Last edited: 2014.12.17. 15:46

Periodica Polytechnica

Transportation Engineering
x(y) pp. x-x, (year)
doi: 10.3311/pp.tr.201xx.xx
web: http://www.pp.bme.hu/tr

RESEARCH ARTICLE

Study of screws for femoral neck fixing, using finite element calculation and *in-vitro* testing

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Received 201x-xx-xx

Abstract
One of the most wide-spread illnesses of our age is osteoporosis at elder age (senilis osteoporosis), and as a consequence, the frequent hip fracture. In case of fracture of the neck of the femur a common way of the successful rehabilitation of the injured is osteosynthesis. An essential condition of the 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. By finite element calculations, we would like to verify the effect of the shape of the thread of screws, playing an important role in the stability of fixation –for the neck of the femur.

Keywords
fracture of the neck of the femur, fixation with screws, shape of thread, duplex screw

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1 Introduction

In Hungary the most widespread technique for the treatment of dislocated fractures of the neck of the femur is the method of percutaneous duplex canulated screwing of the neck of the femur, developed by professor Jenő Manninger and co., which has been used since the middle of the 1990s. The aim of the development was that with minimal invasive intervention, i.e. the least operative stress, it should provide the largest possible stability for the osteosynthesis of dislocated fractures of the neck of the femur. Apart from group Garden type III involving moderate displacement, (according to AO / Müller's classification groups 31B2.2 and B3.1), in selected cases it can also be used in group Garden IV and, applying appropriate stability-increasing procedures, in case of group Pauwels III and in lateral fractures of the neck of the femur (AO / Müller groups B3.2, B2.1, B2.2). [1-3, 7]

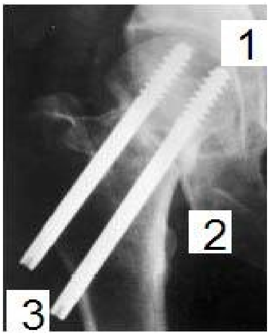

Fig. 1 Fixation of fracture of the neck of the femur by duplex canulated screwing

Canulated femoral neck screws have three support points (Fig. 1): the subchondral region (1); Adam's arch and calcar femoris (2); and also lateralis (3). Primary support is provided by the lower one; so-called caudalis screw, laid on Adam's arch. The upper screw partly frees the lower one, on the other hand, it increases rotation stability. The parallel position of screws is very important so that the bone can be reduced and osteosynthesis can take place properly.

The thread-shaping of traditional femoral neck screws further on referred to as Manninger's screws (shaped similarly to HB thread profile according to ISO 5835:1991), however, ignores the fact that the bony matter of the head of the femur is not homogeneous. The spongiosa matter of the neck of the femur is more and more porous at old age, the density of the bony matter keeps decreasing, whereas the bone tissue in the subchondral region remains relatively dense. Since canulated screws fix best mostly in this, above already mentioned thin bone layer of maximum 4-5mm, in case of screws of traditional rise of threads and traditional shaping it is hardly more than on thread that fixes the screw. In case of so-called duplex screws, we changed thread-profile, and, by a profile division, it was possible to double the number of threads in the upper, 4-5mm long part of the screw. Thus, in the subchondral region, where the tissue is denser (Fig. 2), we, with the help of a larger number of threads, hope to reach stability increase. [4-6]

Fig. 2 Picture of a screw, fixing the neck of the femur, driven into the head of the femur (in section)

2 Objective

For preliminary experiments we use pork femur bones. Because of their properties, similar to juvenile bone structures, these pork bones can be considered good basic materials. Based on the experience gained from these samples, we shall continue our experiments on human explants (frozen heads of the femur). We strive to prepare and carry out the experiments similarly to the way the research team used to do that in connection with canulated screws under Manninger's guidance.

The stability of fixation is also going to be studied by finite element calculations in case of both traditional (HB thread profile) and duplex screws with altered thread profile. To calculate the primary stability of implants, the finite element analysis is widely used method in several proximal femoral fixation system. [8-9]. We study pull-out power, local tension arising in the screw, displacements and the effects of shaping the screw on the stability of fixation.

We also see the practical use of the study in that case if the shaping of the screw really increases the stability of the screw concerning its fixation of the fracture. If it does, then, in case of a proper surgical indication and fracture reposition, redislocation can decrease.

3 Method of calculation

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

Structure of the geometric model: in the course of biomechanical modelling, screws for the neck of the femur were constructed in compliance with reality, both in traditional and duplex constructions, whereas the related subchondral bone layer was modelled by a spherical calotte form approximating to the real geometry of the head of the femur. In the course of modelling the subchondral bone layer, the bone layer of cortical type was modelled by an 80° section of a spherical calotte of 51mm of outer diameter and a thickness of 4mm, while the spongiosa layer of 10mm was fitted to it continuously (Fig. 3).

