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Experimental study of osteosynthesis stability of the distal part of the humerus

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Unresolved issue is improving of the osteosynthesis of extra-articular fractures of the distal humerus. Search for a simplified method of biological fixation, which assumes, with low trauma, to ensure the stable fixation of fragments and movements in the elbow joint in the early postoperative period. Objective. To carry out a comparative analysis of the bone fragments displacement of the distal humerus in extra-articular fractures, stabilized by extraosseous and transosseous osteosynthesis. Methods. Biomechanical study of the distal humerus model was made. Transosseous osteosynthesis was modeled using the author's external fixation apparatus (EFA). For comparison, we chose an osteosynthesis with a Y-shaped plate. The humeral models were loaded with an interval and a stepwise increased in the load for compression along the axis, flexion in a parallel plane, as well as perpendicular to the fixing elements of the plate and EFA. The magnitude of the load gradually increased from 0 to 250 N with a step of 50 N. The magnitude of the forces at which, due to the action of various loads, a displacement at the level of the fracture appeared. Results. The analysis of experimental studies showed that the rod apparatus and the plate provide the same stability of fixation of the fragments of the humerus under conditions of axial compression load ($p > 0.05$). Under the influence of bending loads of more than 100 N in a plane parallel to the fixing elements, the plate had a slight advantage (10 %). A significantly better result ($p < 0.01$) was obtained when an external device was used under the action of bending loads in a plane perpendicular to the fixing elements. Conclusions. In the case of fractures of the distal humerus, the transosseous osteosynthesis using the proposed external fixation rod device ensures the stability of the fragments under all loading options. It is quite reliable and can be recommended for use in clinical practice. Key words. Distal humerus, transosseous osteosynthesis, external osteosynthesis, full-scale biomechanical studies.

Предметом невирішених питань удосконалення остеосинтезу позасуглобових переломів дистального відділу плечової кістки є пошук спрощеної методики біологічної фіксації, що передбачає за малої травматичності забезпечення стабілізації відламків кісток і рухів у ліктьовому суглобі в ранньому післяопераційному періоді. Мета. Провести порівняльний аналіз залежності величини зміщення фрагментів у дистальному відділі плечової кістки за умов позасуглобових переломів, стабілізованих за допомогою накісткового та черезкісткового остеосинтезу. Методи. Проведено стендове біомеханічне дослідження стану моделі дистального відділу плечової кістки. Моделювали черезкістковий остеосинтез із використанням авторського апарата зовнішньої фіксації (АЗФ). Для порівняння вибрали накістковий остеосинтез Y-подібною пластиною. Моделі плечової кістки навантажували з інтервалом і ступінчастим збільшенням навантаження на стиск по осі, згинання в площині, що проходить паралельно, а також перпендикулярно фіксувальним елементам пластини й АЗФ. Величину навантаження поступово збільшували від 0 до 250 Н із кроком 50 Н. Фіксували величину сил, за яких унаслідок дії різних навантажень з'являлося зміщення на рівні перелому. Результати. Аналіз експериментальних досліджень показав, що стрижневий апарат і пластина забезпечують однакову стабільність фіксації відламків плечової кістки за умов осьового навантаження на стиск ($p > 0,05$). Під впливом згинальних навантажень понад 100 Н у площині, паралельній фіксувальним елементам, незначну перевагу (10 %) має пластина. Суттєво кращий результат ($p < 0,01$) отримано в разі застосування зовнішнього пристрою під дією згинальних навантажень у площині, перпендикулярній фіксувальним елементам. Висновки. У випадку переломів дистального відділу плечової кістки черезкістковий остеосинтез запропонованим стрижневим апаратом зовнішньої фіксації забезпечує стабільність відламків за всіх варіантів навантаження. Він є досить надійним і може бути рекомендованим до використання в клінічній практиці. Ключові слова. Дистальний відділ плечової кістки, черезкістковий остеосинтез, накістковий остеосинтез, натурні біомеханічні дослідження.

