Original Articles

DOI 10.18019/1028-4427-2017-23-3-284-291

Comparison analysis of using three methods for humeral shaft fracture osteosynthesis

B.A. Maiorov[1,2,3], I.G. Belen'kii[2], A.Iu. Kochish[1]

[1]Vreden Russian Research Institute of Traumatology and Orthopedics, St. Petersburg, Russia
[2]Pavlov First Saint Petersburg State Medical University, St. Petersburg, Russia
[3]Vsevolozhsk clinical inter-district hospital, Vsevolozhsk, Leningrad region, Russia

Introduction The tactics of surgical treatment of patients with humeral shaft fractures have beenactively discussed in special scientific literature. The development of new osteosynthesis methods requires their careful comparative evaluation. **Purpose** To compare the treatment results in the three comparable clinical groups of patients with fractures of the humeral diaphysis in its upper and middle thirds after using a minimally invasive osteosynthesis with a helical plate (MIHPO), locked intramedullary osteosynthesis (LIO) and conventional plating osteosynthesis (CPO). **Materials and methods** 92 patients with fractures of the humeral diaphysis in its upper and middle thirds were divided into three groups, comparable in number, sex, age, mechanism of injury, location and nature of fractures, according to the osteosynthesis performed: MIHPO (33 patients), LIO (33 Patient) and CPO (26 patients). Terms prior to surgery, intervention time, image intensifier time (IIT), restoration of the humerus anatomy, functional results using DASH and Constant systems, and complications were compared. Control examinations were performed at 1, 6, 12, 18 and 24 weeks after the operation. Clinical, radiographic and statistical methods of study were used. **Results** Duration of the operation in all three groups did not differ significantly. The IIT was significantly less ($p < 0.001$) in the MIHPO group when compared to LIO. The lowest residual angulation and translation after the osteosynthesis was observed in the CPO group while in MIHPO and LIO groups these findings were not significantly different. The dynamics of restoring the functions of the damaged limb on the DASH and Constant scales did not differ significantly in three groups at all time-points of follow-ups. After 24 weeks, fracture consolidation was noted in all the patients in the MIHPO and CPO groups and in 31 (91.7 %) patients in the LIO group. Six events (18 %) of complications of two types were observed in four patients of MIHPO group (12 %). Ten patients in LIO group (30 %) had 15 complications (45 %) of 6 kinds and 9 complications (35 %) of three kinds were noted in eight CPO patients (30 %). **Conclusion** The MIHPO method is safe and effective. Its results are comparable with the techniques of LIO and CPO in frequency and timing, functional results. However, it results in a lower incidence of complications. Therefore, it can be recommended for a wider application on the appropriate indications.

Keywords: humerus, diaphysis, fracture, minimally invasive plating osteosynthesis, helical plate

INTRODUCTION

Treatment of humeral shaft fractures remains challenging for trauma and orthopedic surgeons. Their incidence is quite high (from 3 % to 5 % of all skeletal bone fractures), and the osteosynthesis techniques have been constantly improved and discussed by the professional community [1, 2, 3, 4, 5, 6, 7, 8]. Currently, surgical treatment of such patients is considered preferable as it provides an early restoration of the damaged limb functions [1, 9, 10, 11].

However, all the known methods of surgical treatment of the fractures discussed are associated with a relatively high risk of complications. Thus, complications of intramedullary nailing of the humerus were observed in 19 % of cases [12]. In particular, the antegrade insertion of an intramedullary nail can be accompanied by the damage to the rotator cuff of the shoulder joint [1, 8, 9, 13, 14], and the retrograde one by the lesions of the elbow joint capsule and iatrogenic fractures of the distal humeral fragment [9, 15]. In addition, intramedullary osteosynthesis is complex technically and is contraindicated in some cases, and namely, in a narrow or tortuous medullary canal as well as in periimplant fractures.

Conventional plating osteosynthesis is accompanied by significant complications even more frequently (from 13 to 35 % of cases) as it involves the use of large surgical approaches for bone fragments exposure [6, 10]. This inevitably leads to significant lesions of soft tissues as well as to the disturbance of the blood supply to bone fragments and, accordingly, to disorders in the processes of reparative bone tissue regeneration [16]. In addition, with the exception of very low or high

Maiorov B.A., Belen'kii I.G., Kochish A.Iu. Comparison analysis of using three methods for humeral shaft fracture osteosynthesis. *Genij Ortopedii*. 2017. T. 23. No 3. pp. 284-291. DOI 10.18019/1028-4427-2017-23-3-284-291. (In Russian)

shaft fractures, such operations involve the isolation of the radial nerve and the insertion of a plate under it that frequently results in neuropathies and requires long-term treatment [7, 13, 16].

