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EVALUATION OF LOCKING BONE SCREW HEADS

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Abstract: *When extracting a trauma/orthopaedic titanium alloy implant, there are some difficulties in trying to release some locking bone screws from locking holes of the angularly stable plates (stripping the internal hexagon in the screw heads or twisting off the screw). Experimentally, the magnitude of the torque that causes stripping of the internal hexagon (the Inbus type head) of 3.5 mm locking cortical bone screw made of titanium alloy Ti6Al4V according to ISO 5832-3 was determined. It has been experimentally found that slipping the end of a screwdriver with a hexagonal end inside the head of the locking cortical bone screw when stripping the internal hexagon causes a deformation of the screw head circumference and thus increases the thread friction. The influence of the tightening torque on the ability to unscrew the locking cortical bone screw from the locking hole of the angularly stable plate was evaluated experimentally. The numerical assessment of the five alternatives of the head shapes of the locking cortical bone screws in terms of stresses and resulting deformations has shown that the screw with the Torx type head, which reaches the lowest values of reduced stress and plastic deformation, is the best option.*

Keywords: locking bone screw, osteosynthesis, biomechanics, experiments, FEM

1. Introduction

Osteosynthesis of complicated skeletal trauma is usually performed using trauma implants. These implants are introduced into the body permanently, or temporarily until the fracture heals, or until it is reoperated (osteolysis or other reasons), or the patient requires it (Perry et al., 1992).

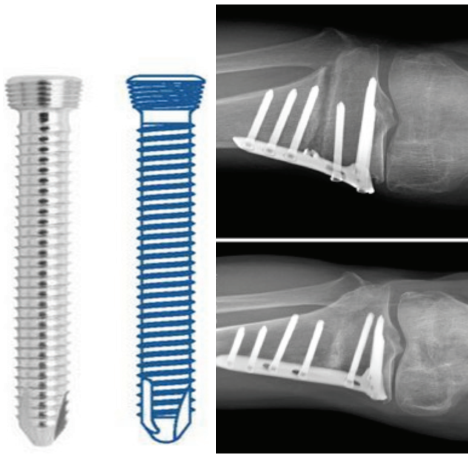

Fig. 1 Locking screw and its applications

Currently, angularly stable plates, which have a significant use in more complicated fractures, are commonly used in medical practice (e.g. bone epiphysis, etc.) (Frydrýšek et al., 2014). By joining the screw and the plate with a double start fine thread on a conical surface, the desired self-locking connection with the angularly stable plate is achieved, see Fig. 1. Thus, a part of the load of the plate system is transferred from the screw & bone joint to the screw & plate joint. Because the joint is sufficiently tough, the system can also be successfully used in lesser quality e.g. osteoporotic bone. The plate does not necessarily have to be pressed to the bone (it may be placed at some distance from the bone) and there is no reduction in blood supply to the bone. Locking screws (see Fig. 1) can be introduced

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monocortically without weakening the assembly strength or fracture fixation because the screws are firmly anchored in the plate.

According to the surgical procedures, locking cortical bone screws in the angularly stable plate should be manually tightened over a torque clutch with a torque of 1.5 Nm. However, even when this procedure is followed, extraction of the titanium alloy implant results in frequent difficulties in trying to loosen some locking bone screws from locking holes of the angularly stable plate (Heller et al., 1996). Occasionally, the internal hexagon (Inbus) in the screw heads is stripped. This is followed by complicated drilling of the heads of such bolts and the subsequent removal of the bolt shanks from the bones using the extraction set, which is associated with an undesirable prolongation of the operation times.