Key words. Distal humerus, transosseous osteosynthesis, external osteosynthesis, full-scale biomechanical studies

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Introduction

The most severe injuries of the upper extremity in adults include fractures of the bones that form the elbow joint [1]. Among them, the lower end of the humerus has a special anatomical shape, causing a wide variety of injuries in this area. Proponents of the AO/ASIF system recommend surgical treatment of humeral fractures, namely open repositioning and internal fixation [2, 3]. Due to the complex configuration and biomechanics of the elbow joint (physiological flexion and flattening in the suprascapular area with the presence of the ulnar fossa, the proximity of the nerve trunks), repositioning of fragments and their osteosynthesis is a rather difficult process. Specialists are forced to use small, but comparable in size fragments of the device during osteosynthesis of the distal end of the humerus, which should provide rigidity of fixation and the ability to move the elbow joint in the early postoperative period. Most prefer active surgical tactics, which involve the use of various LCP-plates, needles, screws and wire [4]. Under these conditions, the uncertainty of specialists about the sufficient rigidity of fixation of bone fragments determines the duration of immobilization, and during the restoration of movements in the elbow joint forces to use the safest amplitude, which leads to various complications [5].

Today, the dominance of AO/ASIF technologies does not mean that it is necessary to exclude from clinical practice and forget the domestic technology of extracellular fixation, which has no alternative in the treatment of open and gunshot fractures [6]. The rapid development and implementation of transosseous osteosynthesis (TOO) of the distal humerus on the basis of rods have shown the benefits of minimally invasive surgery [7, 8]. However, in modern literature we have not found full-scale experimental studies that analyze the stability of osteosynthesis of the humerus in extra-articular fractures of its distal part.

The aim of the study: to conduct a comparative analysis of the dependence of the amount of displacement of fragments in the distal part of the humerus in extra-articular fractures, stabilized by bone and transosseous osteosynthesis.

Material and methods

Experimental studies of the stability of fixation of fragments in the case of fractures of the distal humerus using an external device of the author's design [9] and bone reconstructive plate were conducted in the laboratory of biomechanics of the State Institution «Professor M. I. Sytenko Institute of Abnormalities of the Spine and Joints of the National Academy of Medical Sciences of Ukraine».

The object of comparative research was the models of the human left humerus, made of plastic, the mechanical characteristics of which are close to the properties of bone tissue. In the distal humerus with a circular saw, respectively, fractures were simulated with a fracture line distal to their body without touching the articular part of the condyle, which corresponded to the type of fractures 12A1-3 according to the AO/OTA classification. Full-scale models of fractures were divided into two groups, in each of which bone fragments were fixed by transosseous and extra-cortical osteosynthesis.

The first group involved consideration of the model of external fixation device (EFD), which due to mechanics belongs to complex spatial systems and is a structure consisting of a set of thick-walled arc plates (width 16 mm; thickness 3 mm) with uniform holes 8 mm in diameter, screw studs with a diameter of 6 mm, threaded connections and 4 rod clamps, with 6 × 100 mm threaded rods in the holes with mechanical properties of titanium alloy VT-16.

The second group involved a Y-shaped reconstructive plate consisting of 12 holes, 2 mm thick, 110 mm long, fixed with 2.5 mm diameter screws with mechanical properties of titanium alloy Ti6Al4V (Fig. 1, a, b).

Experimental studies were performed on a stand for biomechanical studies using different types of load on the distal fragment of the humerus in each group (Fig. 2).

Models of the humerus were loaded with an interval and stepwise increase in the load on compression along

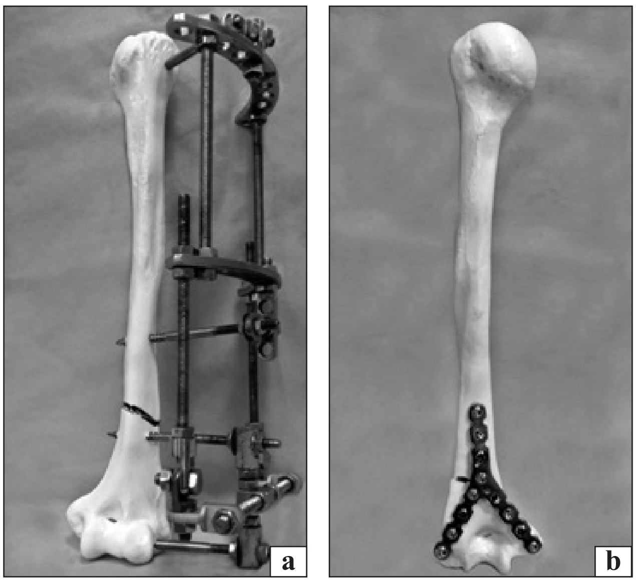

Fig. 1. General view of the objects under study: a) rod apparatus; b) Y-shaped plate

