580. Strength analysis of the plated clavicle

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(Received 20 September 2010; accepted 9 December 2010)

Abstract. This paper discusses the methods of fastening a clavicle reinforcement plate to the bone. In order to identify the advantages and disadvantages of different types of plates, computer modeling and strength analysis was performed for two plates, which were manufactured from different materials and which employed different mounting design elements.

Keywords: clavicle plate, screws, fastening methods, stress

Introduction

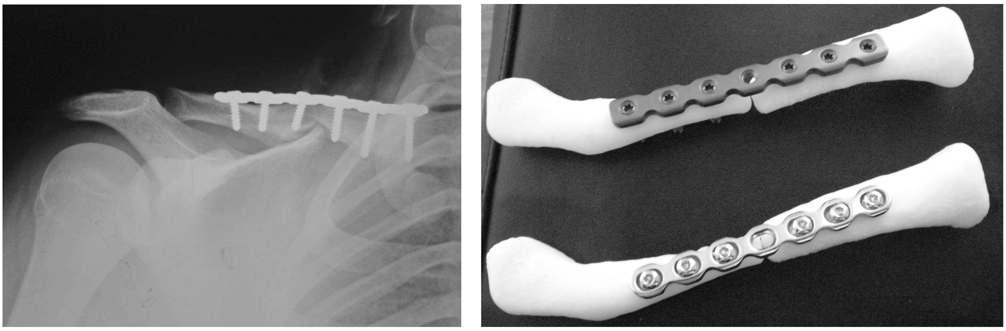
Clavicle fractures are quite frequent. They constitute up to 4% of all fractures of human bones. A clavicle may be dislocated or broken in case of falling down, due to car accident or as a result of sports trauma. Fracture or dislocation happens when falling down on straight arms or when hitting a shoulder. The effect of the hit passes on to the clavicle through the arm. In more than 76% of all cases the clavicle breaks in the middle. In the case of open clavicle fracture it is necessary to anatomically reconstruct parts of the broken bone, to preserve bone blood circulation (healing time and growing of the bone predominantly depends on it), and to protect the body from infection. Therefore surgery is performed on the bone: during the surgery the broken parts of the bone are connected with a special plate – an implant. The plates are manufactured from special metals and their alloys (titanium, titanium alloys, stainless steel), which do not induce a reaction in the body, and the plates are attached to the bone with screws [1-3].

Two methods of fastening the clavicle plate are analyzed in the work: fastening with the screws, when their heads are fixed in the plate with the help of a thread, and fastening by means of screws, the heads of which may slide along the plate [4].

The aim of the work is to determine advantages and disadvantages of different types of plates by performing numerical analysis of the clavicle, joined by plates with fastening screws, fixed and not fixed in it. For that purpose geometrical and computational models of the clavicle, joined by a plate, are constructed, following by strength computations by means of finite element method under varying plate material and fastening method [5].

Fastening of a clavicle plate to the bone

Plates, intended for joining the fractured clavicle (Fig. 1), are fastened with screws with heads from stainless steel or titanium alloy, which may be fixated (with a special thread) or not fixated in the manufactured plate (Fig. 2). The plate is intended to join the broken bone for it to stay stable and to grow together in an anatomically correct way, and when the bone becomes stronger, the plate is taken out. The condition of functionality of the joint is that the details that are tightened together should not move with regard to each other [6,7].



a b

Fig. 1. Clavicle, reinforced with a plate (a) and artificial clavicles, reinforced with different plates (b)

a b

Fig. 2. Clavicle plates used in surgery with a thread to fixate the screw head (a) and without the thread (b)

Seeking to ensure the quality of plate mounting, the primary pre-stress should be composed as accurately as possible. If pre-stress is too small, the joint does not perform the necessary function (e.g., the bone grows together inadequately), if it is too large, the bone may be damaged when screwing the screws too much. The axial force of the screw is calculated from the formula:

$$F_M = \frac{T_u}{0.5\left(d_2 \cdot tg\left(\varphi + \rho^{'}\right) + \mu_g \cdot D_v\right)} \quad (1)$$

where: T_u – total tightening moment, φ – rising angle of thread coil, ρ'– assumed angle of friction, μ_g– coefficient of friction of support surface, D_v– middle diameter of support surface.

