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Simulation of the sinus floor elevation

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In order to anchor implants in the severely atrophic maxilla, the method of sinus floor elevation has been introduced about ten years ago. For this purpose the bony support is extended into the sinus floor by filling it up with bone graft. It was not clear yet which degree of maturation the augmented bone must reach to distinctly reduce stress peaks in the bony structures. The results of this FE-study show that it seems to be essential for the bone graft to attain at least the stiffness of cancellous bone.

1 Introduction

As shown in Fig. 1 the bone graft is inserted into the maxillary sinus through a so-called bone window. With growing healing time the augmented bone undergoes maturation (new bone formation). Conventionally, the implants are not loaded until the expiration of a certain healing period of several months. Finally, the implants are supported by the natural structure of the atrophic maxilla (cancellous bone between two thin layers of cortical bone) and the matured bone graft.

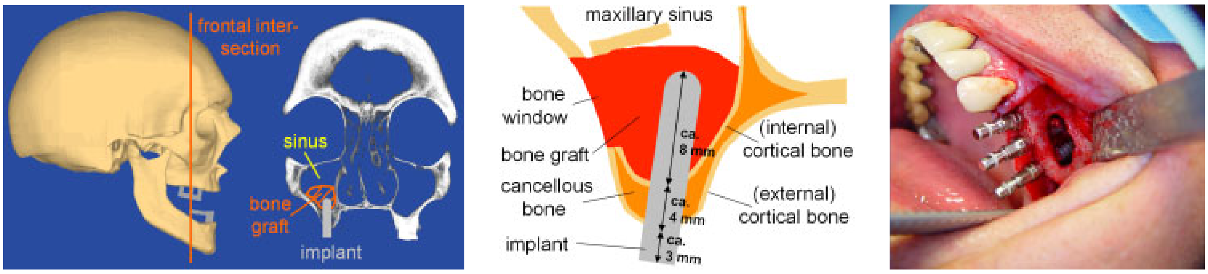
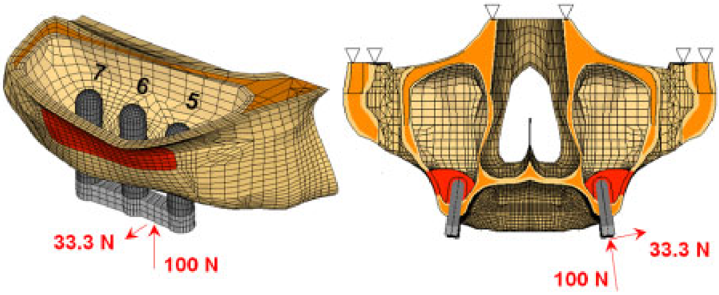


Fig. 1 Frontal intersection containing the sinus (left), scheme of the augmented sinus (center), and surgical procedure (right)

In this study the effect of the stiffness of the bone graft on the distribution of forces in the bony structures around the implants was analysed in order to determine the degree of maturation necessary for a distinct improvement of the bony support. Furthermore, the distributions of displacements and stresses in the vicinity of the implants were investigated.

2 Material and methods

For the FE analysis (ANSYS 7.1) an anatomically realistic model of the facial skull was developed. Fig. 2 shows intersections through this model containing the sinus. Three cylindrical titanium implants (in region 5,6,7) splinted with a titanium connector, were inserted in the sinus floor. To simulate maturation, Young's modulus of the bone graft was varied between the limits 0 and 15 GPa corresponding to total resorption or total corticalization (Young's modulus of cortical bone; cf. table in Fig. 2).



material	E [GPa]	ν
titanium	110	0.3
cortical bone	15	0.3
canc. bone	2	0.3
bone graft	0 - 15	0.3

Fig. 2 FE-model: horizontal intersection without bone graft (left), frontal intersection (center); material parameters (right)

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Two loading conditions (LC) were considered: 100 N in axial (z-) direction (LC1), and 100 N in axial (z-) plus 33.3 N in buccal (horizontal negative x-) direction (LC2), both simulating moderate chewing forces. The forces were applied to the connector between implants 5 and 6 (cf. Fig. 2).

