BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS
Faculty of Mechanical Engineering

Summary of PhD dissertation

István Bagi

M.Sc. in Mechanical Engineering

Biomechanical investigation of screw fixation of bone fractures

Supervised by: Dr. László Dévényi

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The premises of the research

Osteoporosis at old age is a disease of our era with an increasing incidence, which, according to statistical data, can be detected in nearly 80% of the population over 60. One of the most important consequences of osteoporosis is the occurrence of bone fractures due to a relatively small impact. The number of this type of fractures has drastically increased over the last few decades with the growth of life expectancy and the related diseases, also associated with altered lifestyle.

Out of fractures of osteoporotic origin the most important ones are those in the region of the hip. These fractures prevent patients from pursuing their former ways of living for a longer time: restricted functions, and motions and movements, developed as a result of fracture, can also restrict self-care to a great extent. In my research I treat fractures of the neck of the femur in more details.

From biomechanical and circulation-physiological points of view the fractures in the region of the femoral neck are divided by the literature into two main groups: intracapsular (medical neck of the femur) and extracapsular (lateral neck of the femur, basal and trochanteral) fractures. These two types of fracture also demonstrate differences in the forms and consequences of complications, showing significant differences in their operative treatment, and therefore I describe them in detail in my paper.

The common complications associated with the fracture of the neck of the femur and the high mortality rate resulting from it still impose a big burden on both the health care system and the society. Owing to the rise in life expectancy and the specific diseases of the "civilized" societies, the number of fractures in the region of the hip has started to elevate dramatically. Until those with fractures in the hip region were treated conservatively, a large proportion of them died from the complications resulting from the lengthy immobilization in half a year following the injury. Although the first operative possibilities meant a great advance, but, because of the high rate of complications continuous research has been done in order to develop more effective techniques. In the research on and the development of operative therapies internationally acknowledged results were achieved by the team of the former National Institute of Traumatology led by Professor Dr Jenő Manninger.

In Hungary, a research team was established to deal with fractures in the region of the femoral neck in the National Institute of Traumatology in 1953, where the so-called Smith-Peterson's nailing was developed for decades. Professor Dr Jenő Manninger started to apply the minimally invasive duplex canulated screwing technique. However, initially this technique was not common and could not be used successfully. The research team, led by Professor Manninger, developed a complete operative treatment for the fracture of the neck of the femur and also developed the related instrumentation. From 1993 on the so-called percutaneous duplex canulated technique was generally applied for the osteosynthesis of dislocated fractures of the neck of the femur. Apart from type Garden III, involving a moderate dislocation, this technique can be used for type Garden IV and, applying the appropriate stability-increasing techniques, also for Pauwels III and for lateral fractures of the neck of the femur.

In a few years considerable results were achieved with the percutaneous duplex canulated technique. As a sign of respect, the canulated screws for fixing the femoral neck are still called as “Manninger’s screws” by the medical jargon.

Having been invited by Professor Manninger, I joined this research team. Having joined in the development of the so-called “Swedish screws”, I carried out the formulation of the various geometric and constructional types of femoral neck screws, and then, from 1994 on, as a senior lecturer of the Department of Material Science and Technology at the Budapest University of Technology I performed their biomechanical testing. The first reports on successful clinical experience appeared in 1993 and 1994, and the first results of the biomedical tests were published in 1996.

Objectives

Increasing the stability of fixing the fracture is an essential condition of successful recovery. The thread formation of traditional screws, however, does not take into account the fact that the bone matter of the head of the femur is not homogeneous. At old age, the spongiosa matter of the femoral neck becomes more and more porous, the density of the bony matter decreases, whereas the bone tissue in the subchondral region remains relatively dense. As at old age canulated screws are best to fix in the bone layer of cortical character, in case of screws of traditional thread rise and thread formulation scarcely more than one thread fixes the screw. In case of the so-called duplex screws, changing the thread profile allowed the duplication of threads by profile division in the top, 4 to 5 mm part of the screw. By this, the stability of fixation in the subchondral region, where the tissue is denser, is expected to be increased due to the larger number of threads. Screws of such formulation have not yet been used for the fixation of bone fractures with screws.

In case of fractures of the neck of the femur, having determined the stability of screws driven into the subchondral region and the factors that influence stability, I carry out finite element calculations for screws fixing the neck of the femur. I determine the pulling-out force, the local tensions in the screws, displacements and the effect of the individual parameters on the stability of fixation.

1. My research objective has been the finite element analysis of the effect of the various thread profiles of femoral neck screws on the stability of fracture fixation. I do not test the screws with a simplified model, but with their actual geometry and with several kinds of thread profile.

2. With numerical calculations, I test whether the screws of new formulation, the so-called duplex screws have a stability-increasing effect and, if so, what numerical degree of it can be detected.

3. With finite element calculations I aim to prove the importance of positioning of femoral neck screws and also confirm a decrease in stability owing to positioning errors.

4. In my calculations I also examine the degree of the role of friction at the screw and bone contact in the fixation of the femoral neck fracture.

5. My research objectives include testing the effect of the geometrical formulation of the environment of screws on the punctuality of the results (i.e. testing the effects of the simplified and true-to-facts segment of the femoral head and also those of the geometric model of the whole femoral head).

