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Total elbow arthroplasty due to injuries

V.A. Kalantyrskaya[1,3]✉, I.O. Golubev[2], A.Yu. Zarov[1], K.A. Egiazaryan[3]

[1] Autonomous non-profit organization Central Clinical Hospital of St. Alexy Metropolitan of the Moscow, Moscow Diocese of the Russian Orthodox Church, Moscow, Russian Federation
[2] N.N. Priorov National Medical Research Center of Traumatology and Orthopaedics, Moscow, Russian Federation
[3] Pirogov Russian National Research Medical University, Moscow, Russian Federation

Corresponding author: Valentina A. Kalantyrskaya, kalan.v@mail.ru

Abstract

The **aim** of the study was to identify the features of total elbow arthroplasty in traumatic cases and their consequences in patients of different age groups and to conduct a comparative retrospective analysis of differentiated treatment tactics. **Materials and Methods** A retrospective analysis of the results of total elbow arthroplasty (TEA) in the period from 2009 to 2019 was carried out in 101 patients with injuries and severe consequences of elbow joint injuries, 56 (55.4 %) men and 45 (44.5 %) women among them in the average age of 48.5 ± 12.5 years. Three groups of patients were formed. Group I were 29 (28.7 %) subjects who underwent conservative treatment of fractures before TEA; the second group (II) of 52 (51.5 %) patients underwent TEA after ORIF, the third group of 20 (19.8) individuals (III) were patients who had primary TEA. We investigated pain (VAS), range of motion, tests with the DASH and MEPS scales, hand strength. **Results** One year later, there was a statistical difference in the results (p = 0.0213) between group III DASH = 7.3 ± 2.1) compared with groups I (DASH = 20.6 ± 3.3) and II (DASH = 18.4 ± 4.2); in group III, MEPS was excellent (90.7 ± 8.4), and in groups I (MEPS = 83.8 ± 7.4) and II (MEPS = 84.2 ± 5.6) good (p = 0. 0344). There were no differences in the dynamometry of hand strength and pain. **Discussion** Treatment of fractures of the elbow joint is a challenge that has several aspects. Conservative treatment results in high incidence of pronounced contractures, which affect the range of motion in the elbow joint after TEA; in severe damage to bone and cartilage, it is necessary to evaluate many factors in order to make the right choice between ORIF and primary TEA. New prosthetic technologies are needed to ensure good long-term functioning of the elbow prosthesis, especially in young patients. **Conclusion** To choose the treatment tactics in severe injuries of the elbow joint, it is necessary to consider not only the severity of the injury, but also the age of the patient and the quality of the bone, especially in elderly patients. Rejection to perform osteosynthesis in favor of primary total arthroplasty is aimed at maintaining the range of motion, improving the functional results and survival of the endoprosthesis.

Keywords: injuries of the elbow, primary total elbow arthroplasty

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INTRODUCTION

Total elbow arthroplasty (TEA) is an effective surgical intervention that provides restoration of the range of motion in the elbow joint (EJ), the strength and function of the upper limb, and relieves pain [1]. Injuries and fractures of the bones that form the EJ take the second place in terms of arthroplasty between the leader, rheumatoid arthritis, and primary osteoarthritis. Indications for TEA are the so-called "non-fixable" intra-articular comminuted fractures of the distal humerus and proximal forearm bones, osteoarthritis (OA) and post-traumatic arthritis [2–10].

If the issue of treating fractures of the distal humerus and proximal forearm in elderly patients has been practically resolved, and TEA has been chosen to manage them by an increasing number of surgeons [5, 7–9, 11–13], the question regarding TEA in young patients remains open, since as there are not enough works on the analysis of its long-term results [14, 15].

Rajaee et al. (2016) compared the results of TEA with open reduction and internal fixation (ORIF) using data from the National Inpatient Registry in 2002–2012 with previously published results from the study of McKee M.D. et al. (2009). This comparative analysis showed that the frequency of TEA in elderly patients with fractures of the distal humerus, not amenable with stable fixation, increased by 2.6 times, and according to the functional results, TEA is more preferable than ORIF [9, 16].

Barco et al. (2017) reported that the mean visual analog scale (VAS) score for pain was 0.6; the average flexion was 123° and the average loss of extension was 24°. The mean MEPS score was 90.5. However, there are no clear data on the functional outcomes and survival of elbow endoprostheses in young patients [17].

Many authors have shown that severe post-traumatic osteoarthritis may be managed with TEA but the functional results are much worse than in rheumatoid arthritis and primary arthroplasty for fractures [9, 18–22]. The surgery was much more complicated and traumatic if patients with osteoarthritis after osteosynthesis (plus removal of metal fixators) had rough scars and contracture of the elbow joint while the results of arthroplasty deteriorated significantly and were accompanied by severe limitations in the range of motion due to soft tissue contraction [23]. The results were even worse in patients who experienced inflammatory arthritis during fracture treatment [24, 25].

