone overload with magnitude greater than 100 MPa in cortical and 5 MPa in cancellous bone adopted as bone tissues ultimate strength.

MES maximal values were found in crestal bone. The spectrum of maximal MESs in cortical bone was between 17 MPa (III,A,W) and 55 MPa (IV,C,N). They were influenced by cortical bone thickness, bone quality and implant dimensions. MES reduction due to cortical bone thickness increase from 0.5 to 1.0 mm was 25, 35, 17% for N, M and W implants and type IV bone, while for type III it was 25, 34, 19%. Cancellous bone quality was found to have a substantial impact on biomechanical state of cortical bone: two-fold reduction of elasticity modulus (1.37 versus 0.69 GPa) corresponded to 24.2, 30.2 and 26.5% MES rise for N, M and W implants and 1.0 mm cortical bone, 26.6, 23.6 and 20.5% MES rise for N, M and W implants and 0.75 mm cortical bone, and 25.0, 23.1 and 23.8% MES rise for N, M and W implants and 0.5 mm cortical bone. MESs magnitudes in cancellous bone were found below its ultimate strength (5 MPa) only for M and W implants placed into 1.0 mm cortical bone.

Stresses in posterior maxilla were influenced by cortical bone thickness, bone quality and especially implant diameter. Under 120.92 N load and 0.5…1.0 mm cortical bone, failure of 4.0×5.0 mm, 5.0×5.0 mm, 6.0×5.0 mm Bicon SHORT® implants was highly unlikely from the viewpoint of cortical bone overload. To avoid cancellous bone overstress, both 5.0×5.0 and 6.0×5.0 mm implants were found applicable, but only in case of 1.0 mm cortical bone.

Background and Aim

Poor bone quality and anatomic restrictions significantly influence the implant success in the posterior maxilla[1]. Furthermore, occlusal loads in the molar region are substantially higher comparing to the frontal area. Among other disadvantages of the posterior maxilla there are limited visibility, reduced interarch space and sinus pneumatization due to post-extraction bone loss[2]. In order to improve bone quantity and to allow conventional implant placement, additional surgical procedure, such as bone augmentation, should be performed[2-5]. Unfortunately, it is associated with increased postoperative morbidity, higher costs and risks of complications[3-6], e.g. sinus membrane perforation, maxillary sinusitis, etc.[7,8]. But even after sinus lifting, bone quality and quantity is not fully predictable, however the implant load-carrying capacity is directly dependent on additional surgery results.

Placement of short implants provides a successful alternative in the region with insufficient bone height, specifically the posterior maxilla[9]. Their advantages include avoidance of additional surgery procedure (e.g. sinus augmentation) and as a result, reduced chance of complications, lower cost, easier placement planning, shorter treatment period, less bone overheating, etc.[10-12]. Moreover, recent studies have revealed that the failure rate of short implants is not higher than that of conventional ones[8,13]. Contrarily, short implants have smaller surface area, which leads to reduction of the bone-implant contact area, so increased stress and strain concentrations are observed in the crestal bone. Fortunately, this disadvantage is overpassed through contemporary surface treatment and modification of implant shape[2], e.g. plateau design of Bicon SHORT ® implants, which are widely used[14,15]. From the biomechanical perspective, bone tissue at the implant neck is considered the most critical place of the bone-implant interface[16], so short implants with wider diameter should be used for in case of deficient bone height to increase the surface area and to improve stress and strain distributions in the surrounding bone[17].

The finite element (FE) method is a precise instrument capable to simulate mechanical behavior of complex bone-implant systems under functional loading[18]. Stress fields around bone-implant contact area are affected by implant dimensions and mechanical properties and surrounding bone quality/quantity. The most crucial cause of peri-implant bone overload and following implant failure is inadequate implant dimensions.

The aim of the study was to evaluate and compare the prospect of different short plateau implants placed in atrophic posterior maxilla under 120.92 N mean maximal functional load[19].

Methods and Materials

Three Bicon SHORT ® implants with 4.0 (N), 5.0 (M), 6.0 (W) mm diameter and 5.0 mm length were studied. Posterior maxilla segment 3D models were designed in Solidworks 2016 software (Fig. 1, 3). 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 1.0 (A), 0.75 (B), and 0.5 (C) mm crestal cortical bone thickness consisted of types III/IV bone simulated by different cancellous bone elasticity moduli. Implant and bone were assumed as linearly elastic and isotropic and all materials volumes were considered homogeneous. Implant models were placed in jaw segment models with implant apex supported by sinus cortical bone (see Fig. 1). The length of maxilla segment was 30 mm. 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] for both bone quality types, for Type III bone cancellous bone it was 1.37 GPa and for type IV - 0.69 GPa. Ultimate tension strengths of cortical and cancellous bone were 100 and 5 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.