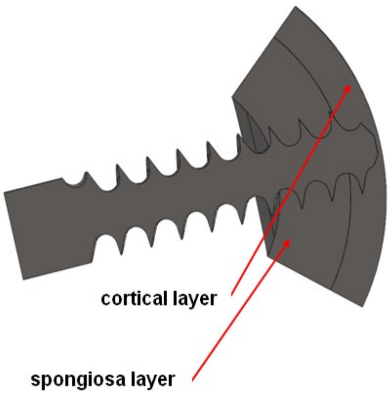

Fig. 3 The initial geometric model presented in case of a traditional screw with HB threads

Structure of the finite element mesh: to mesh the models, we used tetrahedron elements with 4 points of junction. The global size of elements was 2 mm. Local thickening of net was carried out at the screwed-in part of threads (here the size of the elements dropped to 0.12 mm) and also at the inner-threaded part of the bone layer (here, similarly to the screw, the size of the elements decreased to 0.12 mm). For a more precise follow-down of the shape of the non-coupling thread profile, we applied some further net-thickening; here the size of the elements decreased to 1 mm (Fig. 4 and 5).

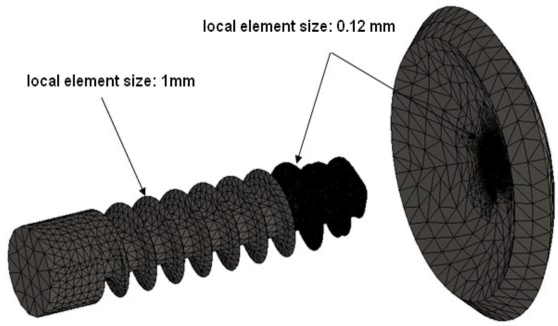

Fig. 4 The structure of the finite element net presented in case on a duplex screw

Fig. 5 A thickened finite element applied at the end of the screw (presented on a duplex screw)

Edge conditions and loading: on the lower surface of the cortical bone sample, outside a circle with a diameter of 13 mm from the centre of the thread-coupling, we applied a fix holding in order to prevent any move or turning of the bone layer. To ensure the move of the implant 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 (Fig. 6).

Loading power was placed on the model across the lower surface, parallel to the lateral side of the bone layer.

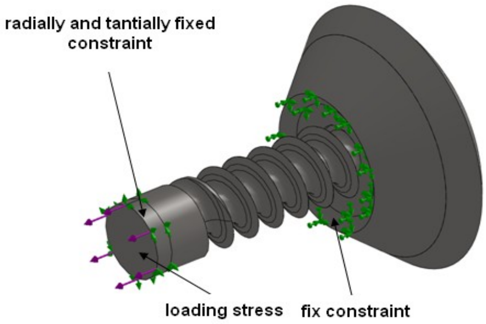

Fig. 6 Loading and holdings shown on a duplex implant

Characteristics of materials: characteristics of materials used in case of models and used for the study are included in the table below. During calculations we used a linearly flexible material law.

Table 1 Mechanical properties

	Flexibility module	Poisson number	Ultimate tensile strength
Cortical layer	16500 MPa	0,3	165 MPa
Spongiosa layer	400 MPa	0,2	1,8 MPa
Screw (ISO 5832-9 stainless steel)	200000 MPa	0,26	1000 MPa

Contact relation between contiguous elements: taking into account the actual relations between the implant and bone layers, we defined a so-called *No Penetration* contact relation, owing to which the individual surfaces can freely move on each other but they cannot penetrate into the other one and thus modelling the real contact relation. On the contrary, between the two layers we established *Bounded*, so-called attached contact, modelling that the two bone layers – at their contact point – move together.

4 Results of calculation

Illustrating the results (see Fig. 7-9), we maximized surface tension scope in 70 MPa for the cortical bone layer and 20 MPa for the spongiosa layer. Runs were carried out until tension, in case of the threads cut into the bone, at some local site exceeded 70 MPa and 20 MPa, respectively.

Straight driving of the traditional, HB-type threaded screw. The loading power, upon which tension exceeds the border tension: 850 N.

Testing straight driving for a duplex screw. The loading power, upon which tension exceeds the border tension: 1400 N (Table 2).