2. Implant materials

Austenitic stainless steel (1.4441 according to ISO 5832-1, earlier in the Czech Republic, according to ČSN – Czech National Standard – 17 350), and titanium alloy (Ti6Al4V according to ISO 5832-3) are used for implant production. For these materials the tensile strength is almost the same $R_m = (860 \div 1050)$ MPa. Tensile modulus of titanium alloy $E = 113.5$ GPa, stainless steel tensile modulus $E = 210$ GPa. To produce trauma implants, titanium alloy is more suitable than austenitic steel because it is more inert and more flexible from the point of view of biocompatibility. Titanium alloy can be surface-treated by anodization, a process during which electrolysis produces titanium oxide (Antoszewski et al., 2008) on the surface of the implant.

3. Determining the magnitude of the torque that causes stripping of the internal hexagon in the head of the bone screw (Inbus)

Experimentally, in the laboratory, the magnitude of the torque that causes stripping of the internal hexagon in the head of the locking cortical bone screw was determined (Čada, et al., 2017). The shank of the locking bone screw was held in a vertical position in a bench vice using great force to prevent it from slipping while using a torque screwdriver. A torque screwdriver with 2.5 mm hex bit was used for the experiments. On the torque screwdriver, the torque from 1 Nm to 0.1 Nm was gradually adjusted using its scale. Manual rotation of the screwdriver with a 2.5 mm bit in the head of the locking bone screw always followed. When the low torques had been set, the internal part of the screwdriver always slipped, which indicated that the internal hexagon in the bolt head was not stripped at the given torque. After stripping the internal hexagon with the torque screwdriver bit, the torque applied was measured on the torque screwdriver scale. Experiments have shown that when the torque increases up to the limit of stripping the internal hexagon, the plastic deformation of the internal hexagon occurs in the head of the locking bone screw – undesired state of pressure mark. The existence of plastic deformations is apparent after the relief, when the hex bit is pressed into the head so that it is difficult release (see Fig. 2). Either repeated effect of a lower torque and a gradual accumulation of plastic deformations, or increasing the torque set on the torque screwdriver results in stripping the internal hexagon in the head of the locking bone screw.

Fig. 2 Internal hexagon in the head of a locking self-tapping bone screw (a) before, (b) after using a screwdriver

Fig. 3 Locking self-tapping bone screw in the plate (a) stripped internal hexagon in the screw head after using the screwdriver, (b) fracture surface after fracture of the screw shank)

It is also important to find out if slipping of the end of the screwdriver with a 2.5 mm hex bit on the inside of the head of the locking cortical bone screw when the internal hexagon is stripped causes a larger deformation of the screw head circumference.

A larger deformation of the bolt head necessarily leads to an undesirable increase in thread friction in the locking hole of the angularly stable plate. Therefore, the diameter of the head of each locking bone screw was measured 10 times at various points when turning the screw using a digital micrometre with an accuracy of 0.001 mm. Subsequently, the mean value and the absolute measurement error were calculated. A comparison of the measured values of the 3.5 mm diameter titanium alloy locking bone screw head before and after stripping of the internal hexagon in the screw head (see Fig. 3) was performed, and the absolute measurement error was compared. The experiments show that slipping of the end of the screwdriver with a hexagonal end inside the head of the locking cortical bone screw when the internal hexagon is stripped causes a slight increase in the diameter of the bone screw head. When the locking cortical bone screw is used in the locking hole of an angularly stable plate, the internal hexagon in the screw head is stripped if the torque is exceeded. This is directly related to the enlargement of the diameter of the screw head by plastic deformation, with consequent increase in the frictional forces in the thread in the locking hole of the angularly stable plate.

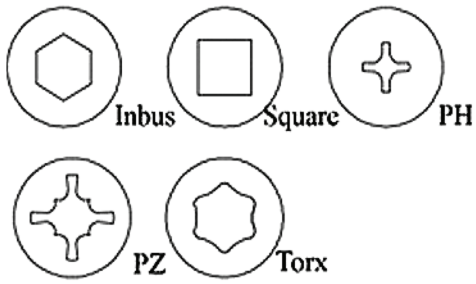

Fig. 4 Geometry of the most commonly used screw heads

The geometry of their heads (CAD models) has been found for the most commonly used Inbus, Square, PZ, PH, and Torx head screws (see Fig. 4). Subsequently, FEM analysis (plasticity, mechanical contact) was carried out in MSC.Marc/Mentat sw. In total, 5 computations simulating tightening, or loosening of the screws were performed (Čada, et al., 2017).