Loading of implant was performed at the center of 7.0 mm abutment, in 3D, by 120.9 N mean maximal functional load[19] 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 fully osseointegrated.

Bone-implant assemblies were analyzed in FE software Solidworks Simulation. 4-node 3D FEs were generated with a total number of up to 2,214,000. Mapped meshing was applied to increase the accuracy of FE analysis in vicinity of neck area of bone-implant interface (see 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 36 bone-implant assemblies were studied to calculate maximal MES values. Areas of bone overload with maximal MES magnitude greater than 100 MPa in cortical and 5 MPa in cancellous bone were analyzed. Advantages of specific implant diameter were compared.

Results

Analysis of MES distribution in adjacent bone was performed. MES maximal values were found on the outer surface of crestal bone. This fact is supported by MES distributions along the critical bone-implant interface for nine tested bone-implant assemblies shown on Fig. 4. The spectrum of maximal MESs in cortical bone was between 17 MPa (III,A,W) and 55 MPa (IV,C,N) (see Fig. 5). They were influenced by cortical bone thickness, bone quality and implant dimensions. MES reduction due to cortical bone thickness increase from 0.5 to 1.0 mm was 25, 35, 17% for N, M and W implants and type IV bone, while for type III it was 25, 34, 19%. Corresponding relationship is shown on Fig. 6. Dependence of maximal MESs on implant diameter is illustrated on Fig. 7

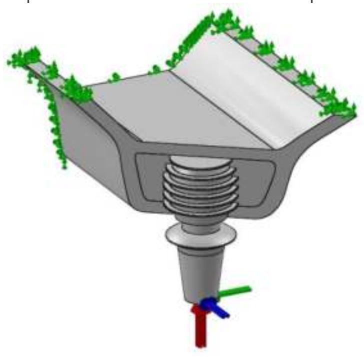


Fig. 1. Typical maxillary bone segment of 1.0 mm crestal and sinus cortical bone thickness with inserted 6.0×5.0 mm implant. Oblique loading is applied to the center of abutment upper surface at 7.0 mm distance from the upper bone margin.

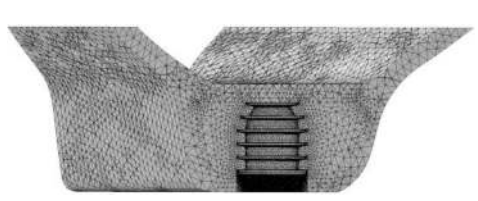
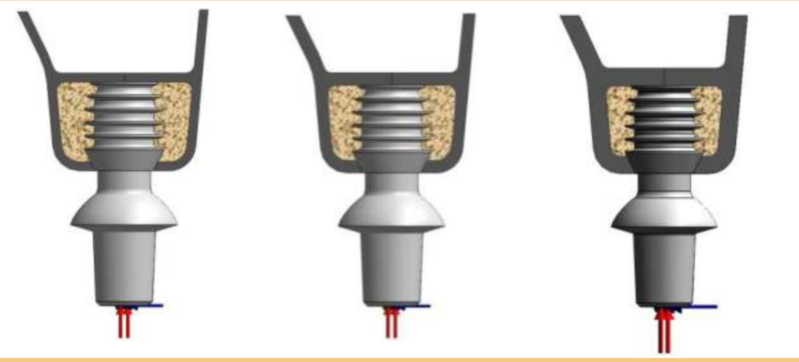
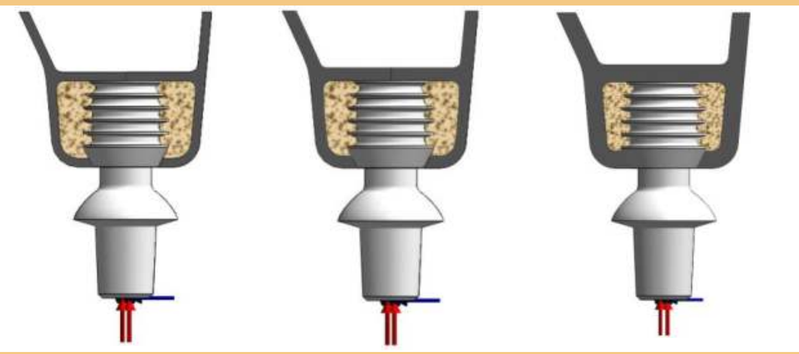


Fig. 2. FE meshing of maxillary bone segment with 1.0 mm crestal and sinus cortical bone and 4.0×5.0 mm implant. Minimal value of FE size is 0.025 mm.

