Acta of Bioengineering and Biomechanics
Vol. 10, No. 3, 2008

Strength of proximal humeral fraction fixation employing implants of various types – a study of porcine bones

MICHAŁ WYCHOWAŃSKI[1],*, MARCIN OBRĘBSKI[2], KAZIMIERZ RĄPAŁA[2],
ANDRZEJ WIT[1], JAN GAJEWSKI[1], KRZYSZTOF MARCZAK[1]

[1] Department of Biomechanics, Faculty of Rehabilitation, Józef Piłsudski Academy of Physical Education, Warszawa, Poland.
[2] Orthopaedic Department, Postgraduate Medical Education Centre, Otwock, Poland.

In this study, the authors assess the strength of proximal humerus fracture fixation using different methods. The strength, while pulling out the chosen single Kirschner wires implanted in porcine bone, has been examined. Tests concerning the strength of fixation with different types of implants have been carried out on prepared models. We observed the maximum strength of the bone–single wire coupling for Kirschner wires of a 2.5 mm diameter with 100 mm thread where mean was 2396 N (SD 345). The mean strength of the 4 wires fracture fixation for Kirschner wires of a 2.5 mm diameter with 100 mm thread was 736 N (SD 229) and was similar to Kirschner wires of a 2.5 mm diameter with 10 mm thread where mean was 709 N (SD 191).

Key words: *proximal humeral fracture, porcine bone, strength fixation, Kirschner wire*

1. Introduction

Proximal humeral fractures account for about 4–5% of all bone fractures. About 80 per cent of proximal humeral fractures can be treated conservatively (BENGNER et al. [1], HORAK and NILSSON [2], LEYSOHN [3], LIND et al. [4]); these are fractures without a displacement of bone fragments or with a small displacement (CORNELL [5], HAWKINS et al. [6], HERSCOVICI et al. [7], KOVAL et al. [8], NEER [9]). Fractures involving displacement still present a considerable surgical challenge because the stable fixation of osteoporotic bone fragments poses a problem, and employing an extensive surgical approach additionally damages the synovial bursa, tendons, and blood supply to the humeral head (BROOKS et al. [10], JABERG et al. [11], MÜNST and KUNER [12], WILLIAMS and WONG [13]).

Post-operation functional ability depends on the chosen methods of surgery and physiotherapy (NICHOLAS and HERSHMAN [14]). Surgery should in general strive to affect the structure of the bone fragments to the smallest possible extent. Proximal humeral fractures are among the most challenging fractures to reduce and stabilize, so as to ensure an optimal mechanical and biological environment for healing [10]–[13]. The strength of the fixation used seems to be the most important criterion in surgical treatment.

Many authors have described original experiments employing various mechanical methods to assess the value of bone fixations. For example, WHEELER and COLVILLE [15] investigated the mechanical strength and durability of intramedullary nailing and percutaneous pinning for the fixation of three-part proximal humeral fractures using a cadaveric model. The purpose of this study was to document and compare the cyclic stability and ultimate number of loading cycles before failure of the intramedullary humeral fixation and standard percutaneous Kirschner wire pinning techniques. AHMAD et al. [16] tested ulnar collateral

---

* Corresponding author: Department of Biomechanics, Faculty of Rehabilitation, Józef Piłsudski Academy of Physical Education, ul. Marymoncka 34, 00-968 Warszawa, Poland, e-mail: m.wychowanski@awf.edu.pl

Received: June 25, 2008
Accepted for publication: November 5, 2008

ligaments reconstructed with interference screw fixation using a tensile testing machine. They obtained 10 sample pairs of elbow specimens from young male human cadavers, measured the load–displacement characteristics of the elbow, determined the maximum load, and calculated the stiffness from the load–displacement curve. BEINGESSNER et al. [17] investigated the effect of radial head fracture size on radiocapitellar stability using a tensile testing machine. They simulated fractures in six fresh-frozen cadaveric radiocapitellar joints and measured the maximum failure load at the radiocapitellar joint using a custom designed jig and employing a compressive joint load.

The rationale for undertaking the present study lies in the fact that stable fixation of osteoporotic bone fragments poses a significant problem in 2- and 3-part fractures of the proximal humerus, and an extensive surgical approach causes damage to the humeral head blood supply. In this paper, special attention is paid to osteosynthesis using a bundle of four Kirschner wires in various modifications, as this is the least invasive osteosynthesis technique, causing the smallest joint destruction during the anatomical reduction and fixation of the bone fragments.