4. Evaluating the alternatives of shapes of locking cortical bone screw heads in terms of stresses and emerging deformations (numerical simulations)

When screwing, the screwdriver (rotating around its longitudinal axis) rotates with the screw head. During the analysis using the finite-element method, the screwdriver was defined as an absolutely rigid (non-deformable) body, which is an acceptable simplification of the real state. A rotary speed of $0.0873\ \mathrm{rad \cdot s^{-1}}$ (corresponding to $5^{\circ}\ \mathrm{s^{-1}}$) was prescribed for the screwdriver. The screw head was defined as a real (deformable) body. The friction between the two bodies was determined by the Coulomb friction coefficient $f = 0.05$.

The boundary condition of the absolutely rigid rotating body distorts the real values of the reduced stress to some extent. However, the use of this computational model is appropriate for determining the comparison of different screw head shapes (observing the trend of comparing the stress magnitudes and plastic deformations). The head of the crew was attached to its outer edge, i.e. outer radius, in all directions, which corresponds to rigid attachment (the screw head is firmly in the plate). For each model, the finite element network was refined in places of expected increase in stress or plastic deformation. The finite element network was made up of 11 type elements (four-point element in the MSC.Marc/Mentat program). All analyses (5 calculations for different screw heads) were set identically. In the screw heads, reduced stress according to the HMH theory (von Mises), equivalent plastic deformation, and dependence of the tightening torque on the angle of the screwdriver twist were examined. Analyses were calculated simply – as 2D (plane strain) tasks.

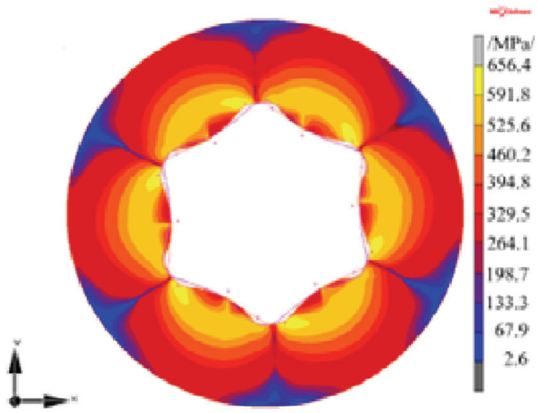

Fig. 5 Reduced stress by HMH (von Mises)

The alloy "asm_Tita 79", which is in the material database of the MSC.Marc/Mentat program, was selected as the material for the screw heads. The alloy has the following mechanical properties: yield strength R_e = 450 MPa, breaking strength R_m = 1000 MPa, modulus of elasticity E = 110 GPa, fatigue strength (10^7 cycles) σ_f = 289 MPa, Brinell hardness HB = 225. Reduced stress maximum values (see Fig. 5) occur at the points of the expected maximum, i.e. at the points of contact (mechanical contact) of the solid body (screwdriver) with the deformable body (screw head).

The results of FEM analysis show that screwing with the screwdriver produces the least tension in the Torx type