Earlier data published by Hildebrand KA et al. (2000) confirm the worse functional outcomes of TEA

in the group of patients with inflammatory arthritis (MEPS = 78 ± 18 points) than in the group with traumatic or post-traumatic osteoarthritis ((MEPS = 90 ± 11 points) [26]. Nevertheless, Celli A and Morrey BF (2009) reported a series of 55 TEA performed in patients aged younger than 40 years with a mean follow-up of 7.5 years, among which 36 patients (65 %) had an "excellent" outcome and 15 (27 %) had a "good" outcome. [27]. Park JG et al. (2015) reported a series of 23 TEA (patients younger than 40 years old, mean follow-up period 10 years) and also showed favorable outcomes, but 25 % of cases developed complications that required revision surgery [28].

In the domestic literature, we did not find studies on this topic, with the exception of the results of a single-center study where the comparison group was resection arthroplasty, and works devoted to microsurgical soft tissue plasty in elbow joint arthroplasty and the problem of treating gunshot wounds of the elbow joint [29, 30, 31].

Given the relevance of the problem and the inconsistency of the literature data, we set the goal to reveal the features of total elbow arthroplasty performed for injuries and their consequences in patients of different age groups and to conduct a comparative retrospective analysis of differentiated treatment tactics.

MATERIALS AND METHODS

The retrospective analysis of the outcomes of TEA was conducted in 101 patients treated from 2009 through 2019 for severe injuries and their consequences such as posttraumatic deformities, contractures and osteoarthrosis of the elbow joint. During the total period of the study, 1653 patients with trauma in the area of the elbow joint were treated inpatiently at our hospital, and TEA was performed in 6.11 % of those cases.

TEA was performed in 56 males (55.4 %) and 45 females (44.6 %), among whom 79 patients were of working age (78.2 %) from 18 to 65 years that led active lifestyle; 22 patients were older than 65 (21.8 %). Mean age was 48.5 ± 12.5 (range, 23–76 years). Patients' gender and age is shown in Table 1.

Among 101 patients, closed trauma in the elbow joint area was in 53 (52.5 %) and open injuries in 48 (47.5 %). Fractures of the distal humerus were diagnosed in 51 (50.5 %), proximal forearm bones in 33 (32.7 %) patients and associated fractures in the area of the elbow joint (distal metaphysis of the humerus and proximal metaphysis of the forearm bones) in 17 patients (16.8 %).

Injuries were caused by traffic accidents in 46.6 %, catatrauma in 32.7 %, gunshot wounds in 10.8 % and household accidents in 9.9 %. Closed fractures were only AO type B and C, open fractures were Gustilo and Anderson (1976) types I–II–IIIA in 40 patients (39.6 %). Six patients (5.9 %) had type IIIB and 2 cases were type IIIC. Those patients had urgent revascularization interventions for brachial artery shunting (autologous vein) without severe ischemic consequences. Irreversible injuries to the forearm and hand due to ischemia and nerve damage were considered a contraindication to TEA. Types of injuries are presented in Table 2.

Table 1

Patients' age and gender

Age, years	Number of patients				Total	
	Males		Females		Number	%
	Number	%	Number	%		
18–45	33	32.7	22	21.8	55	54.5
46–65	13	12.8	11	10.8	24	23.7
66–75	10	9.9	8	7.9	18	17.8
older than 75	–	–	4	4.0	4	4.0
Total	56	55.4	45	44.6	101	100

Table 2

Distribution of patients according to the nature of injuries

Mechanism of trauma	Closed fractures (AO)						Open trauma (Gustilo and Anderson)						Total	
	Distal humerus		Proximal forearm		Distal humerus and proximal forearm		Distal humerus		Proximal forearm		Distal humerus and proximal forearm			
	number	%	number	%	number	%	number	%	number	%	number	%	number	%
Road accident	12	11.9	8	7.9	3	3.0	16	15.9	4	4.0	4	3.9	47	46.6
Catatrauma	7	6.9	9	8.9	4	4.0	4	4.0	7	6.9	2	2.0	33	32.7
Gunshot injury	–	–	–	–	–	–	6	5.9	2	2.0	3	2.9	11	10.8
Household accident	6	5.9	3	3.0	1	1.0	–	–	–	–	–	–	10	9.9
Total	25	24.7	20	19.8	8	7.9	26	25.8	13	12.9	9	8.9	101	100

Plaster immobilization was used for elbow joint undisplaced fractures in 28.7 % cases. Open reduction and plating was used in displaced fractures in 29 patients (28.7 %). Primary TEA was performed in 20 patients over 60 years of age in closed intaarticular fractures of the elbow joint, severe cartilage damage and pronounced osteoporosis (19.8 %). In open fractures in the elbow joint region with displaced fragments, extrafocal external fixation was used in 16 cases (15.8 %), and 10 patients (9.9 %) had combined osteosynthesis: first extrafocal external fixation followed by open reduction and plating upon wound healing. Insecondary open fractures and undisplaced open fractures in 22 cases (21.7 %), surgical debridement and plaster immobilization were used. Osteosynthesis was performed in closed fractures after a mean of 3.2 ± 1.4 days (range, 1 to 6 days); in open fractures the external fixator was placed after surgical debridement of the wound, and combined osteosynthesis after 19.6 ± 5.3 days (range, 12 to 26 days). Distribution of patients according to treatment methods is presented in Table 3.