the axis, bending in a plane running parallel, as well as perpendicular to the fixing elements of the plate and the EFD. The magnitude of the load was gradually increased from 0 to 250 N in steps of 50 N. Load control was performed using a strain gauge SBA-100 L and a recording device type CAS CI-2001A. At a certain interval of the load step, the amount of displacement of the fragments in the diastasis zone was measured using a clock-type micrometer. Three series of studies in each loading mode were employed. Bone fragments and elements of osteosynthesis were analyzed. The magnitude of the forces at which the displacement and deformation at the fracture level visually appeared due to the action of different loads. Load diagrams are shown (Fig. 3) on the example of the model of transosseous osteosynthesis of the humerus by the rod EFD.

The results of experimental studies were statistically processed. The mean (M), standard deviation (SD), minimum (min) and maximum (max) values of the samples were calculated. Comparisons of the considered constructions were performed using the T-test for independent samples. The level of critical significance was considered $p < 0.05$. The processing of the obtained indicators was performed in the application package IBM SPSS Statistics 20.0.

Results and discussion

The first stage of the tests was the compression load along the vertical axis of the prepared models of the humerus. The indicators obtained during the experiment are given in Table 1.

The results of experimental tests showed that the EFD and the bone plate provided almost the same stability of the fixation of the fragments of the humerus under conditions of vertical axial compression load. This is evidenced by the indicators of statistical significance of the difference between the two variants of osteosynthesis, recorded during the experiment ($p > 0.05$). It is possible to visually compare the values of the removal of fragments of the humerus from the value of the vertical axial compressive load using the graph (Fig. 4).

The second stage of testing osteosynthesis models of the humerus determined the effect of loads on the bend. The results of the load on the distal fragment in the plane, which fixed the plate in parallel with screws or rods of the ACP, are given in Table 2.

The study showed that the plate better stabilized bone fragments. Under load conditions of 150 N and

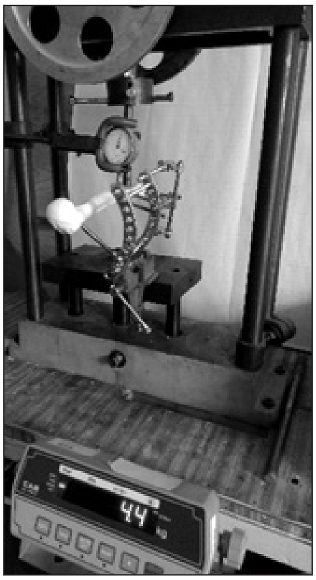

Fig. 2. View of the stand and the model prepared for the experiment

Table 1

Dependence of the amount of displacement of the fragments of the humerus under the influence of vertical axial compression load

Axial load, N	Parameter	Displacement, mm		T-testт
		EFD	plate	
50	M ± SD min ÷ max	0.45 ± 0.06 0.40 ÷ 0.52	0.42 ± 0.07 0.38 ÷ 0.50	t = 0.497 p = 0.645
100	M ± SD min ÷ max	0.98 ± 0.09 0.88 ÷ 1.05	0.91 ± 0.13 0.76 ÷ 1.01	t = 0.763 p = 0.488
150	M ± SD min ÷ max	1.78 ± 0.10 1.69 ÷ 1.88	1.48 ± 0.02 1.47 ÷ 1.50	t = 5.133 p = 0.017
200	M ± SD min ÷ max	2.55 ± 0.58 1.96 ÷ 3.13	2.42 ± 0.09 2.33 ÷ 2.51	t = 0.382 p = 0.722
250	M ± SD min ÷ max	3.58 ± 0.22 3.45 ÷ 3.84	3.80 ± 0.18 3.60 ÷ 3.96	t = –1.318 p = 0.258