The method of minimally invasive plating osteosynthesis used in the fractures under discussion that was proposed by B. Livani and W.D. Belangero in 2004 [17] is devoid of such shortcomings and has been actively used nowadays [11, 15, 16]. This operation is performed from two small approaches, 3 to 5 cm above and below the fracture level with bone fragments bridging by positioning the plate along the front surface of the humerus. Technically, the operation is not complex and provides functional treatment results comparable to traditional plating but with fewer complications [18]. However, the use of this method is limited in fractures of the upper third of the diaphysis due to a conflict of the implant with the long head of the biceps brachii muscle [14]. The solution of this problem with minimally invasive osteosynthesis for the fractures of the indicated localization was proposed by A.A. Fernandez Dell'Oca who used fixation of bone fragments with a spirally curved plate [11, 19]. However, neither he nor other authors attempted to perform osteosynthesis with such a plate throughout the humeral shaft.

With this in mind, we proposed a method of minimally invasive plating osteosynthesis with a helical plate that enables to fix the diaphysis of the humerus throughout its entire length without any conflict with important anatomical structures [20]. In this case, the proximal approach is localized on the lateral surface of the upper third of the humerus, and the distal one is located on the anterior surface in the lower third of this segment. It should be specially noted that the proposed surgical technique avoids the conflict of the plate with the tendon of the long head of the biceps muscle. In addition, the long curved plate used during the operation repeats the spiral course of the radial nerve on the humerus, is always in front of and practically excludes its iatrogenic damage. This was confirmed, in particular, by the previously published results of our topographic and anatomical studies which proved the safety of the proposed osteosynthesis without any damage to the main vessels, large nerves and tendons of the humeral muscles. They also allowed us to work out the optimal technique of the intervention [20].. The safety and efficacy of a new method of minimally invasive plating osteosynthesis with a helical plate in fractures of the humerus have also been confirmed by clinical observations [21]. Nevertheless, it became obvious that it is necessary to compare the results of applying the proposed method with traditional osteosynthesis methods. It determined the purpose of the study presented in this paper.

The **aim of the study** was to perform a comparative analysis of the treatment results after using the method of minimally invasive osteosynthesis by a helical plate (MIHPO), locked intramedullary osteosynthesis (LIO) and conventional plate osteosynthesis (CPO) for fractures in the upper and middle thirds of the humeral shaft in three comparable clinical groups, and also clarify the indications to the application of the new method.

MATERIAL AND METHODS

Our clinical study, approved by the Ethics Committee of the Vreden Russian Research Institute for Traumatology and Orthopaedics, included 92 patients and was conducted during the period from January 2014 to January 2016 in two departments of traumatology and orthopedics, the Alexandrovskaya Municipal Hospital in St. Petersburg and the Vsevolozhskaya Clinical Inter-district Hospital. All patients signed an informed consent for participation in the study. The criteria for patients' inclusion was the presence of an isolated closed fracture of the upper and/or middle third of the humeral shaft, the time from the moment of trauma up to 30 days, as well as the absence of primary neurological symptoms and chronic diseases in the sub- or decompensation stage.

All our patients were divided into three groups according to the method of surgical treatment used. The first group consisted of 33 patients who underwent a minimally invasive osteosynthesis with a helical plate (MIHPO), the second group included 33 patients who underwent antegrade osteosynthesis with a locked intramedullary nail (LIO), and the third group included 26 patients who underwent conventional plating osteosynthesis (CPO) from the posterior (18 patients) or anterior (8 patients) approaches. The mean age of patients in all three groups did not differ significantly ($p > 0.05$), it was quite comparable and was 55.2 ± 2.6 years in the first group, 56.8 ± 3 years in the second and 47.4 ± 3,6 years in the third clinical group. The gender composition of the three groups was also quite similar ($\chi^2 = 0.68$, $p > 0.05$): in the first group, females made 54.5 %, in the second group – 60.6 %, and in the third group – 50 %.

The mechanism of injury in all three groups was low-energy impact due to a fall from the patients' own height. Its share in the first and second groups was 81.8 %, and in the third group low-energy fractures made 69.2 %. In addition, our patients were injured in road accidents, from direct impacts, falls from a height of 3 to 8 meters, or due to a gas cylinder explosion. However, in general, the distribution of patients in the groups by the mechanism of trauma did not have statistically significant differences ($\chi^2 = 13.6$, $p > 0.05$). Differences in the humeral shaft fracture

location were also not significant and were within the statistical error ($\chi^2 = 4.60$, $p > 0.05$).