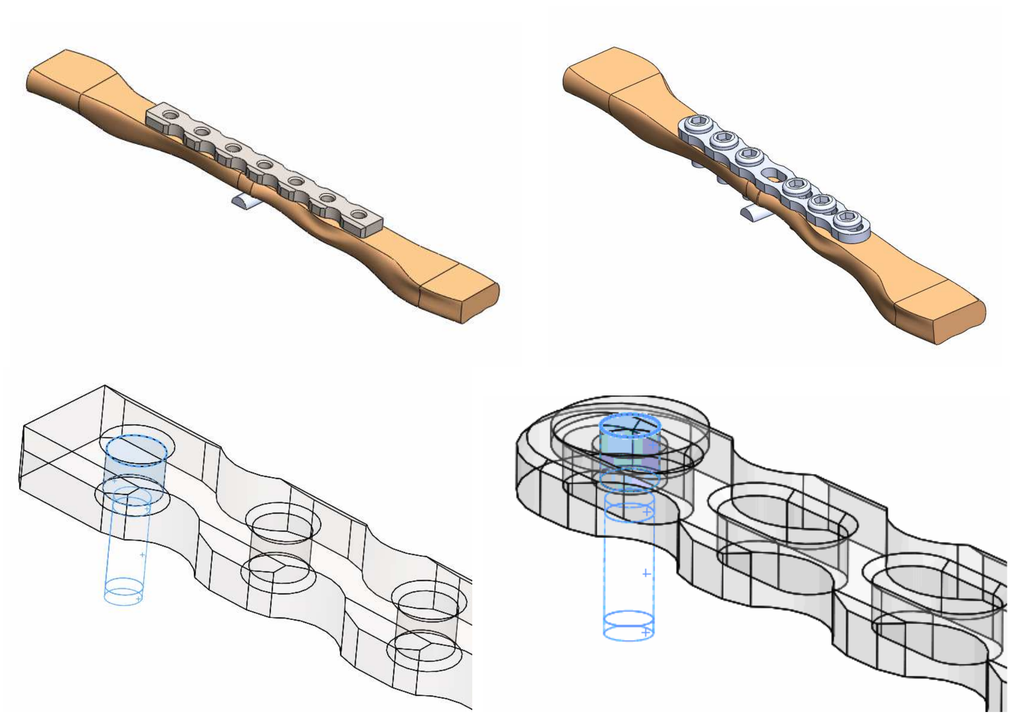
In the analyzed case:

$$F_M = \frac{1.5}{0.5 \cdot \left(0.025 \cdot tg\left(7 + 11\right) + 0.15 \cdot 0.045\right)} = 51.8\ N \quad (2)$$

Computational model of a clavicle, reinforced with a plate

In order to perform the calculated strength analysis of a clavicle plate firstly a computer geometrical model of the system is created. Software SolidWorks is used for this task. It can be used to model surfaces or bodies of complicated spatial forms (curvilinear), and the models may be used for the engineering analysis to be performed with the help of finite element method within SolidWorks environment.

Spatial geometrical models of a clavicle, reinforced with two types of plates, were developed in this research work. In one of the models the plate is fastened with screws, the heads of which are fixated in the plate, in another model they may slide in oblong openings (Fig. 3), assessing plate materials. The geometrical model of the clavicle consists from two layers: 2-mm-thick hard outer layer and a porous filling inside.



a b

Fig. 3. Geometrical models of a clavicle, reinforced with a plate, and position of the screw head in the plate: a – fixated; b – sliding

Numerical analysis of a clavicle reinforced with a plate

Based on the geometrical models of a clavicle, reinforced with a plate, computational models employing finite elements were composed. Strength analysis was performed imitating the bending of a system that is fixed at one end (cantilever-type fixing), by loading the free end with a static force, as the bone, fixed in the middle, is resting on a rigid support (Fig. 4). Since the real system (clavicle) is not fixed very rigidly in the human body, the analysis is performed in a linear regime, i.e. assuming that the plate is impacted by loads that do not induce plastic deformations. Characteristics of materials of the model elements are presented in Table 1. A real contact condition is indicated between the corresponding surfaces of bone and plate as well as between bone and support, and the tightening of the plate to the bone (with a 50 N force) is modeled by a bolt connector, fixating or not fixing the 2.5 mm diameter screw head in the plate (in the latter case a transitional bush is modeled additionally, Fig. 3, b).

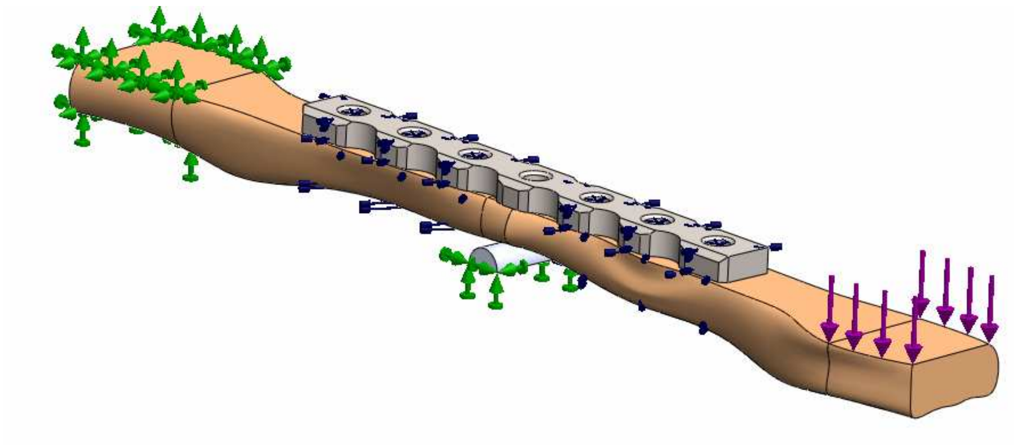


Fig. 4. Boundary conditions of the computational model of a clavicle, reinforced with a plate

