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BASIC RESEARCH

Impact of Augmented Bone Quality on Success of Bicon Short Implants: FE Study

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Abstract

Bicon short implants have successfully proven themselves in the maxillary molar region with insufficient bone height and poor bone quality. To improve crestal bone healing, autogenous bone is placed in the gap between implant neck and implant bed. But even for such approach, the quality of the augmented bone is not fully predictable, though cortical bone strength is the key criterion of implant success. Finite element (FE) method allows precise analysis of this complex biomechanical system.

The aim of this study was to evaluate the prospect of different-sized short plateau implants placed in atrophic posterior maxilla depending on the degree of augmented bone quality under oblique functional loading.

5.0 mm length and 4.0 (N), 5.0 (M), 6.0 (W) mm diameter Bicon SHORT ® implants were selected for this comparative study. Their 3D models were placed crestally in twelve posterior maxilla segment models with type III bone. They were designed using CT images in Solidworks 2016 software with 1.0 mm crestal/sinus cortical and 4.0 mm cancellous bone layers. Each model geometry was 10×30×19 mm. Implant and bone were assumed as linearly elastic and isotropic. Elasticity moduli of cortical/cancellous bone were 13.7/1.37 GPa. Four degrees of augmented bone quality were simulated: 100% (E_1=13.7 GPa), 75% (E_2=10.3 GPa), 50% (E_3=6.85 GPa) and 25% (E_4=3.43 GPa). Bone-implant assemblies were analyzed in FE software Solidworks Simulation. 4-node 3D FEs were generated with a total number of up to 4,040,000. 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 the areas of bone overload.

Analysis of MESs distributions in cortical bone has showed that their maximal magnitudes were found in crestal area. The spectrum of maximal MESs in augmented bone was between 9.5 MPa (W,E_4) and 37 MPa (N,E_1). They were influenced by implant diameter and augmented bone quality. MES reduction due to diameter increase from 4.0 to 6.0 mm was 52.7, 54.5, 55.4 and 54.8% for E_1, E_2, E_3 and E_4 bone quality. MES reduction due to two-fold augmented bone quality decrease (E_1 versus E_3) was 24.3, 30.2 and 28.6% for N, M and W implants. However, reduction of augmented bone quality caused significant overload of cancellous bone (5-17 MPa). Only for E_1 bone, maximal MES in cancellous bone was approximately 5-7 MPa. In all other scenarios, maximal MES substantially exceeded 5 MPa strength of cancellous bone. N implants were found to be the most susceptible to the quality of augmented bone: E_1 to E_4 bone quality reduction has led to 126 and 82% MES rise for N and W implants.

Under mean maximal functional loading, sufficient influence of augmented bone quality on crestal bone-implant interface was established. However, crestal bone overload is highly unlikely because MESs were found to be lesser than 100 MPa ultimate bone strength. Contrarily, E_2-E_4 bone quality scenarios are critical from the viewpoint of cancellous bone overload and implant failure. Placement of wider implant allows to decrease this risk.

Background and Aim

Bicon short implants have proven themselves to be highly successful in the maxillary molar region with insufficient bone height and poor bone quality[1,2]. This is a screwless implant system with plateau root-formed implant body, which provides 30% more surface area when compared with same-sized threaded implants. Bone healing pathway leading to Bicon implant osseointegration is based on healing chambers, which develop due to the interplay between implant design and drilling dimensions. This results in intramembranous-like woven bone formation at large void spaces occupied by the blood clot immediately after implantation[3]. To improve crestal bone healing, autologous bone is placed in the gap between implant neck and drilling dimensions. However, the quality of the newly-formed bone is not fully predictable, though the cortical bone strength is the key criterion of implant success. Finite element (FE) method allows precise analysis of this complex biomechanical system.

The aim of this study was to evaluate the prospect of different-sized short plateau implants placed in atrophic posterior maxilla depending on the degree of newly-formed crestal bone quality under oblique functional loading.