Two following specific objectives were to be achieved:

1. Evaluating primordial stabilization using smooth and threaded Kirschner wires inserted into the proximal part of porcine humeri, which were subsequently pulled out using a tensile testing machine.
2. Checking the fixation strength of joined porcine proximal humeri which were cut to simulate two-part fractures and subsequently fixed with various types of implants. The fixed bones were next torn apart with the same tensile testing machine to examine the strength of the junction.

2. Material and methods

In view of their anatomical similarity to human bones, all the tests were performed on the model of porcine bones on the first day after slaughter, of the same breed and age, of a similar mass.

The first part of the experiment was carried out on 35 anatomic specimens of porcine proximal humeri. Five types of the Kirschner wires were inserted into 35 porcine proximal humeri (each type into 7 bones). After being inserted into the humerus by means of an electric drill, the Kirschner wires were subsequently pulled out using a tensile testing machine. All these strength tests were performed on an FM-500 tensile testing machine, with a force ranging to 5000 N and the first class of precision. The maximum failure forces were determined from the force–displacement characteristics obtained during destructive tests on the specimens. The following types of wires were used in the first part of the experiment:

1. Non-threaded, smooth Kirschner wires, 2.5 mm in diameter (KW Smooth);
2. Kirschner wires, 2.5 mm in diameter with a short 10 mm thread used for the Dynamic Hip Screw and Dynamic Condylar Screw system (KW 10);
3. Kirschner wires of our own design, 2.5 mm in diameter with a 100 mm thread (KW 100);
4. Kirschner wires of our own design, 2.0 mm in diameter with a 100 mm thread (KW 100 Thin);
5. Kirschner wires of our own design, 2.5 mm in diameter with a 50 mm thread – the diameter of the screw inclusive of the thread was 3.5 mm, like for a spongy bone (SBW).

The method employed in implanting the Kirschner wires into the porcine bone is presented in figure 1.

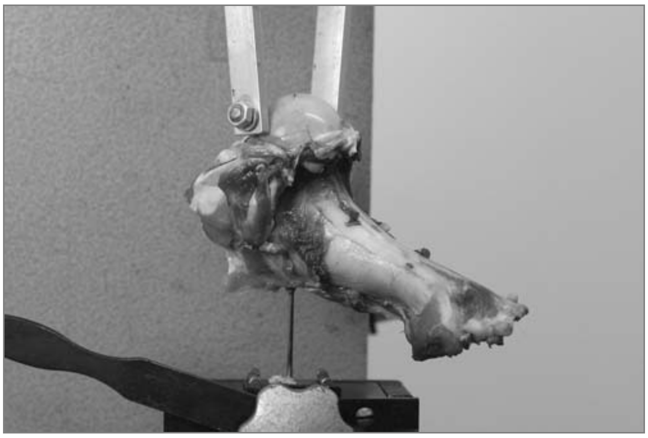

Fig. 1. The single Kirschner wire (KW100) implantation into the porcine bone

The second part of the study focused on testing the stability strength of 66 porcine proximal humeri surgically cut to simulate two-part fractures, subsequently fixed with various methods, and also on determining the force needed to tear the fixation apart using a tensile testing machine. All the bones were prepared in the same way, simulating fractures by cutting the humerus at the surgical neck and the greater tubercle.

In the cases involving the Kirschner wires, 4 such wires were fixed into the bone with an electrical drill. Two of the Kirschner wires were led from the greater tubercle downward and medially, ending in the cortex bone in the middle of the shaft. The two other wires were led from the lateral side of the shaft, up to the surface of the femoral head. The method employed to fix the bone with 4 Kirschner wires is shown in figure 2.