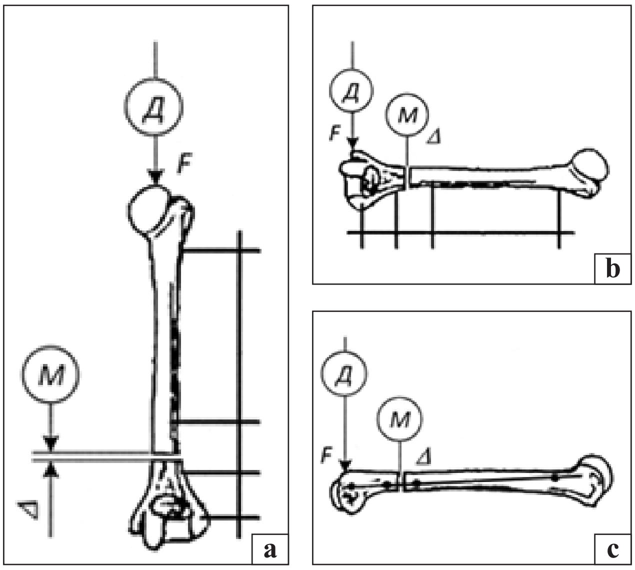

Fig. 3. Schematic representation of the experiment: a) vertical load on the axis of the humerus (compression); b) load on the distal fragment parallel to the rods (bend); c) load on the distal fragment perpendicular to the rods (bend). F — load; Δ — deformation; Д — dynamometer; M — micrometer

Table 2

Dependence of the amount of displacement of the fragments of the humerus on the effect of the load on the bend parallel to the fixing elements

Axial load, N	Parameter	Displacement, mm		T-test
		EFD	plate	
50	M ± SD min ÷ max	1.41 ± 0.10 1.34 ÷ 1.52	1.58 ± 0.12 1.49 ÷ 1.72	t = –1.935 p = 0.125
100	M ± SD min ÷ max	2.79 ± 0.34 2.44 ÷ 3.12	3.33 ± 0.21 3.09 ÷ 3.48	t = –2.314 p = 0.082
150	M ± SD min ÷ max	3.49 ± 0.11 3.37 ÷ 3.56	4.54 ± 0.14 4.39 ÷ 4.67	t = –9.992 p = 0.001
200	M ± SD min ÷ max	4.69 ± 0.37 4.43 ÷5.11	5.75 ± 0.25 5.47 ÷ 5.97	t = –4.099 p = 0.015
250	M ± SD min ÷ max	6.02 ± 0.10 5.92 ÷ 6.12	7.10 ± 0.14 6.99 ÷ 7.26	t = –10.947 p = 0.001

Table 3

Dependence of the amount of displacement of the fragments of the humerus on the effect of the load on the bend perpendicular to the fixing elements

Axial load, N	Parameter	Displacement, mm		T-test
		EFD	plate	
50	M ± SD min ÷ max	0.26 ± 0.06 1.21 ÷ 1.32	0.78 ± 0.13 0.65 ÷ 0.92	t = 5.673 p = 0.005
100	M ± SD min ÷ max	3.09 ± 0.09 2.99 ÷ 3.15	1.61 ± 0.46 1.20 ÷ 2.11	t = 5.500 p = 0.005
150	M ± SD min ÷ max	3.53 ± 0.31 3.31 ÷ 3.89	2.52 ± 0.20 2.33 ÷ 2.72	t = 4.725 p = 0.009
200	M ± SD min ÷ max	5.13 ± 0.18 4.94 ÷ 5.31	3.67 ± 0.49 3.11 ÷ 4.04	t = 4.848 p = 0.008
250	M ± SD min ÷ max	6.11 ± 0.13 6.00 ÷ 6.25	4.81 ± 0.10 4.70 ÷ 4.89	t = 14.237 p = 0.001