4.0 mm diameter (N) and 5.0 mm length implant



5.0 mm diameter (M) and 5.0 mm length implant



6.0 mm diameter (W) and 5.0 mm length implant

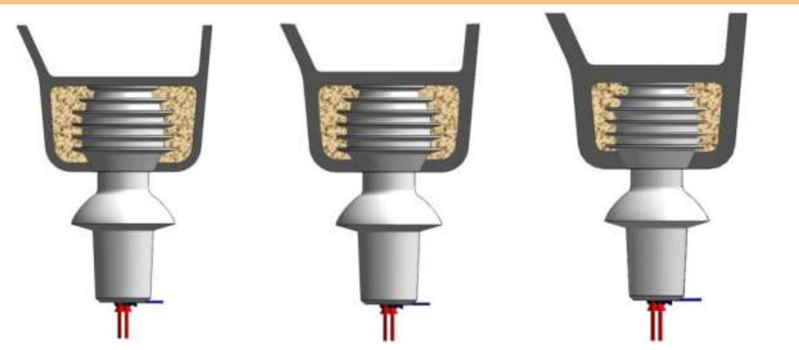
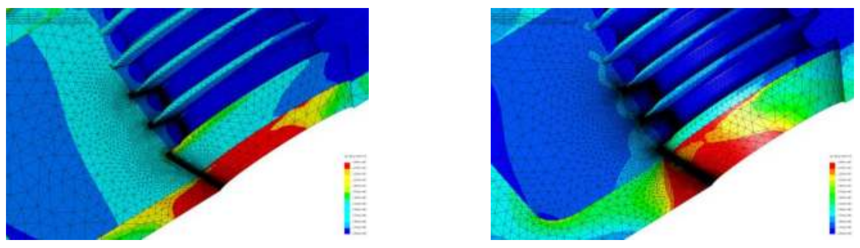


Fig. 3. Cross-sectional views of maxillary bone segments of 0.5, 0.75, 1.0 mm crestal and sinus cortical bone thickness with inserted 4.0×5.0, 5.0×5.0 and 6.0×5.0 mm implants.

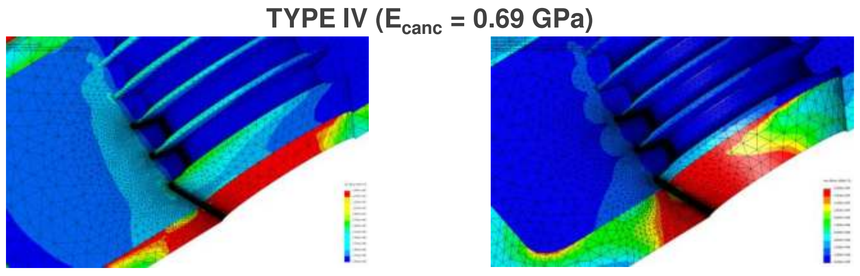
4.0 mm diameter (N) and 5.0 mm length implant

t_{cort} = 0.5 mm t_{cort} = 1.0 mm

TYPE III (E_{canc} = 1.37 GPa)



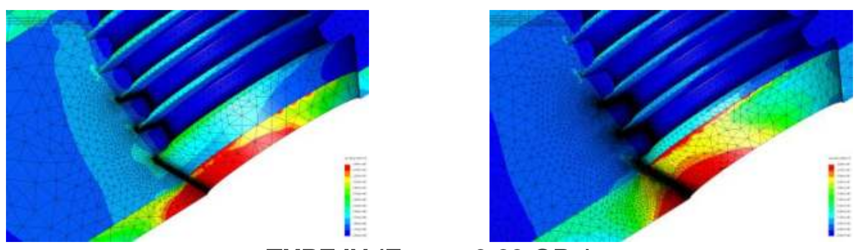
TYPE IV (E_{canc} = 0.69 GPa)