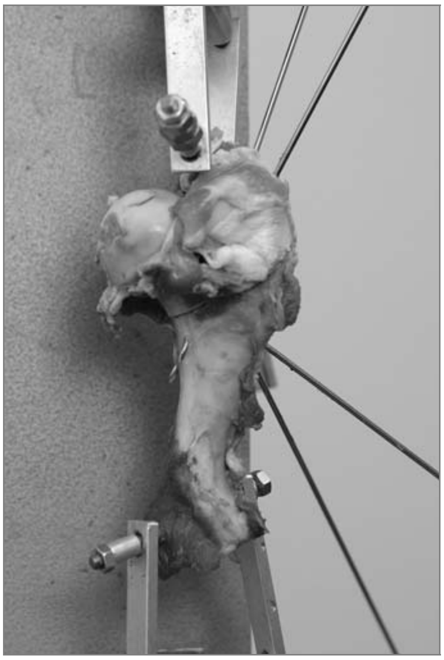

Fig. 2. The bone fixation method with four Kirschner wires (KW100)

We also tested fixations using the Rush nails inserted intramedullarily from the greater tubercle, fixations using the screws and tension band technique, and fixations using only two AO cortical screws. Each type of fixation was tested by tearing the fixed bones apart. All the strength tests took place after the fixed bones were stabilized in special handles (figure 2). The special construction of the handles ensured a certain locking of the bone, stretching the specimen along its long axis only.

Seven types of fixation were examined in the second part of the study: 1. Two AO cortical screws 4.5 mm in diameter and 40 mm in length (SC). 2. KW Smooth. 3. KW 100. 4. KW 10 (these two types of KW wires were tested in the first part). 5. Fixation employing the screws and tension band technique (STBT). 6. Rush nails (RUSH). 7. Wires 2.5 mm in diameter with 100 mm thread incorrectly implanted by performing too many insertions drilled into the bone (KW 100 Incorrect).

Statistical analysis of the data was carried out using the Statistica 7.0 program. Since the variances of the data analyzed were heterogeneous, the Kruskal–Wallis one-way analysis of variance by ranks was employed to test the differences between maximal strengths of various types of fixations. The U-Mann–Whitney test was utilized for two-sample comparisons.

3. Results

Figures 3 and 4 depict two representative force–displacement curves obtained while pulling out wires from the bone (figure 3) and while tearing fixed bones apart (figure 4), respectively.

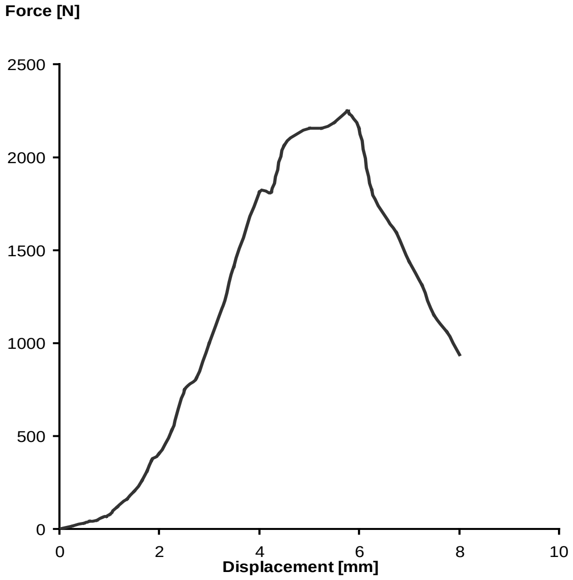

Fig. 3. Force–displacement curve of pulling out the Kirschner wire from the bone (KW100) during the strength test on the tensile testing machine

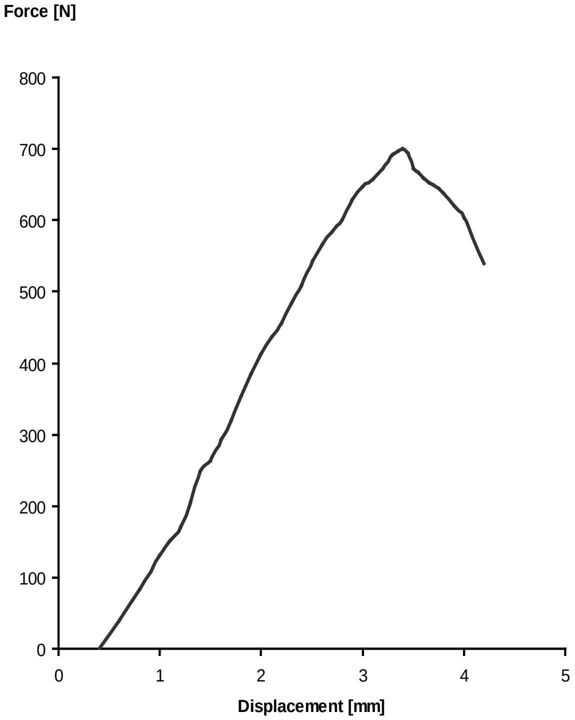

Fig. 4. Force–displacement curve obtained during the fixation strength test of simulated humerus fractures