Indications to TEA after trauma were:

1) contractures associated with severe pain and upper limb functional disorders;

2) flail joint in aseptic necrosis and defects in the bones of the elbow joint;

3) deformities in the distal humeral metaepiphysis and proximal metaepiphysis of the forearm bones due to malunion or articular surface damage.

The study was approved by the ethics board (protocol # 3266 from 24.05.2011). All patients signed informed consents to the intervention, anesthesia and publications of their anonymous data.

There three groups of studied patients: group I of 29 patients (28.7 %) who were treated conservatively before the intervention; group II of 52 patients (51.5 %) who had TEA after surgical management of their elbow joint injuries; and group III of 20 patients (19.8 %) who underwent primary TEA. Their demographic data are given in Table 4.

Table 3

Distribution of patients according to the method of fracture fixation

Method of fracture fixation	Closed fractures (AO)						Open trauma (Gustilo and Anderson)						Total	
	Distal humerus		Proximal forearm		Distal humerus and proximal forearm		Distal humerus		Proximal forearm		Distal humerus and proximal forearm			
	number	%	number	%	number	%	number	%	number	%	number	%	number	%
Conservative (plaster cast)	4	3.9	3	3.0	–	–	16	15.8	3	3.0	3	3.0	29	28.7
Osteosynthesis (plating)	15	14.9	10	9.9	4	3.9	–	–	–	–	–	–	29	28.7
Osteosynthesis (extrafocal)	–	–	–	–	–	–	6	5.9	5	4.9	5	4.9	16	15.8
Combined osteosynthesis*	–	–	–	–	–	–	3	3.0	3	3.0	1	1.0	7	7.0
Primary TEA	6	5.9	7	6.9	4	3.9	1	0.9	2	2.0	–	–	20	19.8
Total	25	24.7	20	19.8	8	7.9	26	25.8	13	12.9	9	8.9	101	100

* – combined osteosynthesis: external fixation followed by plating upon wound healing

Table 4

Patients' demographic data

Demographic parameters		Group			P value
		I	II	III	
Number, n (%)		29 (28.7)	52 (51.5)	20 (19.8)	0.572
Age,* (years)		52.3 ± 3.2	46.0 ± 1.9	68.2 ± 1.3	0.0098
BMI* (kg/m^2)		32.9 ± 2.5	31.8 ± 1.2	34.2 ± 1.1	0.512
Gender$^{\#}$: males/females		15/14	33/19	8/12	0.977
AO$^{\#}$	A (n^1 = 30)**	18	12	0	0.0862
	B (n^1/n^2 = 43/5)	11	27/3	5/2	
	C (n^1/n^2 = 28/12)	0	13/3	15/9	
ASA$^{\#}$ (n/%)	I	14/13.9	34/33.7	0/0	0.0094
	II	13/12.9	8/7.9	1/0.9	
	III	2/1.9	10/9.8	19/18.8	
Time from injury to TEA (months)***		19.9 ± 2.1	29.0 ± 1.4	1.9 ± 1.7	0.00634

BMI – body mass index, ASA – American Society of Anesthesiologists (scale); * – analyzed by one-way ANOVA analysis of variance; ** – values in parentheses: n^1 – number of patients with fractures according to the AO classification; n^2 – number of patients with associated fractures, while in the presence of type B and C fractures the patient belonged to the group of a more severe type C fracture; $^{\#}$ – analyzed using Pearson's chi-square or Fisher's exact test; *** – in the third group in days after the injury

The number of patients in the groups was different. The group with a history of osteosyntheis was most numerous; there was a significant difference in the age between the first two groups. However, other parameters enable to compare the groups.

In the postoperative period, the rehabilitation program was standard. EJ radiography was taken after the intervention. Pain was measured preoperatively and postoperatively using VAS system. Functional outcomes were evaluated annually by measuring the range of motion in degrees (flexion-extension, external and internal rotation) and using DASH and MEPS scales. DASH (Disabilities of the Arm, Shoulder and Hand Score, 2006) score was excellent if measured from 0 to 8 points, good ranged between 9 and 20, fair from 21 to 35 and poor outcome for > 35 points (max. 100). MEPS (Mayo Elbow Performance Score, 1986) ranges were excellent for 90–100, good for 75–89, fair for 60–74, and poor was fewer than 60 points. Hand strength was measured with a medical dynamometer DMK-100 (kg, range 10–100 kg).

Statistical analysis was carried out by one-way ANOVA, Pearson's chi-square, or Fisher's exact test.

RESULTS

After preoperative examination, all patients underwent TEA with cemented semi-constrained implant Coonrad-Morrey (Zimmer, Warsaw, IN, USA) under general anesthesia via a posterior middle longitudinal linear approach of about 15 cm in length with release of the ulnar nerve and without olecranon osteotomy. In 29 cases out of 52 (55.8 %) patients of the second group, TEA was performed with simultaneous removal of the osteosynthesis implant. In the rest 23 patients (44.2 %) metal fixators were removed at previous surgeries. In none of the cases, we removed them during the preparation procedure to TEA.