Methods and Materials

4.0×5.0 (N), 5.0×5.0 (M) and 6.0×5.0 (W) mm Bicon SHORT® implants were selected for these comparative study. Their 3D models were placed in three posterior maxilla segment models (see Fig. 1) with type III bone. Bone models were designed using CT images in Solidworks 2016 software and had two outlines: A-layout corresponded to 1.0 mm crestal cortical bone thickness and 4.0 mm cancellous bone height. B-layout corresponded to 0.75 mm crestal cortical bone thickness and 4.25 mm cancellous bone height. The size of maxilla segment was 30×9×11 mm (length × height × width). All materials were assumed to be linearly elastic and isotropic and all materials volumes were considered homogeneous.

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[4]. The Poisson's ratio of bone tissues (both cortical and cancellous) was assumed to be 0.3[5]. Elasticity modulus of cortical bone was 13.7 GPa[5] and of cancellous bone it was 1.37 GPa. Newly-formed bone (NFB), which replaced bone augmentation material, was modelled by isotropic elastic solid with four degrees of bone quality (100, 75, 50 and 25%), which were simulated by different elasticity modulus (E_1=13.7 GPa, E_2=10.3 GPa, E_3=6.85 GPa and E_4=3.43 GPa). Ultimate tension strength of cortical and cancellous bone was 100 and 5 MPa[4].

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 7.0 mm abutment, in 3D, by 120.9 N mean maximal functional load[6] 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.

Bone-implant assemblies were analyzed in FE software Solidworks Simulation. 4-node 3D FEs were generated with a total number of up to 5,060,000. The example of FE meshing for 5.0×5.0 mm implant and A-layout bone model is shown on 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 critical bone-implant interface for 24 bone-implant assemblies were studied to calculate maximal MES values. Areas of bone overload with MES magnitude greater than 100 MPa in cortical and 5 MPa in cancellous bone were analyzed.

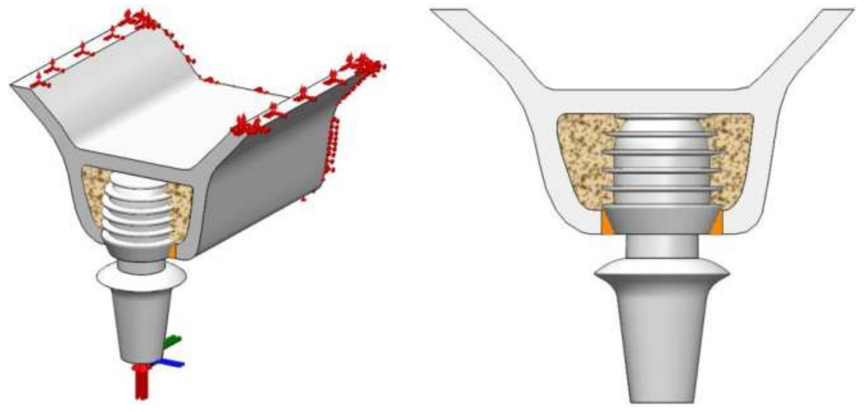


Fig. 1. Maxillary bone segment of 1.0 mm crestal and sinus cortical bone thickness with inserted 5.0×5.0 mm implant. Newly-formed bone, which replaced augmentation material is located between implant neck and bed. Oblique loading is applied to the center of abutment upper surface at 7.0 mm distance from the upper bone margin.

