

Finite element study of some parameters of bone fractures fixed with screws

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Received 2011-04-30

Abstract

In case of fracture of the neck of the femur a common way of successful rehabilitation of the injured is osteosynthesis. An essential condition of successful recovery is the enhancement of the stability of the fixation of fractures. However, at old age the layer of spongiosa becomes so porous that the threads of screws used for the treatment of the fracture of the neck of the femur virtually fulfil their fixing function only in the subchondral region – less and less in the inner layer of the spongiosa. However, in the subchondral region, the outer layer of 4 to 5 mm remains relatively dense. To increase stability, we modified the traditionally – shaped canulated screws, used for the neck of the femur to date, and developed duplex-threaded screws for the neck of the femur, submitted for a patent as well. By finite element calculations, we would like to verify the effect of stress and geometric parameters – playing an important role in the stability of fixation – for both types of screws for the neck of the femur.

Keywords

fracture of the neck of the femur · fixation with screws · canulated screw · duplex screw

1 Introduction

The surgical treatment of medical fractures of the neck of the femur has engaged the attention of traumatologists and researchers dealing with this question since the development of traumatology. In these days, most authors agree that fractures with no displacement or those wedged in a moderate valgus position (groups I-II according to Garden's and 31B.1 according to AO/Müller's classification, respectively) are to be treated by osteosynthesis. Besides this, for the last two decades, a minimally invasive surgical technique has increasingly taken over, providing an alternative for elderly patients in their surgical treatment versus explorative osteosyntheses or hip joint arthroplastic techniques implying larger operative stress and loss of blood and, not least, we should also take into account the Hungarian financing difficulties. Of course, the minimally invasive operative technique must not be detrimental to stability; our aim is that smaller operative stress should provide similar stability. In Hungary the most widely spread procedure for the treatment of dislocated fractures of the neck of the femur is the method of duplex canulated screwing of the neck of the femur developed by Professor Jenő Manninger and co. The aim of this development was to provide the largest possible stability with the smallest possible stress in case of the osteosynthesis of dislocated fractures of the neck of the femur. Apart from group Garden type III (31B2.2 and B3.1 groups according to AO/Müller classification) involving moderate displacement, this technique, in selected cases, can also be used in group Garden IV and, applying appropriate stability-increasing procedures, in case of group Pauwel III and in lateral fractures of the neck of the femur (AO/Müller groups B3.2, B2.1, B2.2). [1, 7]

Precise, covered reposition, the positioning of screws to the anatomical points Fig. 1 and also compared with each other, is an indispensable part of a properly performed operation. This condition can be fulfilled by the determination of the support points of the screws and also their direction along with the wanted reduction of the fracture in such a way that we prevent torsion in relation to the axis [1, 2]. However, shaping the threads of traditional screws ignores the fact that the bony matter of the head of the femur is not homogeneous. The spongiosa

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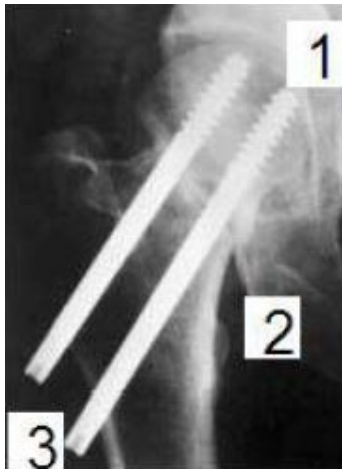


Fig. 1. Double canulated screwing.



Fig. 2. The initial geometric model (prism-shaped bone model.)



Fig. 3. The screw for the neck of the femur in a screwed – in position in the subchondral layer (spherical calotte model.)

matter of the neck of the femur at old age is more and more porous, the density of the bony matter decreases more and more, whereas the bone tissue in the subchondral region remains relatively dense. As at old age canulated screws provide the best fixation mainly in this 4 to 5 mm bone layer mentioned above, in case of screws with the present elevation of threads, the screw is fixed by hardly more than a single thread. In the top 4 to 5 mm thick part of the duplex layer of the screw, we doubled the number of threads by profile division, hoping to achieve an increased stability in the subchondral region with tissues of higher density by increasing the number of threads [3].