In the early postoperative period, the complications were related to the wound (hematomas, seromas) in 3 patients (2.97 %) of groups II and III (2 and 1 case, respectively) which required wound debridement without involving the implant. There were no wound problems in group I. However, one patient of group I developed deep periprosthetic infection 8 months after the arthroplasty and the implant was removed. The most common complication in TEA was postsurgical ulnar nerve neuritis that is mandatory mobilized during the intervention in all the cases. It was associated with scar adhesions in the elbow region and previous surgeries. It was observed in 6 patients (5.94 %), 2 cases in each group. Long conservative treatment was needed, but one patient of group III developed residual anesthesia of the 5th digit that did not resulted in the reduction of the hand movements. No other complications were encountered in the sample under the study.

Passive motion therapy was initiated from the 1st post-surgery day for 3 days followed by active motion and early rehabilitation. Stitching was taken off on days 12 to 14. Radiographic study and follow-up examination were carried out after 3–12 months, and then annually.

The analysis of the functional outcomes in the upper limb after TEA showed functional improvement that was maximal by one year follow-up. It remained was evident at the other time-points of the follow-up observation. At one year term, there was a statistical difference in the results ($p = 0.0213$) between group III (primary TEA, DASH = 7.3 ± 2.1) compared to groups I (DASH = 20.6 ± 3.3) and II (DASH = 18.4 ± 4.2) (Fig. 1).

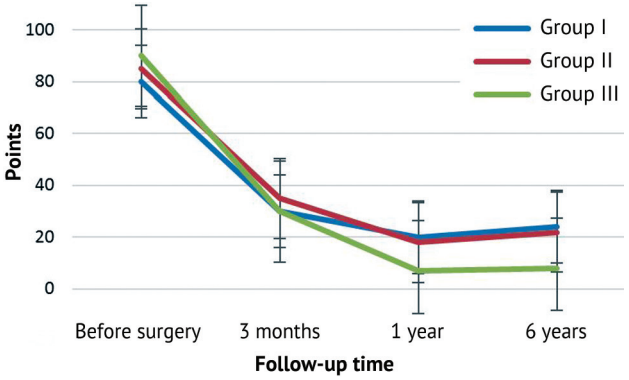

Fig. 1 Dynamics of the changes in the upper limb function (DASH)

Similar dynamics was observed after analyzing the results with MEPS. At one-year follow-up, the results in group III patients (MEPS = 90.7 ± 8.4) could be assessed as excellent, in groups I (MEPS = 83.8 ± 7.4) and II (MEPS = 84.2 ± 5.6) as good, with a significant statistical difference in the results ($p = 0.0344$), which is shown in Figure 2.

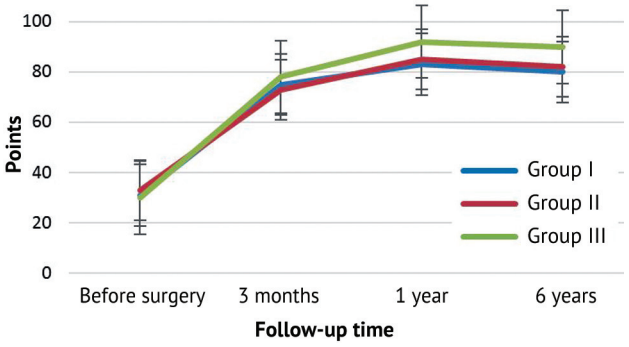

Fig. 2 Dynamics of the changes in the upper limb function (MEPS)

A clear dynamics of improvement in the results after surgery compared with preoperative ones was also noted in all groups by analyzing hand strength, however, there was no statistically significant difference between the groups (Fig. 3).

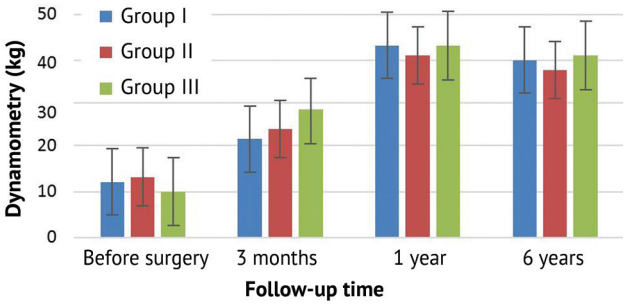

Fig. 3 Dynamics of the changes in the hand strength (dynamometry)

The range of motion in the elbow joint after primary TEA was compared with the preoperative values of the healthy arm that may seem not correct. But the groups of conservative treatment and the osteosynthesis group had considerable limitation in the function. We did not manage to restore the range of motion as in the healthy arm as the results of functional improvement were diverse. However, subjectively we noted the tendency in the first two groups. In the absence of rotation during quite a long time (more than 1.5 years in our study), it was not possible to achieve a good range of rotation, but there were no statistical differences.