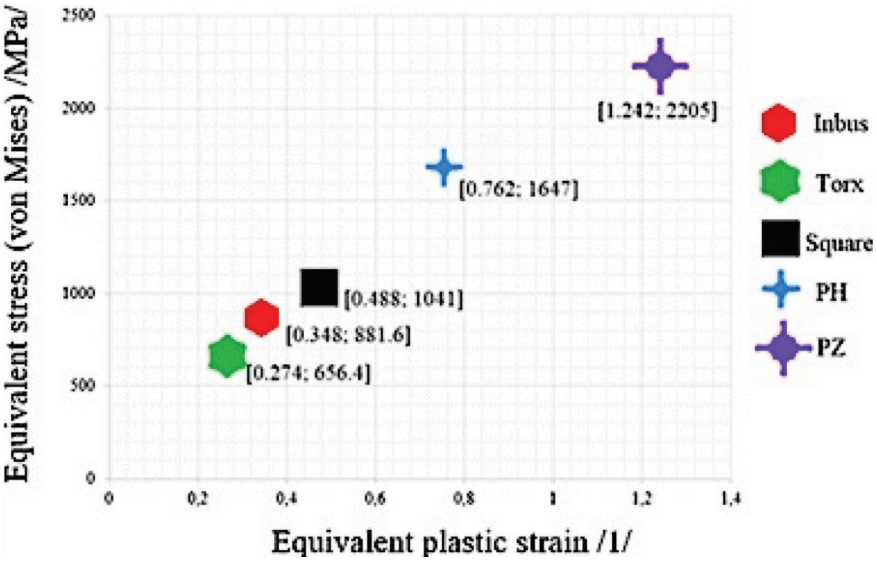

Fig. 6 Comparing the results of the analysis of the screw head shapes alternatives according to the reduced stress in accordance with the HMH theory (von Mises), and according to the equivalent plastic deformation in the screw head

head screw (the tension is lower than in the case of the screw with the Inbus head by about 25.5 %), and the equivalent plastic deformation is the lowest within the screw heads analysed (plastic deformation is lower than in the case of the screw with the Inbus type head by about 21.3 %). The highest stress and plastic deformation occurs when using the screw with the PZ type head. The best choice is therefore to use the screw with the Torx type head (see Fig. 6), which achieves the lowest values of reduced stress as well as the lowest values of plastic deformation.

5. Conclusion

Based on experiments and simulations, the authors of the article recommend to manufacturers of locking cortical bone screws for locking holes of angularly stable plates to use the Torx type heads, not the Inbus type heads, or the Square, PH, PZ type heads.

It is advisable to use conical (self-locking) screwdrivers for bolt insertion; cylindrical (non-self-locking) screwdrivers are suitable for screw extractions. Conical screwdrivers are well suited for inserting the screw due to their self-locking capacity. Cylindrical (non-self-locking) screwdrivers are better suited for screw extraction, as the rounded ending helps to locate the recesses, and insertion in more depth allows maximum torque transfer.

Acknowledgements

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References

Antoszewski, B., Evin, E. and Audy, J. (2008) A study of the effect of type (Cu+Ti) and (Mo+Ti) electro-spark coatings on friction in pin-on-disc testing. *Journal of Tribology,* Vol. 130, No. 1, pp. 26–31.

Čada, R.; Frydrýšek, K.; Sejda, F.; Demel, J. and Pleva, L. (2017) Analysis of Locking Self-Taping Bone Screws for Angularly Stable Plates. *Journal of Medical and Biological Engineering*, 2017, Vol. 37, No. 4, pp. 612–625, DOI: 10.1007/s40846-017-0279-4.

Frydrýšek, K., Pleva, L., Pompach, M., Učeň, O., Fojtik, F., Kubín, T., Theisz, G., Žilka, L. and Poruba, Z. (2014) External and Internal Fixators for Treatment of Complicated Fractures in Traumatology and Orthopaedics. In: *Engineering Mechanics 2014*, Brno University of Technology, Brno, pp. 180–183.

Heller, J. G., Estes, B. T., Zaouali, M. and Diop, A. (1996) Biomechanical study of screws in the lateral masses: variables affecting pull-out resistance. *Journal of Bone and Joint Surgery*, Vol. 78, No. 9, pp. 1315-1321.

Perry, C. R. and Gilula, L. A. (1992) Basic principles and clinical uses of screws and bolts. *Orthopaedic Review*, Vol. 21, No. 6, pp. 709–713.