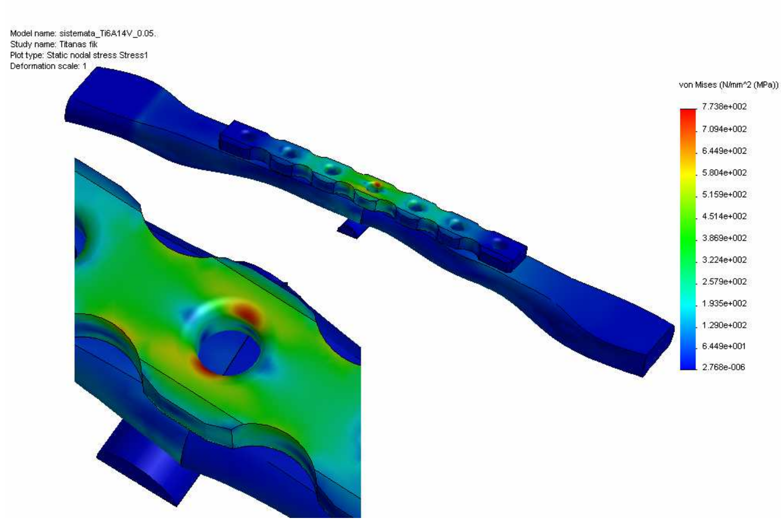
Table 1. Material characteristics of model elements of a clavicle, reinforced with a plate

Material	Yield limit, MPa	Poisson's ratio
Titanium alloy Ti6Al4V	795	0.31
Stainless steel X2CrNiMo1812	190	0.27
Hard bone	106	0.39
Porous bone	60	0.29

The model is meshed by means of spatial tetrahedral finite elements (of 3 mm global size), in separate zones breaking the elements to 2 mm (hard outer bone), 1 mm (plates), and 0.25 mm (surfaces of the middle opening).

Parametric analysis was carried out with varying loads and plate material characteristics (steel or titanium alloy), which provided system stress deformation state. Based on maximum equivalent von Misses stresses (Fig. 5) the maximum permissible bending force was determined in the cases of plates made from different materials and attached to the clavicle in different ways (Table 2).

Numerical analysis revealed that in all cases the nature of plate deformation is the same – it starts to bend in the middle, where the bones are joined, where the maximum stress zone is formed. The plate of titanium alloy Ti6Al4V is obviously stronger, because the permissible level of stresses (yield limit) is reached under the bending force of 180 N, whereas the yield limit in a steel plate is reached already for the load of 20 N.



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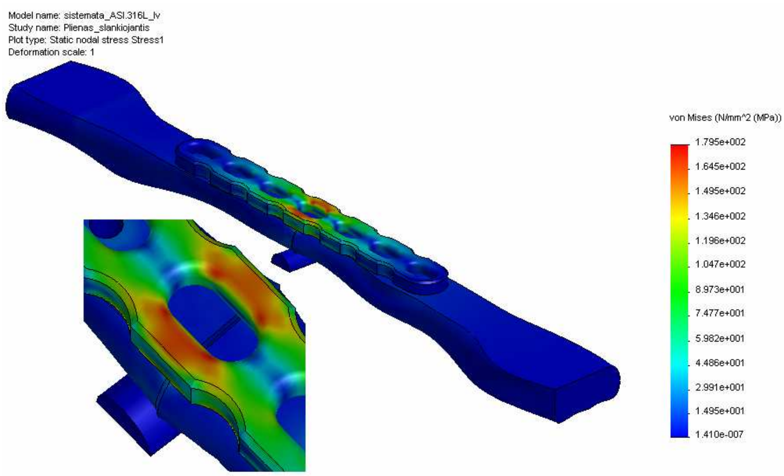

b

Fig. 8. Fields of stress distribution in the clavicle-plate system: a – with fixated screws in a titanium alloy plate; b – with non-fixated screws in a stainless steel plate

Table 2. Main boundary conditions and analysis results of the computational model

Boundary conditions	**Fixed screws Titanium alloy Ti6Al4V**	**Non-fixed screws Stainless steel X2CrNiMo1812**
Load *N*	180	20
Space between bones, *mm*	0.05	0.1
Axial force of screw, *N*	50	50
Friction between bone and plate	0.3	0.3
Yield limit, *MPa*	795	190
Von Misses stresses, *MPa*	760	185
Total shift, *mm*	8.7	1.8
Deformation	0.053	0.014

Conclusions

This paper analyzed the methods of fastening the clavicle reinforcement plate to the bone. Geometrical and computational finite element models were developed. They were used to perform numerical analysis of plates that are made from various materials and employ different fastening approaches. Computations demonstrated that in all considered cases the nature of plate deformation was the same and that the plate of titanium alloy Ti6Al4V sustained higher loads in comparison to other materials used during simulations.

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