Case report (group1) Patient N, 69 years old, had intraaricular comminuted fracture of the right ilbow joint (time from injury 3 years as reported by the patient who did not have any medical documentation or radiographs). His examination revealed a pronounced combined contracture of the elbow joint (flexion 50º, extension 160º, no rotation), severe pain by movements and at rest (VAS = 5, DASH = 90, MEPS = 20, DMS = 14 kg (Fig. 4).

TEA of the right elbow joint was performed with a cemented semi-constrained Coonrad-Morrey implant (Zimmer, Warsaw, IN, USA) (Fig. 5).

Intraoperative movements in the elbow joint were full. After wound healing, a course of standard rehabilitation treatment was indicated and the patient was satisfied with the functional result. At follow-up a year later, pain was relieved (VAS = 1), DASH = 20 and MEPS = 78, DMS = 29 kg, range of motion in the elbow joint: flexion 30º, extension 165º, but rotational movements are absent (Fig. 6).

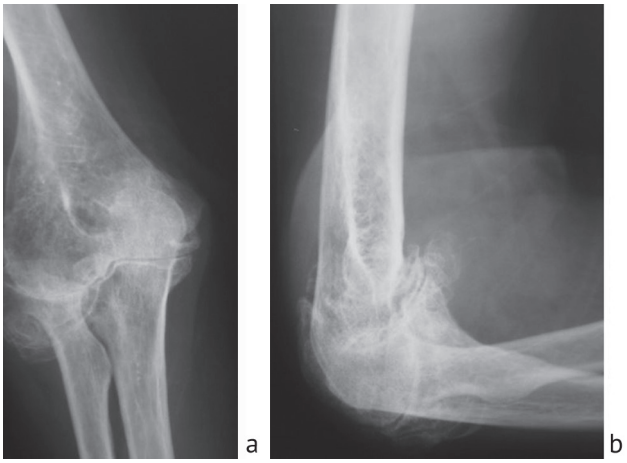

Fig. 4 Patient N radiographs of the elbow joint before the operation: a – AP view; b – lateral view

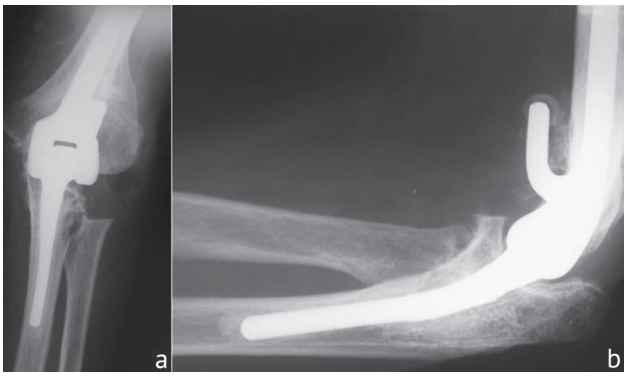

Fig. 5 Patient N radiographs of the elbow joint one year after TEA: a – AP view; b – lateral view

Fig. 6 Patient N functional outcome one year after the operation: a – extension; b – flexion; c – rotation

Case report (group II TEA after osteosynthesis of the distal humeral metaepyphysis)

Patient C., 52 years old, was injured 1.5 years before referral to our clinic. The diagnosis was a closed intra-articular fracture of the distal metaepiphysis of the left humerus (13C2) (Fig. 7). Osteotomy of the olecranon was performed at the hospital of her residence, open reposition, osteosynthesis with a locked reconstruction plate and a spongy screw (Fig. 8). In the postoperative period, pains and a sharp limitation of movements appeared by movements. Radiographs 12 months after osteosynthesis showed migration of the implant structure, nonunion of the humerus, and severe deformity in the EJ area (Fig. 9).

It was not possible to perform reconstruction (reosteosynthesis), so the patient underwent TEA with a semi-constrained Coonrad-Morrey cemented implant (Zimmer, Warsaw, IN, USA) (Fig. 10). At follow-up one year after arthroplasty. There are no complaints. Range of motion in the EJ: flexion – 45º, extension – 175º, pronation – 55º, supination – 85°, DASH = 16 and MEPS = 88, DMS = 32 kg (Fig. 11).

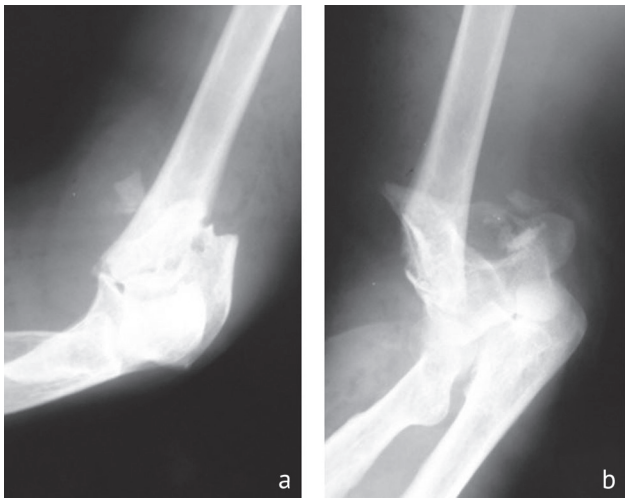

Fig. 7 Patient C radiographs of the left elbow joint after the injury: a – lateral view; b – AP view