2 Objective

Our goal is to study the stability of the first support point, the subchondral layer of the head of the femur in case of osteosynthesis of the neck of the femur with screws. We wish to study to what extent the individual parameters of the biomechanical model influence the stability of fixation during the finite element calculations. We study the local tensions arising in the screw in case of screws with duplex threads. On geometric modelling, we also study the effect of the shape of the related bone layer, the influence of an angle error on driving the screw, the effect of friction between the bone and the metal and also the influence of material characteristics of the bone on stability. We also see the practical benefit of the study: if the positioning error really decreases the stability of the screw fixing the fracture, an increase in the redislocational rate – in case of a proper operative indication and reposition of fracture – may be a consequence of an operation-technical (screw-positioning) error. In this case, we have to strive for the development of such a positioning instrument which decreases the possibility of this error to the minimum [4].

3 Method

3.1 The applied software

The finite element studies were carried out with the integral finite element module of the SolidWorks 2010 CAD designing system, the SolidWorks Simulation software.

3.2 Structure of the geometric model

In the course of biomechanical modelling, we constructed the screw for the neck of the femur in compliance with reality in traditional and duplex constructions, however, first we modelled the related subchondral bone layer with a square-based prism of an area of 20×20 mm and a thickness of 4 mm, into the middle of which, at a depth of 3.5 mm, was screwed the counterpiece of the thread profile of the threads. Then we also studied the case when the bone layer was modelled by a spherical calotte piece, which follows the real geometry of the head of the femur.

3.3 The structure of the finite element net

For making a net on the models (screw and bone) we used tetrahedron elements with 4 points of junction. The global size of elements was 2 mm. Local thickening of net was carried out in case of screws for the neck of the femur at the screwed-in part of threads (here the size of the element decreased to 0.12 mm locally) and also at the inner-threaded part (here, similarly to the screw, the size of the element decreased to 0.12 mm). For a more precise follow-down of the shape of the non-coupling thread profile we applied further net-thickening; here we decreased the size of the element to 1 mm.

3.4 Edge conditions and loading

On the lower surface of the subchondral bone layer, outside a circle with a diameter of 13 mm from the centre of the thread-

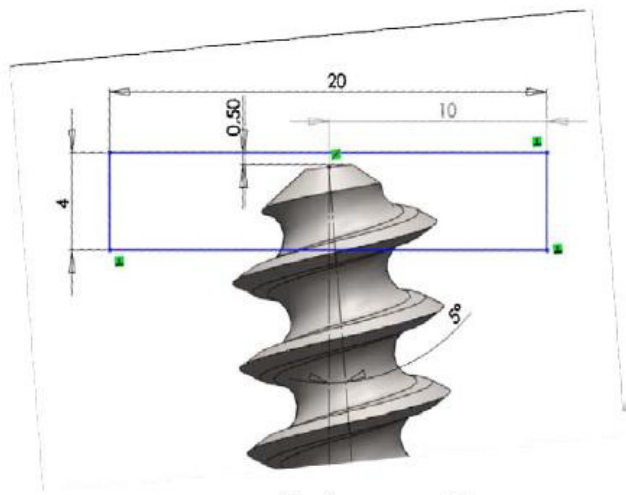


Fig. 4. A 5° positioning error of the screw.

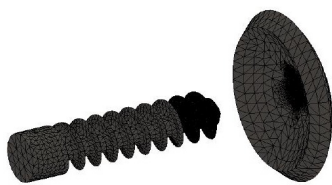


Fig. 5. The structure of the finite element net of the model.



Fig. 6. A thickened finite element net at the end of the screw.

coupling, we applied a fix holding preventing any move or turning in order to prevent a move of the bone layer. To ensure the move of the implant exclusively in the direction of the axis, on its stem we applied a holding of a radial direction and one preventing any turning of the angle. In case of each model, loading power was placed on the model across the lower surface; in case of models carrying out straight driving – perpendicularly to the surface and, in case of models simulating slant driving – parallel to the lateral side of the bone layer.

