Short implants and bone loss – evaluation of bone turnover

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Abstract

Short implants are indispensable in posterior maxilla with insufficient bone height. Implant design, bone quality and degree of bone loss predetermine safe functional load transfer to adjacent bone. Adequate bone strains are key stimuli of bone turnover, but their extreme magnitudes lead to implant failure. Computer simulation allows to correlate bone and implant parameters with bone strain spectrum and to evaluate implant perspective.

The aim of the study was to evaluate the impact of plateau implants and bone quality on strain levels in adjacent bone at several levels of bone loss to assess implant prognosis.

Cortical and cancellous bone first principal strains (FPSs) were selected to evaluate bone turnover around fully and partially osseointegrated 4.5 (N), 5.0 (M) and 6.0 mm (W) diameter and 5.0 mm length Bicon SHORT® implants at five levels of bone loss from 0.2 to 1.0 mm. Implant 3D models were placed crestally in corresponding posterior maxilla segment models with type III bone and 1.0 mm cortical crestal and sinus bone layers. The models were designed in Solidworks 2016 software. All materials were assumed as linearly elastic and isotropic. Elasticity modulus of cortical bone was 13.7 GPa, cancellous bone – 1.37 GPa. Bone-implant assemblies were analyzed in FE software Solidworks Simulation. A total number of 4-node 3D FEs was up to 3,450,000. 120.92 N mean maximal oblique load (molar area) was applied to the center of 7 Series Low 0° abutment. Maximal FPSs were correlated with 3000 microstrain minimum effective strain pathological (MESp) to evaluate bone turnover around the implants.

Maximal FPSs for osseointegrated implants (1800...3270 microstrain) were found in the cancellous bone at the first fin edge. For implants with bone loss, they were observed at the same location and were significantly dependent on bone loss level (2140...3600, 2300...4100, 2800...4900, 3500...5900 and 4200...7000 microstrain for 0.2, 0.4, 0.6, 0.8 and 1.0 mm bone loss). Maximal FPSs were also substantially dependent on implant diameter: diameter increase from 4.5 to 6.0 mm have led to 41, 44, 43, 41, 40% FPS decrease for 0.2, 0.4, 0.6, 0.8 and 1.0 mm bone loss. Comparing to the osseointegrated implants, the following FPS increase on five bone loss levels was determined: for N implants it was 10, 25, 50, 80 and 114%, for M implants – 12, 32, 62, 92, 131%, for W implants – 19, 28, 56, 94 and 133%.

Bone turnover was found to be significantly influenced by implant diameter and bone loss level. 4.5 mm diameter implant is not recommended for type III bone because bone strains exceed 3000 microstrain threshold even for the osseointegrated implant. 6.0 mm diameter implant caused positive bone turnover balance for up to 0.6 mm bone loss, while 5.0 mm – only for up to 0.3 mm bone loss. Clinicians should consider these findings in treatment with short plateau implants.

Background and Aim

Posterior maxilla usually offers very limited bone height and poor bone quality¹. Nevertheless, short implants have proved themselves as indispensable in restoring missing teeth in such a sensitive anatomical location^{2,3}. This has become possible after significant advancement of implant design, while from the perspective of implant success, bone quality and bone loss still remain the challenge for implantologists. The major goal is to offer safe functional load transfer to adjacent bone resulting in adequate bone strains as key stimuli of bone turnover⁴. In its turn, excessive strains result in bone loss and following implant failure.

Among various shapes of short implants, Bicon® plateau design is one of the most sophisticated types^{5,6}. Plateau implants provide bone loss reduction, but there is no quantitative confirmation to this effect. Computer simulation allows to correlate bone parameters and implant design with bone strain spectrum and to evaluate implant perspective. Finite element (FE) method is the most reliable instrument to provide such a numerical analysis of bone-implant interaction⁷.

The aim of the study was to evaluate the impact of plateau implants design and diameter on strain levels in adjacent bone at several levels of bone loss to assess implant prognosis.