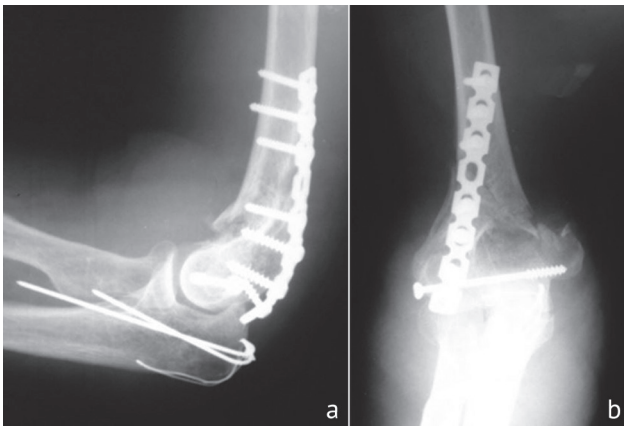

Fig. 8 Patient C radiographs of the elbow joint after osteosynthesis: a – lateral view; b – AP view

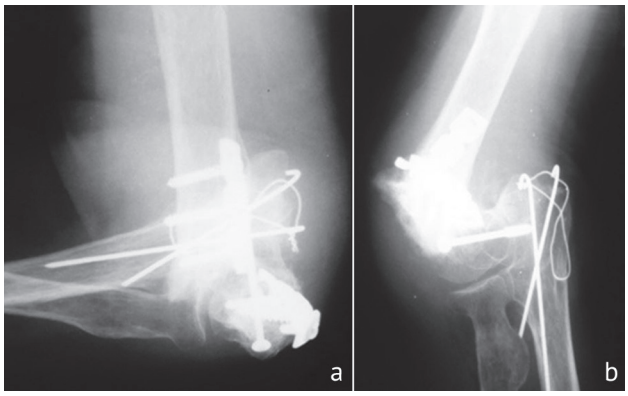

Fig. 9 Patient C radiographs of the elbow joint 12 months after the osteosynthesis (migration and plate breakage): a – lateral view; b – AP view

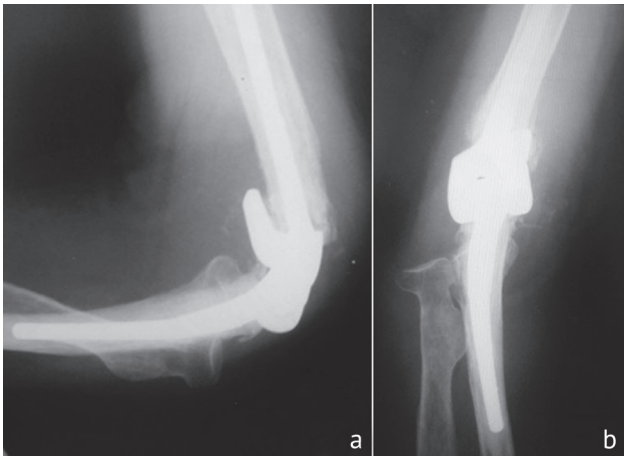

Fig. 10 Patient C radiographs of the elbow joint 12 months after TEA: a – AP view, b – lateral view

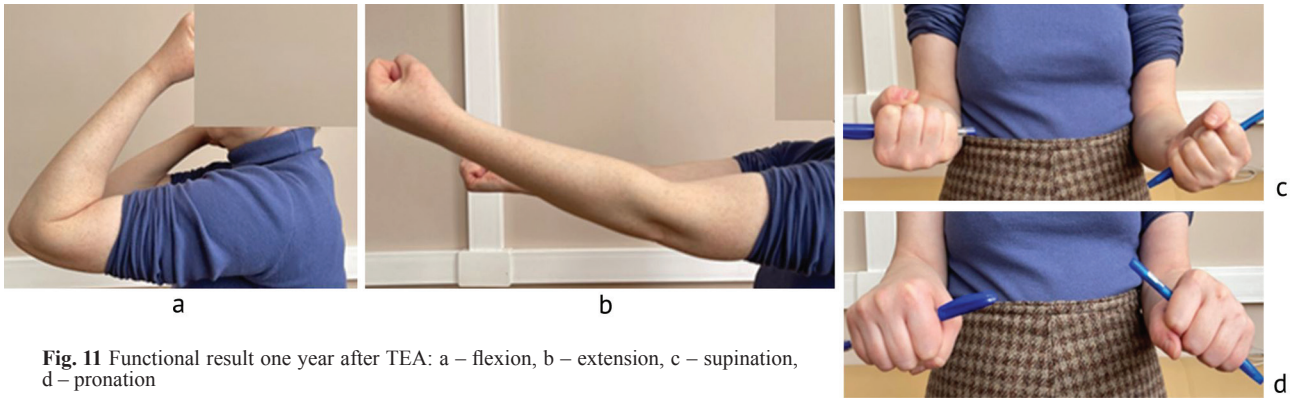

Fig. 11 Functional result one year after TEA: a – flexion, b – extension, c – supination, d – pronation

It should be noted that complete intraarticular fractures of the distal humeral metaepiphysis (13 type C) should be fixed with two plates with angular stability. It is supposed that fixation was insufficient in this case. Pronounced dysfunction and low hand strength were revealed before TEA. Arthroplasty enabled to recover the upper hand functions.