3.5 Characteristics of materials

Characteristics of materials used in case of models and essential for the study are included in the table below. During calculations we used a linearly flexible material law [5, 8].

3.6 Contact relation between contiguous elements

Taking into account the actual relations between contacting items we defined the so-called *No Penetration* contact relation,

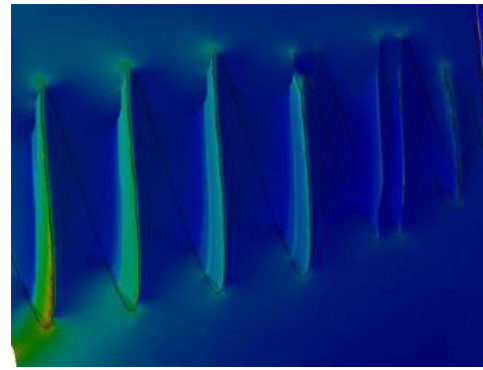


Fig. 8. The site of the appearance of critical tension on the studied models.

Tab. 1. Characteristics of the materials of the individual elements

	Flexibility module	Poisson factor
Subchondral layer	16500 MPa	0,3
Spongiosa layer	400 MPa	0,2
Implant (stainless steel)	200000 MPa	0,26

owing to which the individual surfaces can freely move on each other, but they cannot penetrate into the other one, thus modelling the real contact relation. We also studied the effect of the friction factor on the contact relation. When calculating, we first set the value of friction factor at near zero (base of comparison), then at $\mu = 0.5$. We took 70 MPa as a **critical tension** maximally allowed for surface pressure. In each case, critical tension appeared at the last thread in the bone and in its environment, which we show in Fig. 8 based on the results of a 5° slant driving of the duplex screw.

4 Results

See in Tab. 2

Tab. 2. Cases of loading and the related critical loading

Studied case	Critical loading
Traditional screw straight driving	3000 N
Slant driving (+5° deflection)	2500 N
Slant driving (-5° deflection)	2700 N
Duplex screw straight driving	3600 N
Slant driving (+5° deflection)	3300 N
Slant driving (-5° deflection)	3400 N

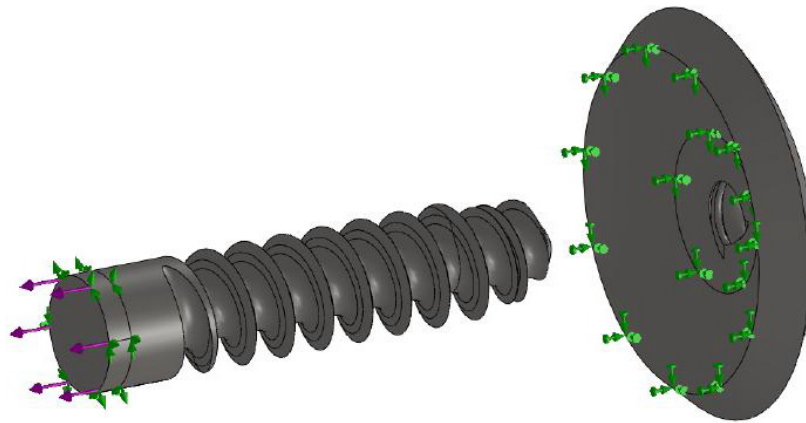


Fig. 7. Loading and holdings.