Table 1. Descriptive statistics of maximum forces [N] of pulling out different types of implants from the bone

	KW Smooth	KW 10	KW 100	KW Thin	SBW
N	7	7	7	7	7
Mean	421	767	2396	529	1843
SD	67	181	345	103	315
Min	357	630	1997	388	1554
Max	522	1122	2883	644	2391

Table 2. Descriptive statistics of fixation strengths [N] of simulated humerus fractures

	SC	KW Smooth	KW-100	KW-10	STBT	RUSH	KW-100 Incorrect
N	7	7	17	9	9	7	10
Mean	254	201	736	709	438	62	157
SD	96	50	229	191	304	15	69
Min	140	153	450	353	127	47	67
Max	393	293	1217	967	1083	80	273

The maximum forces for pulling out different types of single wires from the bone are presented in table 1. A one-way analysis of variance (ANOVA) showed that the mean force sufficient to pull out the wire differed significantly between implant types ($p < 0.001$). The Newman–Keuls post-hoc test was used to compare the individual means, demonstrating that the forces of extraction differed significantly ($p < 0.001$) for each pair of types of wires.

The measurements confirm that the force needed to pull out a threaded Kirschner wire from the bone is greater than that for a smooth wire. Among wires belonging to the threaded group, the greatest extraction forces were required for the wire 2.5 mm in diameter with 100 mm thread (KW 100) and for spongy bone threaded wires (SBW).

The smallest significant difference in strength was seen for fixation performed with smooth wires (KW Smooth). The strength of bone–implant connections performed with short thread wires (KW 10) was more than three times weaker than those done with long thread wires (KW 100).

The mean fixation strengths of simulated humeral fractures for the fixation methods analyzed are shown in table 2. In view of the non-homogeneity of variances, mean strengths were compared using the Kruskal–Wallis ANOVA for ranks.

The analysis revealed significant differences ($p < 0.001$) between the mean forces tearing the fixation apart. The fixations with the 100 mm (KW 100) and 10 mm (KW 10) thread wires showed the greatest strength and did not differ significantly from each other. The 100 mm thread fixation with incorrectly implanted wires (KW 100 Incorrect) showed a significantly lower strength than the KW 100 and KW 10 fixations ($p < 0.001$ for both comparisons). Fixation using KW Smooth wires proved to be more than three times weaker than fixation employing correctly implanted KW 100 wires ($p < 0.001$). Fixation performed with the two AO screws and tension band technique achieved a relatively good stabilization of the bone segments and a relatively high value of SD. The weakest fixation was observed for the Rush nails.

4. Discussion

Primordial stabilization is essential for the success of fracture treatment, and this was the main rationale for testing the mechanical strength of various methods of fracture fixation. In operations of a complex and unrepeatable type, it is difficult to select, based on observation, a surgical method that will ensure better primordial stabilization of osseous fragments. The model similarity between the porcine humerus and the human humerus, and their similarity of weight, size and bone density, enabled the experimental conditions to be met.

Using special models for simulating bone–implant strength tests is a very well known approach. VOOR et al. [18] investigated the stiffness of fixation and tilt angles for different wire types using a fibreglass composite tibia model. VOOR and KHALILY [19], WHEELER and COLVILLE [15], WIDJAJA and HARTUNG [20], and YERBY et al. [21] tested cadaver segments. KAULESAR SUKUL et al. [22] studied scaphoid bone screws commonly used for internal fixation in scaphoid bone fractures, using models made of ash-wood. ROKKANEN et al. [23] reported, using animals in the growth stage for studying, the influence of bioabsorbable wires on bone growth. KOUSA et al. [24] used bovine bones for testing implant fixation properties for several types of bioabsorbable implants.

Many authors have used material-mechanics methods for assessing the fixation strength of primordial bone fractures. A very popular method that is easy to implement involves measuring the maximum force required to disintegrate the specimen. We recorded the maximum force for pulling out KW 100 Kirschner wires from the bone – 2396 N (SD 345), and the maximum force for disintegrating the pinning fixation of proximal humeral fractures using a bundle of 4 Kirschner wires – 736 N (SD 229).