Case report of primary TEA experience for severely comminuted articular ends of the humerus, radius and ulna in patients older than 65 years (group III)

Patient K., 68 years old, sustained a domestic injury: a closed intra-articular multi-comminuted fracture of the distal end of the humerus, a fracture of the head of the radius and the olecranon with displacement of fragments (Fig. 12). Upon admission, an attempt was made to close reduction which did not improve the position of the fragments; immobilization was performed with a plaster splint. Due to the nature of the fracture and the age of the patient, it was decided to perform TEA.

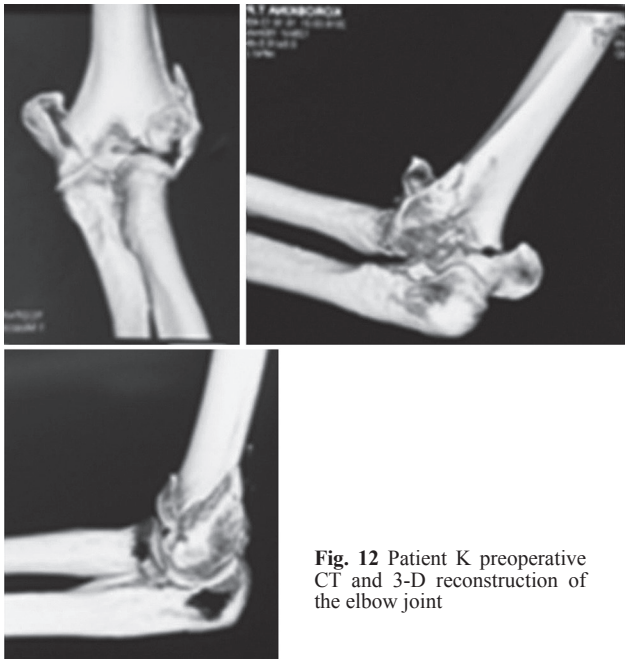

Fig. 12 Patient K preoperative CT and 3-D reconstruction of the elbow joint

Intraoperatively, a large number of small, free bone fragments, a fracture of the head of the radius, capitate eminence and block of the humerus were revealed, which were decided to be removed (Fig. 13 a). Resection of bone fragments of the humerus and ulna, treatment of the medullary canals with rasps was performed followed by determination of the size and range of motion on the fitting endoprosthesis and cement fixation of the implant (Fig. 13 b). Postoperative radiographs show a satisfactory position of the implant (Fig. 14).

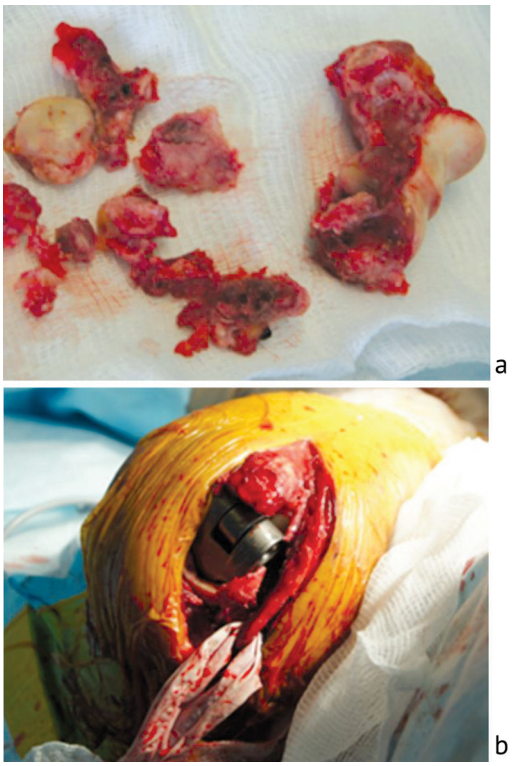

Fig. 13 Patient K intraoperative photos: a – fragments of the elbow joint fragments; b – implant placed

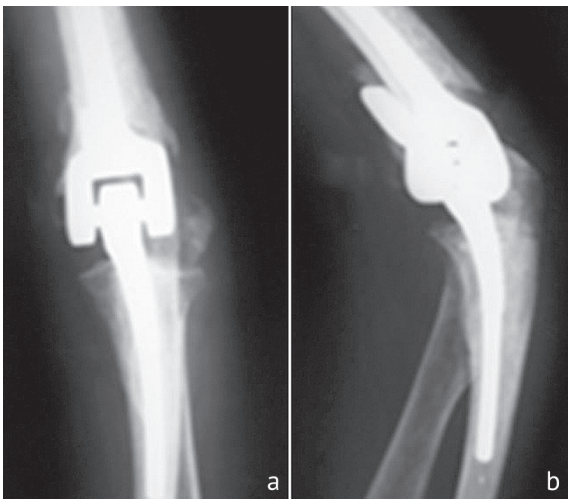

Fig. 14 Patient K radiographs of the elbow joint after TEA surgery: a – AP view, b – lateral view

The patient was discharged after rehabilitation, the function of the limb recovered.