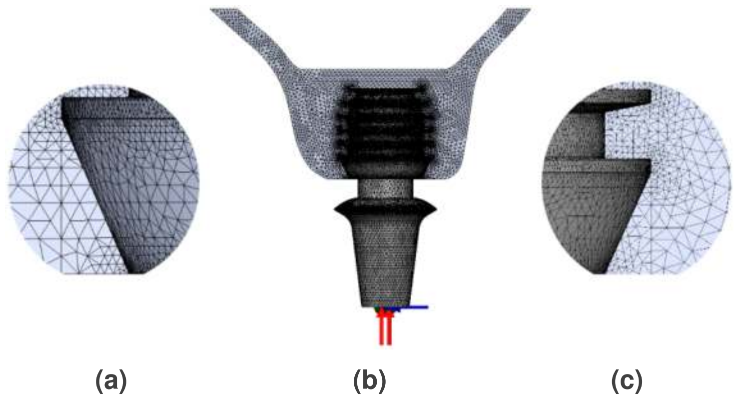


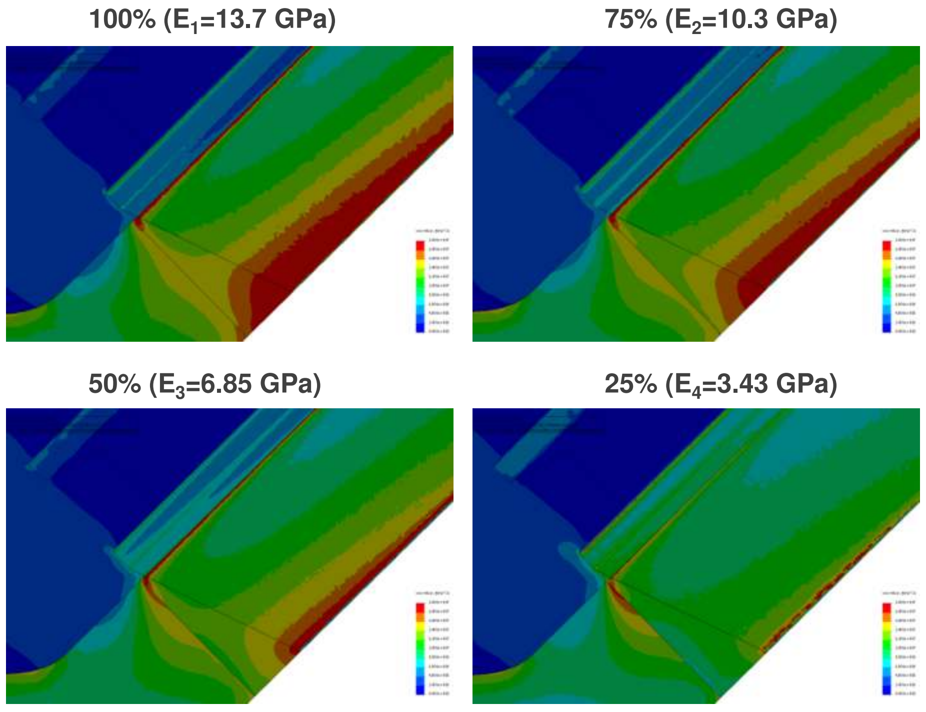
Fig. 2. (a) Example of FE meshing of maxillary bone segment with 1.0 mm crestal and sinus cortical bone and 5.0×5.0 mm implant. (b,c) Mapped meshing in the neck area of bone-implant contact. Minimal value of FE size is 0.025 mm.

Results

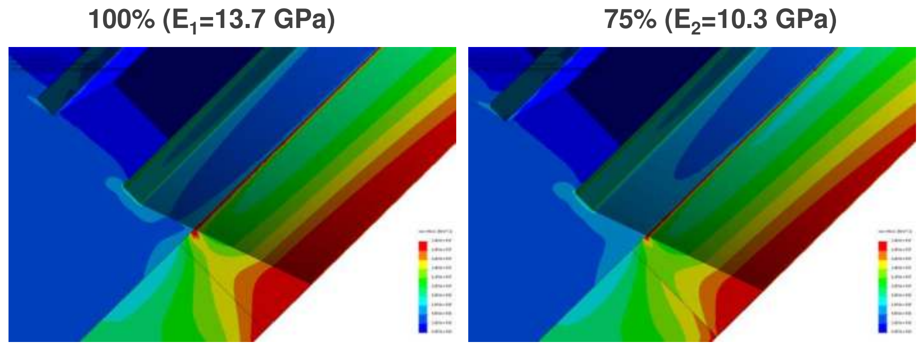
Analysis of MESs distributions in cortical and cancellous bone has showed that their maximal magnitudes were found at the implant neck (see Fig. 3, 4). Maximal MESs were influenced by implant diameter and augmented bone quality. The spectrum of maximal MESs in NFB was 9.5 MPa (W,E_4) … 37 MPa (N,E_1) for A-layout (Fig. 5.a) and 10.5 MPa (W,E_4) … 50 MPa (N,E_1) for B-layout (Fig. 5.c). MES reduction due to diameter increase from 4.0 to 6.0 mm was 52.7, 54.5, 55.4, 54.8% (A-layout), and 52.0, 52.3, 52.9, 56.2 % (B-layout) for E_1, E_2, E_3, E_4. MES reduction due to two-fold NFB quality decrease (E_3 versus E_1) was 24.3, 30.2, 28.6% (A-layout) and 32.0, 30.8, 33.3 (B-layout) for N, M and W implants.