ROHLMANN et al. [25] applied the latest technology for measuring forces and moments acting on implanted fixators in vivo. These authors stressed that upper vertebral tilting in the sagittal plane must have been the cause of the screw breakage. KOUSA at al. [24] tested the properties of several types of bioabsorbable implants. An SR-PLLA screw, 6.3 mm in diameter, was found to be as good as a metal screw in fixing a bone-patellar tendon-bone graft for the anterior cruciate ligament in a bovine experimental model, showing failure forces of 1211 N (SD 362) and 1081 N (SD 331), respectively.

AHMAD et al. [16] tested cadaveric elbows under conditions of an intact, released, and reconstructed ligament. Average stiffness for intact elbows, 42.81 N/mm (SD 11.6), was significantly greater than that for reconstructed elbows, 20.28 N/mm (SD 12.5). The ultimate moment for intact elbows, 34.0 Nm (SD 6.9), was not significantly different from that seen for reconstructed elbows – 30.6 Nm (19.2). Although the load that can be transmitted across the elbow is up to three times the body weight, BEINGESSNER et al. [17] applied a compressive axial radiocapitellar joint load of 100 N because of the risk of fracture of the cadaveric specimens at higher loads. This study demonstrated an inverse relationship between the radiocapitellar joint stability and the radial head fracture.

VOOR and KHALILY [19] applied a cyclic transverse load of ±300 N through the pins for 10,000 sinusoidal cycles in both fully tightened and reduced axial load situations. Load-to-failure testing was also performed to determine the strength and stiffness of each configuration. The failure strength of the experimental pins, 2010 N (SD 366.4), was significantly greater than that of the conventional pins – 1128 N (SD 94.5). VOOR and his colleages [18] also demonstrate "safe" corridors for transfixion wire placement by tilting the wire plane with respect to the bone axis.

WHEELER and COLVILL [15] reported that the intramedullary interlocking nail showed greater stiffness and less angular displacement of fragments during cyclic loading. With the specimen approaching failure, the intramedullary interlocking nail proved to have greater failure torques, stiffness, energy absorbed, and angular displacement before failure. The authors concluded that this biomechanical study showed that for multi-fragment proximal humeral fractures with minimal comminution, the intramedullary nailing device provided a stronger, more stable, and durable fixation option than percutaneous pinning fixation did. The maximum failure force was determined by a destructive test. The specimen began to bend at force magnitudes between 3000 and 3500 N. Afterwards the characteristic force against the displacement line continued to increase proportionally to insertion of the interlocking screw into the femur, between 4500 and 5000 N. Specimens without additional implants failed at approximately 2500 N. At this value the interlocking screws were inserted into the bone of the femur. The additional implant improved the strength of the bone–implant unit. The use of an additional implant is recommended in the case of osteoporotic bone (WIDJAJA and HARTUNG [20]).

In the first part of our study, we measured the maximum forces needed to pull out different types of Kirschner wires from the bone. Based on the results achieved in that part, we expected the best stabilization of fracture fixation to be achieved using long-thread Kirschner wires. We tested the fixation strength of three types of Kirschner wires: 2.5 mm in diameter – smooth, short-thread, and long-thread – as well a few other methods used in the treatment of humeral fractures. We also tested the strength of fixations incorrectly performed by making repeated insertions into the same place with 4 long-thread Kirschner wires. This sometimes occurs in clinical situations, when the surgeon experiences difficulty in supporting the reduction of bone fragments and when the wire was inserted too far into the joint or is in malposition. The construction of the long-thread wires was based on the authors' ideas for improving primordial stabilization. The results concerning the strength of the bond between the single wire and the bone suggested that fixation employing smooth wires had the smallest value; the wires with long thread had the greatest value. It was assumed that increasing the thread contact length would increase the fixation strength, and this was confirmed by the experiments. Nonetheless, the strength of long-thread fixation was not as high as we had expected. The results indicate fixation employing threaded Kirschner wires to be superior to all other fixation types. Fixation with 4 Kirschner wires entered multiplanarly can be viewed as stable; the forces needed to tear the fixation apart are great. At the present stage of the research we can observe that wires 2.5 mm in diameter with 100 mm thread fulfill the conditions of the smallest implant assuring the best primordial stabilization. Using a deep thread, such as for the spongy bone, which we can find in the humeral head, does not increase the force needed to stabilize the implant.