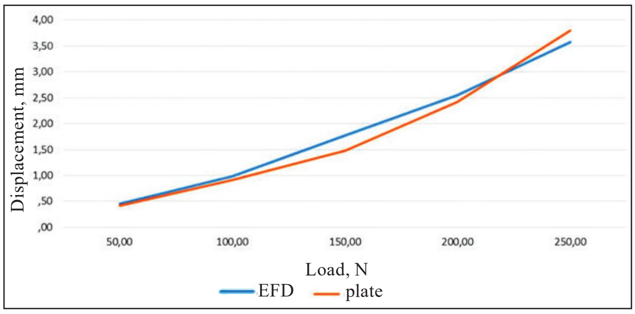

Fig. 4. Graph of the dependence of the amount of displacement of the fragments of the humerus from the vertical axial compressive load

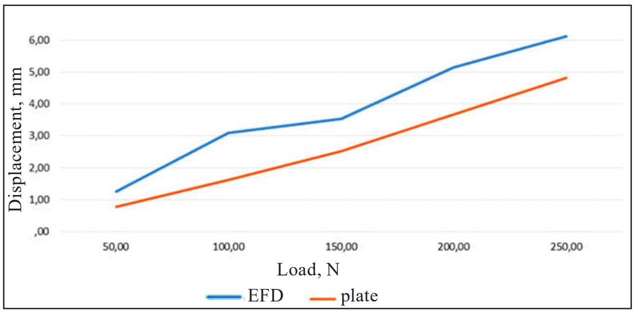

Fig. 6. Graph of the dependence of the amount of displacement of the fragments of the humerus from the load on the bend perpendicular to the fixing elements

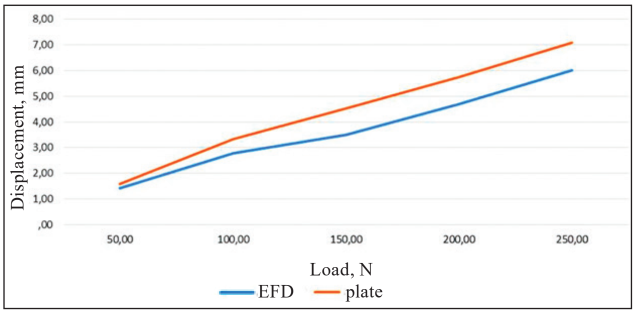

Fig. 5. Graph of the dependence of the magnitude of the displacement of the fragments of the humerus from the load on the bend parallel to the fixing elements

above, the difference in the values of the displacement of the fragments became statistically significant ($p < 0.05$). At loads of 50 N and 100 N, no statistically significant difference was found between the models of EFD and the plate. The dependence of the displacement of the distal fragment of the humerus on the amount of bending load in the plane parallel to the screws fixing the plate or the rods of the EFD is shown in the graph (Fig. 5).

At the end of the experiment, the models were tested for bending under the action of a load on the distal fragment in a plane perpendicular to the fixing rods of the EFD or the screws of the plate. The results of studies after statistical processing are given in Table 3.

The mean values of the load showed that the model of the humerus with extra-articular fracture of the distal part in the rod EFD was much better able to resist bending loads acting in the plane perpendicular to the rods between the screws fixing the bone plate. Indicators of statistical significance of the difference in the values of the displacement of the fragments of the humerus during exercise did not exceed $p < 0.01$. The graph clearly shows the dependence of the magnitude of the displacement of the fragments of the humerus on the magnitude of the flexion load (Fig. 6).

Conclusions

The results of experimental studies have shown that the proprietary rod EFD and bone plate provide almost the same stability of fixation of fragments of the humerus model in the case of extra-articular fractures of its distal part.

The bone plate and the EFD also provide the same stability of the fragments under the influence of bending loads up to 100 N, acting in a plane parallel to the fixing screws of the plate or the rods of the EFD. For loads exceeding these values, the bone plate has a slight advantage (up to 10%), due to its rigidity and the presence of direct contact with the bone.

A significant advantage (p <0.01) of EFD was found in the case of loading the models in the plane perpendicular to the fixing screws of the plate or the rods of the EFD. In this case the advantage of rigidity of fixing of rods before screws plays a crucial role.

In the case of fractures of the distal humerus, transosseous osteosynthesis of the proposed rod EFD provides stability of the fragments under all load options, so it is quite reliable in use and can be recommended for clinical practice.

Conflict of interest. The authors declare no conflict of interest.

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EXPERIMENTAL STUDY OF OSTEOSYNTHESIS STABILITY OF THE DISTAL PART OF THE HUMERUS

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