However, reduction of NFB quality caused significant overload of cancellous bone (see Fig. 5.b, 5.d). The spectrum of maximal MESs in cancellous bone was 5.5 MPa (W,E_4) … 17.0 MPa (N,E_1) for A-layout (Fig. 5.b) and 6.0 MPa (W,E_4) … 20.0 MPa (N,E_1) for B-layout (Fig. 5.d). Only for E_1 bone, maximal MES in cancellous bone was approximately 5.5…7.6 MPa for A-layout and 6.0…9.5 MPa for B-layout. In all other scenarios, maximal MES substantially exceeded 5 MPa strength of cancellous bone. N implants were found to be the most susceptible to the NFB quality: E_1 to E_4 reduction has led to 124, 97, 82% (A-layout) and 111, 86, 83% (B-layout) MES rise for N, M and W implants.

5.0 mm diameter (M) and 5.0 mm length implant, t_{cort} = 1.0 mm



5.0 mm diameter (M) and 5.0 mm length implant, t_{cort} = 0.75 mm



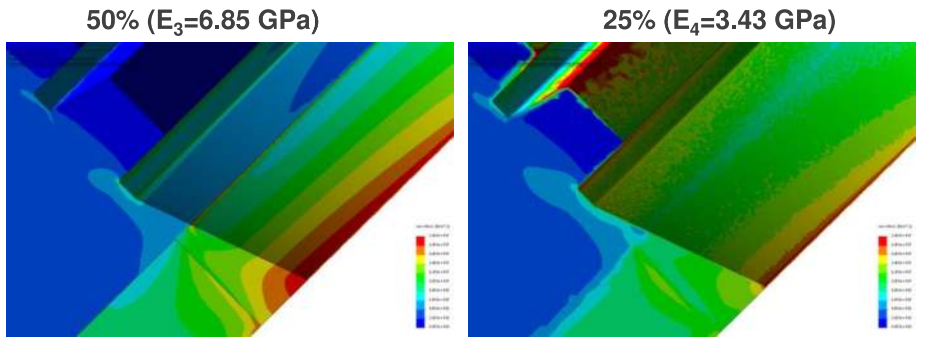


Fig. 3. Von Mises stress distributions along the line of critical bone-implant interface for 5.0×5.0 (M) mm Bicon SHORT® implant, bone segments and newly-formed bone quality degrees.