Among many types of fixations (BHANDARI et al. [26], BJÖRKENHEIM et al. [27] and RICKMAN et al. [28]), we decided to test experimentally the stabilization of primordial fixation employing 4 Kirschner wires. These research results seem to be useful for treatment. Such fixation strength measurements are worth recommending for future fixation modelling research of this sort. Small standard deviations testify to the accuracy of this study. It seems warranted to test different implants in the bone. The number of wire insertions performed during implanting may be especially important for fracture stabilization. It would also be reasonable to analyze the costs of different methods of treatment, which depend on the price of the implants. Long-thread Kirschner wires (KW 100) are not costly. The wires used for spongy bones are more technologically complicated and more expensive, yet they are still cheaper than the former methods, especially the intramedullary interlocking nail.

5. Conclusions

In conclusion, this study allowed us to find the greatest force required to pull out a single Kirschner wire from the bone to be noted for wires 2.5 mm in diameter with a 100 mm thread – a type of wire designed by the authors. The smallest force was observed for smooth Kirschner wires. The strength of the bond between a single long-thread wire and the bone is about 6 times greater than that achieved with a smooth one. The strength of the fixation employing a long-thread wire is about 3 times greater than the same fixation employing short-thread wires. The greatest strength to failure of the proximal humerus fixation was observed in the case of a bundle of 4 long-thread Kirschner wires. Fixations performed with 4 short-thread wires presented a lower value, yet they did not differ significantly from the fixation made with long thread wires. Fixations employing the two AO cortical screws and tension band technique were comparably strong; this method of osteosynthesis always requires extensive access during surgery. The lowest strength of fracture fixation was seen for the Rush nails, a method that cannot be recommended for that reason. Among the Kirschner wire methods, the worst strength of fixation was observed for incorrectly implanted wires and smooth wires.

Not all types of the Kirschner wires fixed the proximal humerus fractures sufficiently. However, in operations of an unrepeatable type, the primordial stabilization requires individualized choice of the Kirschner wires, in order to achieve success in fracture fixation.

References

[1] BENGNER U., JOHNELL O., REDLUND-JOHNELL I., *Changes in the incidence of fracture of the upper end of the humerus during a 30-year period. A study of 2125 fractures*, Clin. Orthop. Relat. Res., 1988, 231, 179–182.

[2] HORAK J., NILSSON B.E., *Epidemiology of fracture of the upper end of the humerus*, Clin. Orthop. Relat. Res., 1975, (112), 250–253.

[3] LEYSHON R.L., *Closed treatment of fractures of the proximal humerus*, Acta Orthop. Scan., 1984, 55(1), 48–51.

[4] LIND T., KRONER K., JENSEN J., *The epidemiology of fractures of the proximal humerus*, Arch. Orthop. Trauma Surg., 1989(5), 108, 285–287.

[5] CORNELL C., *Master techniques in orthopaedic surgery, fractures*, Lippincott-Raven Publishers, Philadelphia, 1998.

[6] HAWKINS R.J., BELL R.H., GURR K., *The three-part fractures of the proximal part of the humerus. Operative treatment*, J. Bone Joint Surg. Am., 1986, 68(9), 1410–1414.

[7] HERSCOVICI D.J., SAUNDERS D.T., JOHNSON M.P., SANDERS R., DIPASQUALE T., *Percutaneous fixation of proximal humeral fractures*, Clin. Orthop. Relat. Res., 2000, (375), 97–104.

[8] KOVAL K.J., GALLAGHER M.A., MARSICANO J.G., CUOMO F., MCSHINAWY A., ZUCKERMAN J.D., *Functional outcome after minimally displaced fractures of the proximal part of the humerus*, J. Bone Joint Surg. Am., 1997, 79(2), 203–207.

[9] NEER C.S. 2nd., *Displaced proximal humeral fractures.* I. *Classification and evaluation*, I. Clin. Orthop. Relat. Res., 1987, (223), 3–10.

[10] BROOKS C.W., REVELL W.J., HEATLEY F.W., *Vascularity of the humeral head after proximal humeral fractures. An anatomical cadaver study*, J. Bone Joint Surg. Brit., 1993, 75(1), 132–136.