3 Results

With increasing stiffness the bone graft rapidly carries most of the axial force component acting on each implant ($F_{z,total}$). As can be seen from Fig. 3 the bone graft when homogeneously reaching the maturation of cancellous bone, picks up approximately half of the axial load. Horizontal forces, however, cause high reaction forces in the external cortical bone. These reaction forces decrease drastically with increasing Young's modulus of the bone graft.

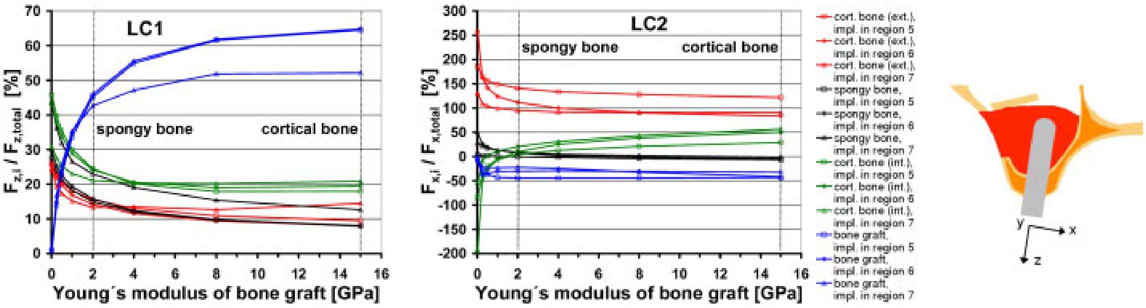

Fig. 3 Influence of Young's modulus of the bone graft on the reaction forces in the different bone regions

For the two considered loading conditions, Table 3 contains the maximum tensile and compressive stresses in the different bone structures for the following values of the bone graft's Young's modulus E_{graft}: 0.01 GPa (practically no ossification of the graft), 2 GPa (corresponding to cancellous bone), and 15 GPa (corresponding to cortical bone).

	$\sigma_{I,max}$, LC1			$\sigma_{I,max}$, LC2			$\sigma_{III,max}$, LC1			$\sigma_{III,max}$, LC2		
E_{graft} [GPa]	0.01	2	15	0.01	2	15	0.01	2	15	0.01	2	15
ext. cort. bone	5.4	2.5	1.5	11.5	8.2	9.5	-23.4	-13.8	-9.2	-32.4	-15.8	-13.9
canc. bone	3.5	0.5	0.4	5.9	1.1	0.8	-2.5	-0.9	-0.6	-4.6	-1.1	-1.0
int. cort. bone	9.5	2.0	0.6	16.0	2.8	1.4	-13.3	-4.8	-2.9	-22.1	-6.8	-5.0
bone graft	0.0	0.5	0.7	0.0	0.8	0.7	0.0	-0.8	-1.8	0.0	-1.2	-2.6

Table 1 Stresses in the bone structures surrounding the implants

In analogy to the reaction forces the significant changes of both stress components occur in the interval $0 \leq E_{graft} \leq 2$ GPa. The stresses in the cortical and cancellous bone essentially decrease with growing E_{graft} while the stresses in the bone graft increase, of course. They remain low, however, due to the fact that the graft covers approximately two thirds of the implant's surface. Throughout, the highest stresses are found in the cortical bounds (thin shells) which must be attributed to the comparatively high Young's modulus and the very small fraction in the contact surface to the implants.
Horizontal forces superimposed on axial forces (LC2) create dominantly higher stresses than purely axial forces (LC1).

4 Summary

This simulation seems to prove that the sinus floor elevation can indeed lead to a mechanically firm incorporation of implants in the atrophic maxilla if the graft reaches Young's modulus of cancellous (spongy, trabecular) bone.

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