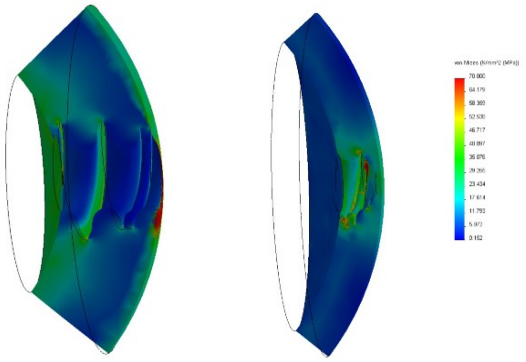

Fig. 7 Tensions in the individual bone layers and their location illustrated on a duplex screw

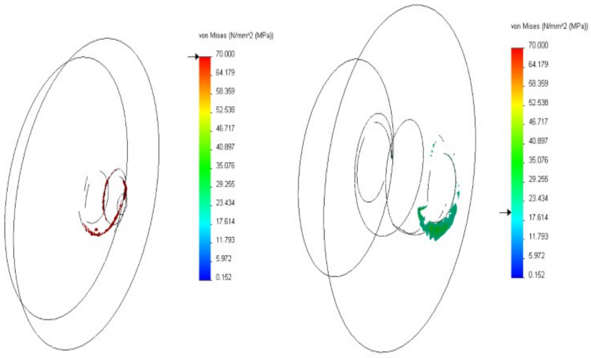

Fig. 8 Extent of scopes where tensions approach the border tension a) Cortical layer b) Spongiosa layer

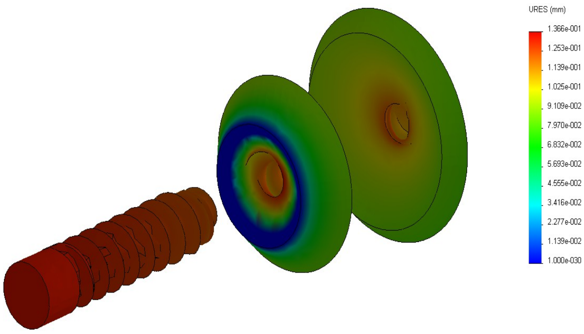

Fig. 9 Displacement of linked elements

(URES: Resultant Displacement – equipollent displacement)

Summary: *Table 2.* contains the total of the results of finite element calculations.

Table 2 Tested screws and the related critical loading

Studied case	Critical loading
Straight driving of a ***traditional*** screw	850 N
Straight driving of a ***duplex*** screw	1400 N

5 Method of measuring

Preparation of measurements: for proper preparation of preliminary experiments, for precise pre-drillings we used a traditional drill to find the normal direction from the lateral plane. This is important because this way we were able to avoid bending upon measuring, and measure the pulling bearing force alone. For drilling we used a drill stem of 5.5 mm in diameter, also applied in Manninger's instrumentation.

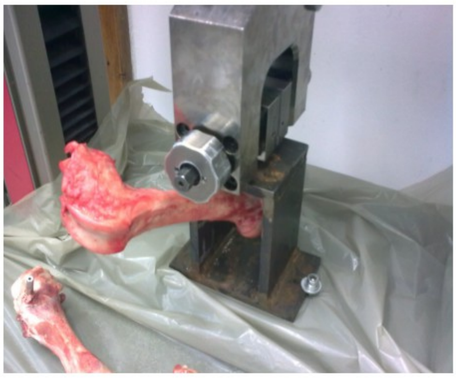

Fig. 10 Preparation of pork femoral bones

In the process of preparing human specimen it was a traumatologist head doctor's responsibility to check the proper driving of the screw. For preliminary drilling we used a targeting wire and drill stem found in Manninger's instrumentation; we did not use a thread-cutter.

Carrying out measuring: testing of properly prepared sample pieces was carried out on a Zwick Z020 tensiometer equipped with special clamping tool (Fig. 10-11).

Fig. 11 Tensile test on a resected head of the femur

6 *In vitro* measuring results

In the courses of measurement we, separately for each test, calculated the rate for the average of maximal tensile stresses so as to be able to describe the stability of the duplex screws numerically, compared to Manninger's screws. For each course of measurement we used similar bones.

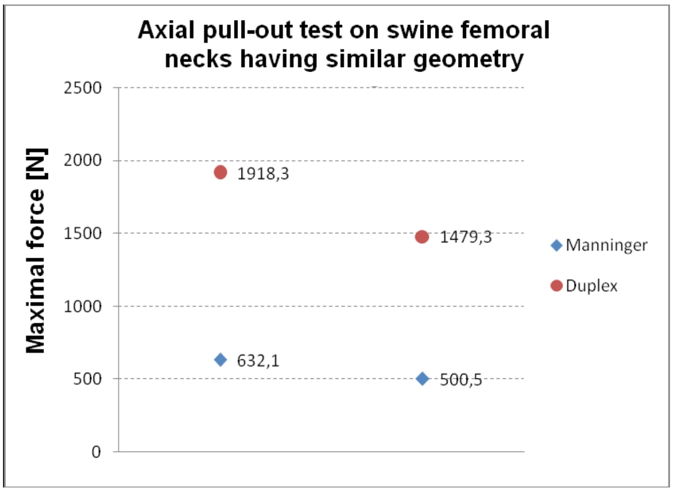

Fig. 12 Measurements carried out for swine pairs of bones

Based on the result we can state that duplex screws are significantly more stable upon pulling pork bones (Fig. 12). To obtain further average results we carried out mixed experiments on both pork femoral bones and tibiae.