[11] JABERG H., WARNER J.J., JAKOB R.P., *Percutaneous stabilisation of unstable fractures of the humerus*, J. Bone Joint Surg. Am., 1992, 74(4), 508–515.

[12] MÜNST P., KUNER E.H., *Osteosynthesen bei dislozierten Humeruskopffrakturen*, Orthopäde, 1992, 21(2), 121–130.

[13] WILLIAMS G.R. JR., WONG K., *Two-part and three-part fractures: open reduction and internal fixation versus closed reduction and percutaneous pinning*, Orthop. Clin North Am., 2000, 31(1), 1–21.

[14] NICHOLAS J.M., HERSHMAN E., *The upper extremity in sports medicine*, Mosby-Year Book Inc., 1995.

[15] WHEELER D.L., COLVILLE M.R., *Biomechanical comparison of intramedullary and percutaneous pin fixation for proximal humeral fracture fixation*, J. Orthop. Trauma, 1997, 11(5), 363–367.

[16] AHMAD C.S., LEE T.Q., ELATTRACHE N.S., *Biomechanical evaluation of a new ulnar collateral ligament reconstruction technique with interference screw fixation*, Am. J. Sports Med., 2003, 31(3), 332–337.

[17] BEINGESSNER D.M., DUNNING C.E., BEINGESSNER C.J., JOHNSON J.A., KING G.J., *The effect of radial head fracture*

size on radiocapitellar joint stability, Clin. Biomech., 2003, 18(7), 677–681.

[18] VOOR M., ANTOCI V., ANTOCI V. JR., ROBERTS C.S. *The effect of wire plane tilt and olive wires on proximal tibia fracture fragment stability and fracture site motion*, J. Biomech., 2005, 38(3), 537–541.

[19] VOOR M.J., KHALILY C., *Halo pin loosening: a biomechanical comparison of experimental and conventional designs*, J. Biomech., 1998, 31(4), 397–400.

[20] WIDJAJA W., HARTUNG C., *Biomechanical comparison of different fixations of femur-interlocking-nails*, Clin. Biomech., Avon, Bristol, 2001, 16(8), 702–705.

[21] YERBY S.A., EHTESHAMI J.R., MCLAIN R.F., *Loading of pedicle screws within the vertebra*, J. Biomech., 1997, 30(9), 951–954.

[22] KAULESAR SUKUL D.M., JOHANNES E.J., MARTI R.K., KLOPPER P.J., *Biomechanical measurements on scaphoid bone screws in an experimental model*, J. Biomech., 1998, 23(11), 1115–1121.

[23] ROKKANEN P.U., BÖSTMAN O., HIRVENSALO E., MÄKELÄ E.A., PARTIO E.K., PÄTIÄLÄ H., VAINIONPÄÄ S.I., VIHTONEN K., TÖRMÄLÄ P., *Bioabsorbable fixation in orthopedic surgery and traumatology*, Biomaterials, 2000, 21(4), 2607–2613.

[24] KOUSA P., JÄRVINEN T.L., POHJONEN T., KANNUS P., KOTIKOSKI M., JÄRVINEN M., *Fixation strength of bidegradable screw in anterior cruciate ligament reconstruction*, J Bone Joint Surg. Br., 1995, 77(6), 901–905.

[25] ROHLMANN A., BERGMANN G., GRAICHEN F., MAYER H.M., *Placing a bone graft more posteriorly may reduce the risk of pedicle screw breakage: analysis of an unexpected case of pedicle screw breakage*, J. Biomech., 1998, 31(8), 763–767.

[26] BHANDARI M., DEVEREAUX P.J., MCKEE M.D., SCHEMITSCH E.H., *Compression plating versus intermedullary nailing of humeral shaft fractures – a meta-analysis*, Act. Orthop., 2006, 77(2), 279–284.

[27] BJÖRKENHEIM J-M., PAJARINEN J., SAVOLAINEN V., *Internal fixation of proximal humeral fractures with a locking compression plate*, Act. Orthop. Scand., 2004, 75(6), 741–745.

[28] RICKMAN M., SALEH M., YANG L., *Tensioning technique and fixator stability of a circular external fixator with threaded fine wires*, J. Biomech., 2006, 39(3), 544–550.