Methods and Materials

The novel method⁷ was applied to evaluate strain fields surrounding fully and partially osseointegrated (0.2 mm annual bone loss) 4.5 (N), 5.0 (M) and 6.0 mm (W) diameter and 5.0 mm length Bicon Short® plateau implants. Their 3D models were placed crestally in corresponding posterior maxilla segment models with type III bone (Fig. 1) and 1.0 mm cortical crestal and sinus bone layers. The models were designed in Solidworks 2016 software. Implant and bone were assumed linearly elastic, isotropic and homogeneous. 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, respectively⁸. The Poisson's ratio of bone tissues (both cortical and cancellous) was assumed to be 0.3⁹. Elasticity modulus of cortical bone was 13.7 GPa⁹, for cancellous bone it was 1.37 GPa (simulation of type III bone).

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).

Bone-implant assemblies were analyzed in FE software Solidworks Simulation. 4-node 3D FEs were generated with a total number of up to 3,450,000 (Fig. 2).

Loading of implant was performed at the center of 7 Series Low 0°, in 3D, by 120.9 N mean maximal functional load¹⁰ applied obliquely at the angle of approximately 75° to the center of 7 Series Low 0° abutment. 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 represented the resultant vector of 29.5 N horizontal functional load acting in the plane of critical bone-implant interface. Initially, all implants were assumed to be fully osseointegrated, then five levels of cortical bone loss from 0.2 mm to 1.0 mm were simulated by establishing non-frictional contact with non-penetration constraints (Fig. 3).

For implant success evaluation, first principal strain (FPS) was chosen as an indicator of bone failure risk. FPS distributions in bone peri-implant area of 18 bone-implant assemblies were studied. Maximal FPSs were correlated with 3000 microstrain minimum effective strain pathological (MESp) to evaluate the perspective of bone turnover.

Fig. 1. 3D and cross-sectional views of maxillary bone segments with 1.0 mm crestal and sinus cortical bone thickness and inserted 4.5×5.0, 5.0×5.0, 6.0×5.0 mm implants. Oblique functional 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 5.0×5.0 mm implant with mapped meshing in the neck area of bone-implant contact. Minimal value of FE size is 0.020 mm.

Fig. 3. Maxillary bone segment with completely osseointegrated 5.0×5.0 mm implant (top left) and the implant with 5 levels of bone loss (0.2 (top middle), 0.4 (top right), 0.6 (bottom left), 0.8 (bottom middle) and 1.0 mm (bottom right)).

Results

Maximal FPSs for osseointegrated implants (1800...3270 microstrain) were found in the cancellous bone at the first fin edge under the results of FPS distribution study in the plane of critical bone-implant interface (Fig. 4). For implants with bone loss, they were observed at the same location and were significantly dependent on bone loss level (2140...3600, 2300...4100, 2800...4900, 3500...5900 and 4200...7000 microstrain for 0.2, 0.4, 0.6, 0.8 and 1.0 mm bone loss (Fig. 5)). Maximal FPSs were also substantially dependent on implant diameter: diameter increase from 4.5 to 6.0 mm have led to 41, 44, 43, 41, 40% FPS decrease for 0.2, 0.4, 0.6, 0.8 and 1.0 mm bone loss. Comparing to the osseointegrated implants, the following FPS increase on five bone loss levels was determined: for N implants it was 10, 25, 50, 80 and 114%, for M implants – 12, 32, 62, 92, 131%, for W implants – 19, 28, 56, 94 and 133%.

Fig. 4. First principal strain distributions in the plane of critical bone-implant interface for selected osseointegrated 5.0×5.0 mm Bicon SHORT® implant (top left) and at five levels of the bone loss: 0.2 (middle left), 0.4 (bottom left), 0.6 (top right), 0.8 (middle right), 1.0 (bottom right) mm.

Fig. 5. First principal strain distributions along the critical line of bone-implant interface for 4.5×5.0 (top), 5.0×5.0 (middle), 6.0×5.0 (bottom) mm implants at five levels of bone loss (0.0...1.0 mm).

Conclusion

Bone turnover was found to be significantly influenced by implant diameter and bone loss level. 4.5 mm diameter implant is not recommended for type III bone because bone strains exceed 3000 microstrain threshold even for the osseointegrated implant. 6.0 mm diameter implant caused positive bone turnover balance for up to 0.6 mm bone loss, while 5.0 mm – only for up to 0.3 mm bone loss. Clinicians should consider these findings in treatment with short plateau implants.

References