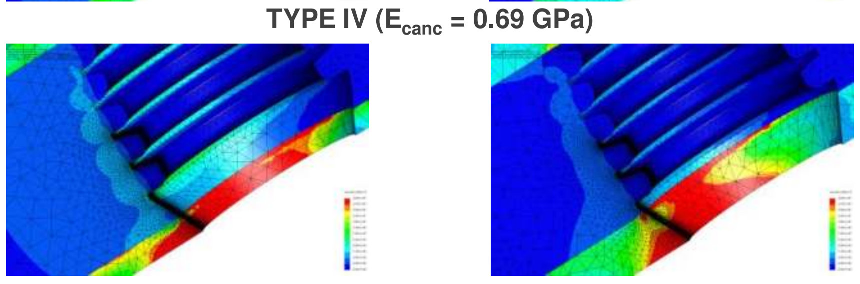
5.0 mm diameter (N) and 5.0 mm length implant

t_{cort} = 0.5 mm t_{cort} = 1.0 mm

TYPE III (E_{canc} = 1.37 GPa)



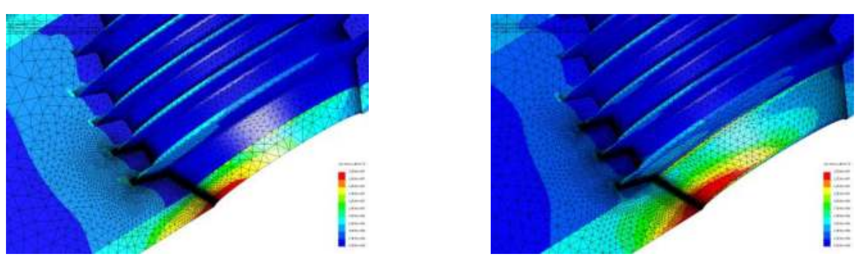
TYPE IV (E_{canc} = 0.69 GPa)



6.0 mm diameter (W) and 5.0 mm length implant

t_{cort} = 0.5 mm t_{cort} = 1.0 mm

TYPE III (E_{canc} = 1.37 GPa)



TYPE IV (E_{canc} = 0.69 GPa)

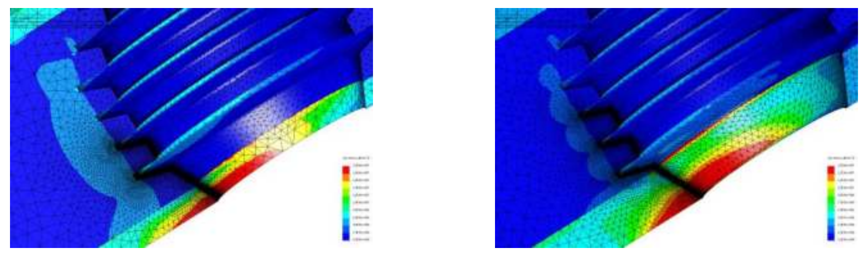
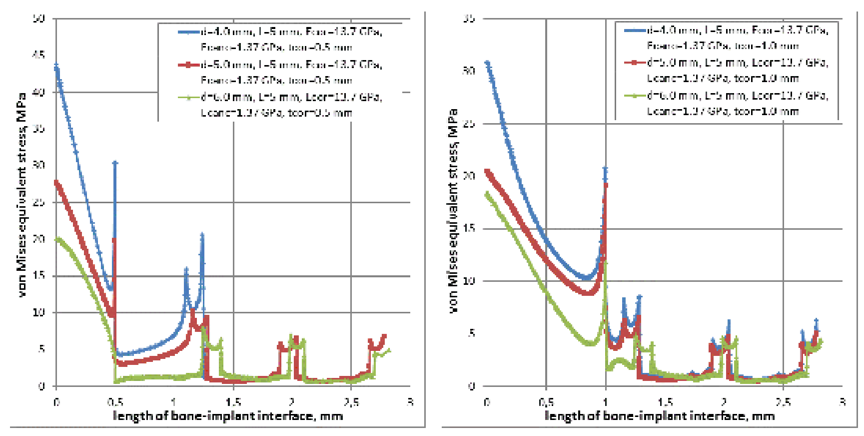


Fig. 4. Typical von Mises stress distributions along the critical bone-implant interface for all tested implants and bone segments.