6. In my calculations, besides the cortical matter of the femoral neck (subchondral region), I take into account the spongy bone structure.
7. I carry out the comparative finite element examination of femoral neck screws of various formulations for various loading conditions.
8. I compare the results of the finite element endurance tests to the results of the laboratory experimental tests carried out earlier.

Methods of examination

With finite element calculations I test the stability of fixation of femoral neck fractures with screws and the factors influencing stability.

I test three femoral neck screws of different thread profiles for various models. For the examinations I select uniquely formulated geometric models and their finite element smashing, loadings, holdings, material characteristics and contact relations according to tested parameters influencing stability.

I carry out the simpler modelling with the integral finite element module of SolidWorks 2010 CAD planning system, with the help of SolidWorks Simulation software. In case of more complex models and the application of non-linear material law derived from the measuring results, where calculation capacity is a lot larger, I use ANSYS V13.0 finite element software. In the course of numerical simulation I determine the pulling-out power, local tensions in the screws, displacements and the effect of the individual parameters on the stability of fixation.

I compare the results of calculations to those of measured in the laboratory.

New scientific results

1st thesis: Based on the results of finite element analysis I have used, out of the tested parameters the geometry of screws and, within this, particularly the formulation of the thread-profile is the most influential for the stability of fixation of femoral neck fractures with screws. In case of each tested bone model, out of the examined screws of HB, simplex and duplex thread-profiles, I obtained the largest loading capacity in case of duplex screws – with values larger 55±30% compared to Manninger's screws. **[4]**, **[5]**, **[6]**

2nd thesis: In case of the tested screws, the positioning error of the screw used in the course of bone fixation causes a decrease in stability. Based on the results of my finite element calculations, I stated that in case of screws driven into the bone segments with ±5 degrees of positioning errors, the maximal load-bearing is decreased by 10 ± 2,5% for screws of traditional and simplex threads, whereas for screws of duplex threads this value was 15 ± 3,3%. Screws of duplex threads are more sensitive to positioning errors than traditional and simplex screws. **[3]**, **[4]**

3rd thesis: The geometry of bone segment, modelled in the course of the analysis of bone-fixing screw relations, has a complex effect on the size of pulling-out power and also on the formation of local tensions. On one hand, taking into account the geometry close to the actual spherical shape (spherical calotte, hemisphere) involves an increase in stability compared to prismatic models, on the other hand, however, it increases the importance of the position of the thread running out, and thus it increases the importance of the positioning error decreasing tearing-out power. On the whole, taking into account the spherical geometry resulted in a mean increase in tearing-out power of 10 ± 1.5% in case of each screw type. **[3]**, **[4]**, **[6]**

4th thesis: By numerical testing I detected that in femoral neck screws, driven into the bone tissue in case of shape closing distortion, a change in the frictional factor between 0,0 and 0,5 brings about a 6% maximal modification in the tension field, therefore this test parameter is the less influential for calculation results. In calculations of this type, a frictional factor of zero is acceptable. **[4]**, **[6]**

5th thesis: By biomechanical measurements, based on curves placed on particular measuring points, I described the equations of tension-shape correlations for the head of the femur, which are valid at a temperature of 20 °C for cortical and spongiosa tissues of measured biological samples.

For pulling out:

$$\sigma = 9\cdot10^{8}\,\varepsilon^{5} - 2\cdot10^{8}\,\varepsilon^{4} + 8\cdot10^{6}\,\varepsilon^{3} - 146978\,\varepsilon^{2} + 1105{,}9\,\varepsilon - 0{,}1459 \quad (1)$$

For pressing attempt:

$$\sigma = 3\cdot10^{10}\,\varepsilon^{5} - 5\cdot10^{9}\,\varepsilon^{4} + 2\cdot10^{8}\,\varepsilon^{3} - 4\cdot10^{6}\,\varepsilon^{2} + 33220\,\varepsilon - 4{,}3891 \quad (2)$$

Equations (1) and (2) describe the average of my measurement results with a regression value of 0.9785 and 0.9876, respectively, so they can be used as model materials for modelling bones. In finite element studies of these material models, also the screws of duplex threads gave the more favourable results: on tearing out they showed stability bigger by 41,2% and on pressing bearing force larger by 54,1% compared to Manninger's screws. **[1]**, **[2]**, **[4]**, **[6]**

6th thesis: Besides numerical studies, I also showed in laboratory experiments that the force needed for tearing out a duplex screw grew by 65% compared to traditional screws. This value corresponds to the results obtained from numerical simulations within an error rate of 10%, so I can state that the initial data taken by me and also the modelling settings (geometric model, finite element netting, loadings, holdings, material law) gave a reliable result, well approaching reality. **[4], [6]**

Utilization of results

The practical use of the study I see is, on one hand, that, if the proposed formulation of screws really increases the stability of screws, than in case of appropriate operative indications and reposition of fractures, the redislocation rates may decrease.

On the other hand, the study may confirm that, apart from accurate and covered reposition, the positioning of screws to the anatomic points and to each other is an indispensable part of a properly performed operation. By determining the supporting points of screws and also the direction of screws the desired shortening of the fracture (the possibility of slipping together according to the axis) can be achieved in such a way that twisting away according to the axis can be pevented. The use of screws of an altered thread profile can result in an increase in the stability of osteosynthesis and the preservation of the viability of the femoral head and, in some cases, the widening of operative indications.

Publication of the new results

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