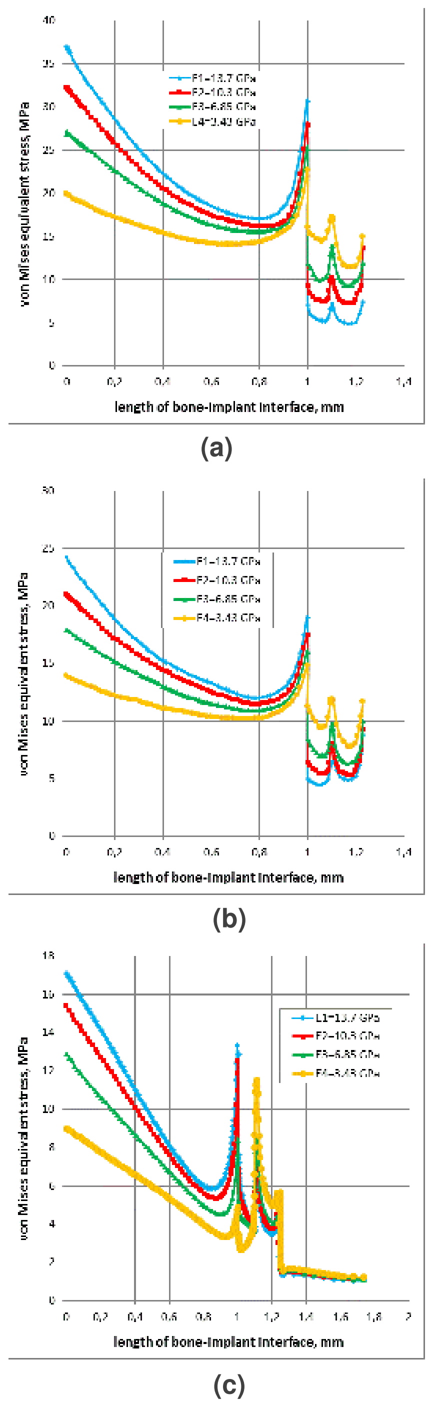


Fig. 4. Von Mises equivalent stress distributions in the neck area of the critical bone-implant interface for 4.0×5.0 (a), 5.0×5.0 (b), 6.0×5.0 (c) mm implants placed into bone segment with 1.0 mm cortical bone thickness and four degrees of newly-formed bone quality.

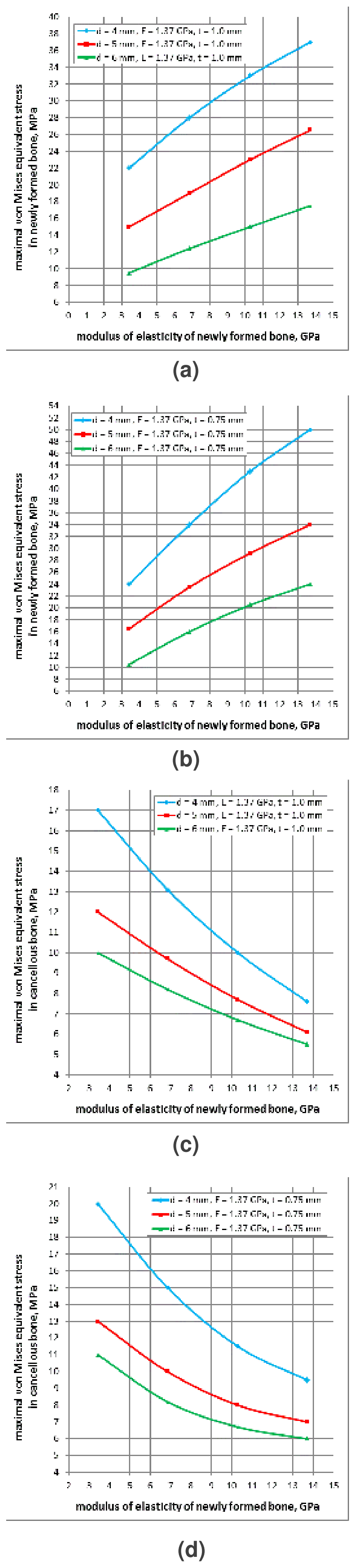


Fig. 5. Dependence of maximal von Mises equivalent stresses in newly-formed ((a),(b)) and cancellous ((c),(d)) bone on the newly-formed bone elasticity modulus for 4.0×5.0, 5.0×5.0, 6.0×5.0 mm implants placed into bone segment with 1.0 and 0.75 mm cortical bone thickness.

Conclusion

Under mean maximal functional loading, sufficient influence of newly-formed bone quality on crestal bone-implant interface was established. However, crestal bone overload is highly unlikely because MESs were found to be lesser than 100 MPa ultimate bone strength. Contrarily, 75, 50 and 25% bone quality scenarios are critical from the viewpoint of cancellous bone overload and implant failure. N implants were found to be the most susceptible to the newly-formed bone quality: E_1 to E_4 reduction has led to 124, 97, 82% (A-layout) and 111, 86, 83% (B-layout) MES rise for N, M and W implants. Placement of wider implant allows to decrease this risk.

References