0.5 mm cortical bone thickness **1.0 mm cortical bone thickness**

Type III bone



Type IV bone

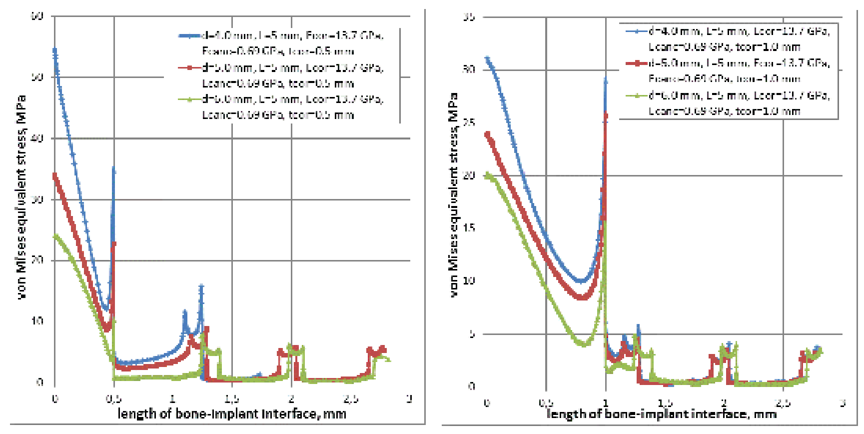


Fig. 5. Dependence of von Mises equivalent stress on the length of bone-implant interface in the neck area for the spectrum of implants placed into bone segment with 0.5 mm and 1.0 mm cortical bone thickness for types III and IV bone.

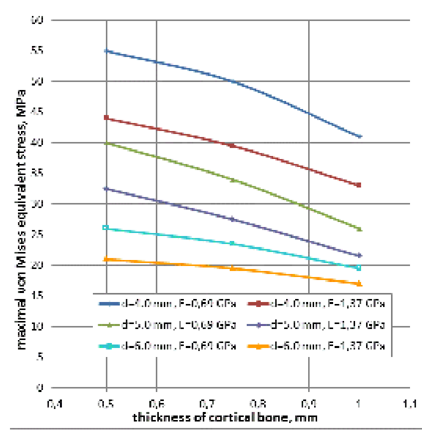


Fig. 6. Dependence of maximal von Mises equivalent stress in the neck area on the thickness of cortical bone for the spectrum of implants placed into bone segment with 0.5 mm, 0.75 mm, and 1.0 mm cortical bone thickness for types III and IV bone.

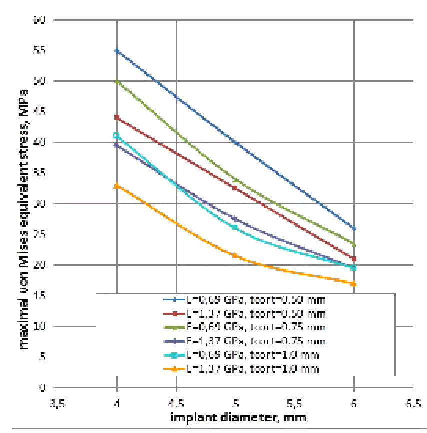


Fig. 7. Dependence of maximal von Mises equivalent stress in the neck area on the implant diameter for the spectrum of implants placed into bone segment with 0.5 mm, 0.75 mm, and 1.0 mm cortical bone thickness for types III and IV bone.

Cancellous bone quality was found to have a substantial impact on biomechanical state of cortical bone: two-fold reduction of elasticity modulus (1.37 versus 0.69 GPa) corresponded to 24.2, 30.2 and 26.5% MES rise for N, M and W implants and 1.0 mm cortical bone, 26.6, 23.6 and 20.5% MES rise for N, M and W implants and 0.75 mm cortical bone, and 25.0, 23.1 and 23.8% MES rise for N, M and W implants and 0.5 mm cortical bone. MESs magnitudes in cancellous bone were found below its ultimate strength (5 MPa) only for M and W implants placed into 1.0 mm cortical bone.

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 MES reduction. We believe this study supports clinical success of plateau implants in posterior maxilla due to their low susceptibility to poor bone quality and implant length. The outcomes of this study enhance understanding of the stress characteristics in the maxilla surrounding different-sized short plateau implants and provide a rationale for selection of appropriate implant for posterior maxilla.

References

Presented at EAO CONGRESS EUROPEAN ASSOCIATION FOR OSSEOINTEGRATION Vienna 2018