Patient K. was followed-up for 10 years. She is satisfied with the range of motion in the elbow joint, strength and functionality of the limb (Fig. 15). In radiographs, the position of the endoprosthesis components is satisfactory, there is slight ectopic ossification, the condition of the cement mantle is satisfactory (Fig. 16).

Fig. 15 Patient K view of the surgical scar and right upper limb function 10 years after TEA

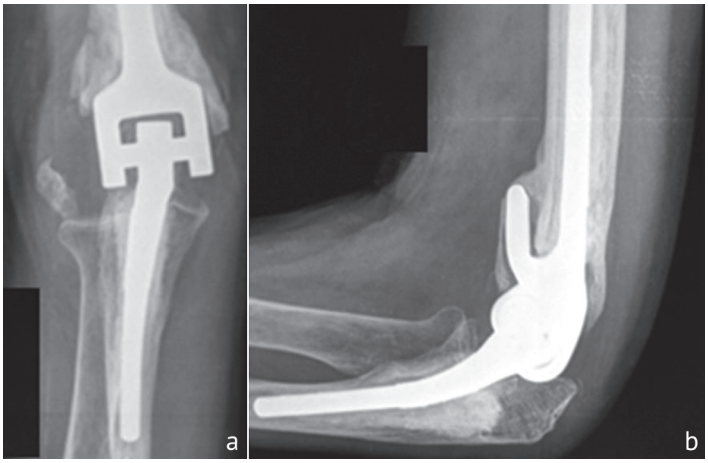

Fig. 16 Patient K radiographs of the elbow joint 10 years after TEA: a – AP view, b – lateral view

DISCUSSION

Fractures of the distal metaepiphysis of the humerus and proximal metaepiphyses of the forearm bones are frequent injuries, reaching 1–2 % of all fractures [32, 33], and challenging in terms of unsatisfactory results. Thus, there are several problems.

1. A common tactics of conservative treatment with a plaster cast for management of intraarticular EJ fractures leads to pronounced contractures, what does not satisfy the doctor and the patient. This fact has been stressed in our study and is emphasized in the works of other authors [34]. We did not conduct a detailed analysis of the results and errors of conservative treatment and rehabilitation, but from the point of view of subsequent total arthroplasty and restoration of the range of motion, this issue is important and it should be remembered that even with plaster immobilization and conservative tactics performed according to the maximum program, it is necessary to preserve the range of motion in the elbow joint, which is the key to further reconstructive treatment and TEA.

2. Another problem is that despite the increasing use of active open surgical reduction and internal fixation of intra-articular fractures of the distal metaepiphysis of the humerus and proximal metaepiphyses of the bones of the forearm, the number of outcomes requiring subsequent arthroplasty has been constantly growing. The problem is not new and is being discussed for more than two decades [16, 36]. This clearly shows the need to develop a tactical approach to solving the issues of bone quality, damage to the bone and articular cartilage, properties of modern metal structures to fix and provide optimal conditions for fracture healing with restoration of the function of the joint and the entire upper limb. These issues are far from being resolved today. Many authors see the solution in the development of surgical methods for treating injuries of the elbow joint [37].

Primary total elbow arthroplasty for injuries and their consequences in elderly patients with osteoporosis with "poor bone quality" is a resolved issue today. However, young patients also sustain fractures that do not have many prospects for restoring good function of the limb. The need to study this issue is high, however, modern diagnostic methods do not allow an objective assessment of bone quality before surgery, and during surgery it is not always possible to accurately determine the prospect of restoring limb function. At the same time, long-term results of arthroplasty after 7 to 10 years are few and not very good. Thus, it is impossible to widely recommend to abandon osteosynthesis in favor of arthroplasty, so this issue requires further research and the introduction of new designs and materials [17, 38, 39, 40].

We recognize that our study has many shortcomings such as a small sample size, being a single center study based on a single implant design. However, it confirmed the main trends in the treatment of fractures of the elbow joint and arthroplasty, showed the relevance and prospects for further research, an increase in the sample by working out protocols for the treatment of elbow joint injuries and creating a registry of its arthroplasty.

CONCLUSION

To choose the treatment tactics in severe injuries of the elbow joint, it is necessary to consider not only the severity of the injury, but also the age of the patient and the quality of the bone, especially in elderly patients. Rejection to perform osteosynthesis in favor of primary total arthroplasty is aimed at maintaining the range of motion, improving the functional results and survival of the endoprosthesis.

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Information about the authors:

1. Valentina A. Kalantyrskaya – Candidate of Medical Sciences, kalan.v@mail.ru;
2. Igor O. Golubev – Doctor of Medical Sciences;
3. Alexey Yu. Zarov – M.D., secretary@ckbsva.ru;
4. Karen A. Egiazaryan – Doctor of Medical Sciences, Professor.