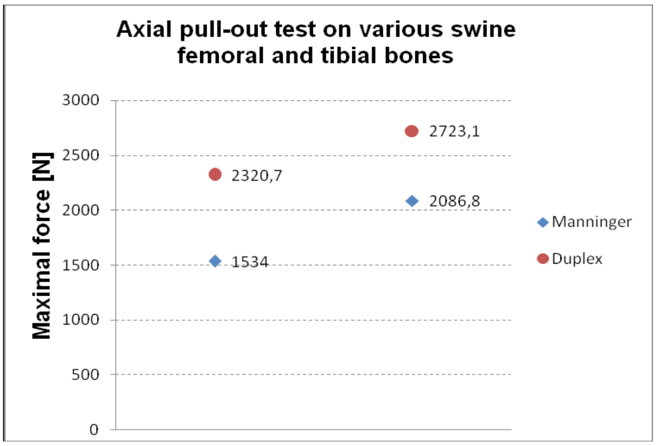

Fig. 13 Experiments on mixed bones

On the basis of measurements we can state that the rate of weighted average for the two types of screws was 219.6 % - in these bone matters the duplex screw showed a significantly larger pulling-out power (Fig. 13).

Similarly to pork bones, the results of tests carried out on human specimen, the duplex screw demonstrated the more beneficial results (Fig. 14 and Table 3).

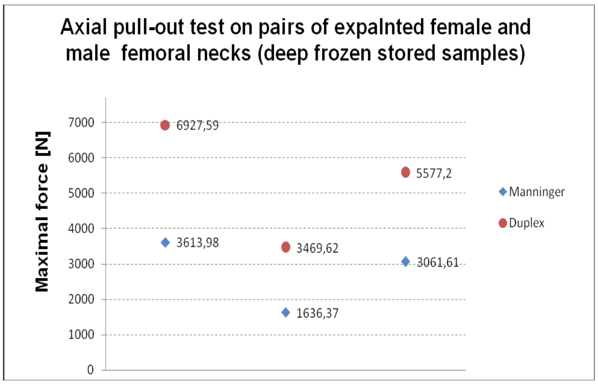

Fig. 14 On the left: 1st pair: a male's bone, Manninger's screw 8 vs. duplex screw; 2nd pair: a particularly old male, Manninger's screw 9.5 vs. duplex screw; 3rd pair: female bone, Manninger's screw 8 vs. duplex screwOn the left: 1st pair: a male's bone, Manninger's screw 8 vs. duplex screw; 2nd pair: a particularly old male, Manninger's screw 9.5 vs. duplex screw; 3rd pair: female bone, Manninger's screw 8 vs. duplex screw

Summary: *Table 3.* contains the total of the results of *in vitro* pull-out experiments.

Table 3 Tested screws and the related critical loading

Number	Human test subjects	Stability increase of duplex screws
1.	male	+91,7%
2.	old male	+112%
3.	female	+82,1%

7 Conclusion

Since, on one hand, the bone tissue is an inhomogeneous living tissue, on the other hand, depending on the extent of osteoporosis and several other factors typical of the individual, there is a very big difference between the mechanical characteristics of bones, therefore large scopes – deviations – in experiments are natural. Due to the above-mentioned facts, upon evaluation it is not the absolute values but the comparative ones that are relevant.

Based on the results of measurements on screws fixing the neck of the femur, we can state that duplex-threaded screw profiles vs. traditional (HB-type) thread profiles appear to be better concerning their pulling-out power.

We can state the same on the basis of finite element analysis. In case of duplex screws, the power of tearing the screw out has increased by 65 % compared to the traditional screws.

Both the experiments and calculations showed significantly better results in case of duplex-threaded screws for fixing the neck of the femur.

Further plans: To develop the model (based on biomechanical experiments) we would like to set an empirical non-linear law. By this it can be examined to what extent the bone layer 'flows apart' upon large stress and causes damage upon the adjusted stress and also to what extent the rest of the thread takes over the stress in case of deformation.

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