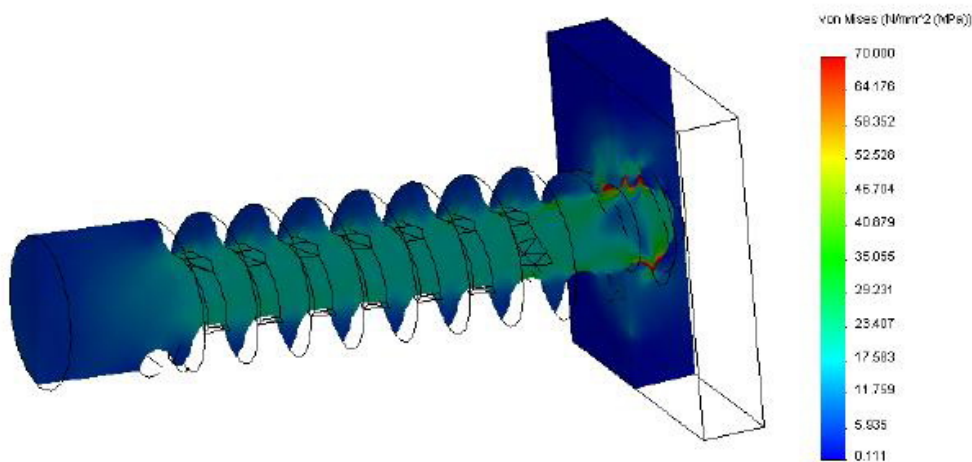


Fig. 9. Rising tensions in case of slant driving (in section).

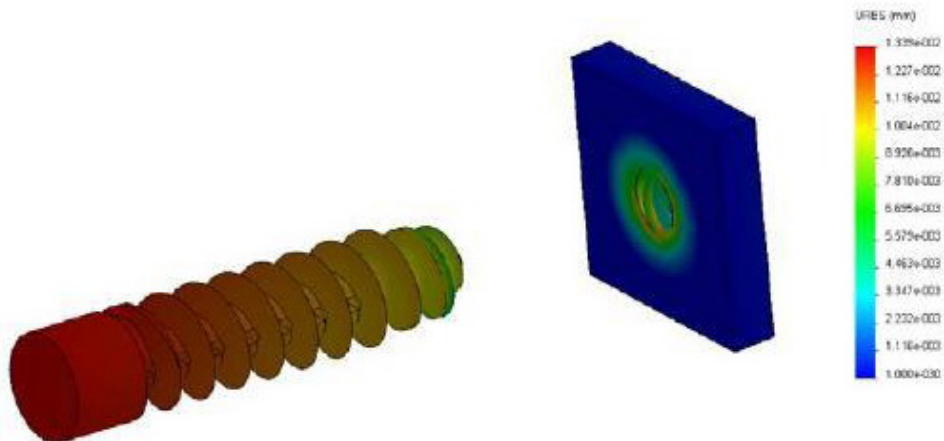


Fig. 10. Move of connecting items in the direction of the axis.

5 Conclusions

5.1 Positioning error

In case of double canulated screwing, when driving the traditional screw into the bone at a 5° positioning error (spherical calotte model), we found that the power needed for pulling the

screw out decreases by at least 10-17 %, depending on the direction of the positioning error. We also examined the effect of positioning error in case of so-called duplex-threaded screws fixing the neck of the femur and we found that in this latter case it was less: 6-9 %, depending on the position of the running out

of the screw in case of a positioning error. When taking into account the **frictional factor**, we found that, on loading, the site of critical tension in the bone itself remains unchanged in case of both types of screw. However, following setting the real value of the frictional factor, tension slightly changed in case of both types of screw.

5.2 Characteristics of materials

The loading capacity of models with spongiosa bone matter differs from that of the subchondral bone layer models merely by a few hundred newtons. In case of spongiosa bone matter itself the flexibility of the studied material is larger than that of the subchondral layer, therefore, due to the effect of loading, it is deformed to a greater extent. Thus, the degree of utilization of the individual threads is bigger, loading is spread on them more evenly. On the contrary, in case of the subchondral layer, on observing the figures of tension, we can see that the degree of utilization of the individual threads in the bone is far not identical; local peak tension occurs at the running-out of the thread, while the utilization of the individual threads is merely one or two thirds of the maximally allowed tension. This could be eliminated by setting an appropriate non-linear material law, so we can examine to what extent the bone layer ‘gets to flow’ due to the effect of a large loading and causes a ‘total damage’ owing to the effect of the loading having been set and as a result of the ‘flowing’ to what extent the rest of the threads takes on the loading. Further on, we are to continue the study by the outlined refining of the biomechanical model and we would like to prove the correctness of the model by biomechanical measurements on bones from cadavers and confirm the results by measurements.

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