The AO/ASIF classification was used to assess fractures of the humeral shaft. The distribution of the injured in groups according to the fracture types is presented in Table 1. It should be noted that all types of fractures, with rare exceptions, were presented in each clinical group. In general, the distribution of patients by humeral shaft fracture type in our three clinical groups was similar, and the differences were within the statistical error ($\chi^2 = 6.92$, $p > 0.05$). It should also be noted that the time relapsed after injury was an average of 8.3 ± 0.6 days for all three groups, and there were no significant differences between groups in the values of this parameter. Thus, all three groups of our patients with closed fractures of the humeral diaphysis were comparable in age, sex, mechanisms of injury, location and character of fractures, and also in average terms that passed from the moment of injury before surgery. This allowed us to conduct a correct comparative analysis of the results of treatment using three techniques of osteosynthesis: MIHPO, LIO and CPO.

The analysis of the interventions and treatment outcomes of our patients was carried out according to the following parameters: duration of the intervention, image intensifier operation time (IIT), humerus anatomy restoration, dynamics of limb function recovery and radiographic union, and complications. Examinations of patients and control radiography of the humerus in two projections were performed at 1, 6, 12, 18 and 24 weeks after the operation.

Mathematical and statistical processing of quantitative data was carried out with the help of "*Data Analysis"* and "*Chart Wizard*" Table Excel Editor, as well as modules of Basic Statistics/Tables (Basic Statistics) and ANOVA (analysis of variance) package for statistical data processing with *Statistica for Windows* software. Assessment of significance of differences of mean values and the onset of manifestation signs in the groups of patients was performed using a parametric method of estimating hypotheses with a parametric Student's t-test. Investigation of the associations between the signs was carried out using a parametric correlation coefficient r (Pearson) and nonparametric test χ^2 (Pearson).

Table1

Distribution of fracture types according to AO/ASIF classification in the groups studied

AO/ASIF classification type	MIHPO		LIO		CPO		Total	
	Number	%	Number	%	Number	%	Number	%
22-A1	5	15.2 %	7	21.2 %	4	15.4 %	16	17.4 %
22-A2	1	3.0 %	1	3.0 %	4	15.4 %	6	6.5 %
22-A3	0	0.0 %	5	15.2 %	1	3.8 %	6	6.5 %
Total type A	**6**	**18.2 %**	**13**	**39.4 %**	**9**	**34.6 %**	**28**	**30.4 %**
22-B1	6	18.2 %	6	18.2 %	1	3.8 %	13	14.1 %
22-B2	1	3.0 %	4	12.1 %	6	23.1 %	11	12.0 %
22-B3	8	24.2 %	6	18.2 %	3	11.5 %	17	18.5 %
Total type B	**15**	**45.4 %**	**16**	**48.5 %**	**10**	**38.4 %**	**41**	**44.6 %**
22-C1	1	3.0 %	0	0.0 %	2	7.7 %	3	3.3 %
22-C2	6	18.2 %	3	9.1 %	3	11.5 %	12	13.0 %
22-C3	5	15.2 %	1	3.0 %	2	7.7 %	8	8.7 %
Total type C	**12**	**36.4 %**	**4**	**12.1 %**	**7**	**26.9 %**	**23**	**25 %**
Total	**33**	**100 %**	**33**	**100 %**	**26**	**100 %**	**92**	**100 %**

RESULTS

In the MIHPO group, the duration of the intervention varied from 45 to 112 minutes, from 70 to 90 minutes in half of the cases, and averaged 79.6 ± 3.0 minutes. In the LIO group, the corresponding time were 30 to 120 minutes, respectively, 60 and 85 minutes, respectively, and the average operation time was 70.3 ± 4.1 minutes. In the CPO group, the values were equal to 40 and 190 minutes, 65 and 90 minutes respectively, and 82.1 ± 6.4 minutes, respectively. Thus, the average time of the osteosynthesis operation was the largest in the CPO group, and the smallest in the LIO group. However, the revealed differences were statistically insignificant ($p > 0.05$). All three types of interventions performed were comparable in time of their implementation.

The average IIT in the MIHPO group was 54.8 ± 2.1 seconds (from 40 to 82 seconds), and in the LIO group it operated for 127.6 ± 5.1 seconds (from 75 to 193 sec-

onds). The differences were statistically significant with a reliability of 99.9 % ($p < 0.001$). In the CPO group, the IIT was rarely used (in 7 out of 26 cases) in a short-term fluoroscopic mode.

It should be noted that a limited open reduction through small additional cuts of the skin was performed in four MIHPO cases (12.1 %) and in two LIO cases (6.1 %) due to the technical impossibility of performing an indirect closed reduction. In all the cases of CPO, an open direct reduction of bone fragments was performed. In this group, revision of the radial nerve from the posterior approach was done in 18 patients out of 26 (69.2 %) in accordance with the technology of this method of osteosynthesis. In the other two clinical groups, the radial nerve was neither visualized nor revised during operations.

Restoration of the anatomy of the humerus was assessed in postoperative control radiographs. Thus, a close to the anatomical position of bone fragments was achieved after their open reduction in 19 (73.1 %) out of 26 patients in the CPO group. This result was significantly more frequent in this group ($p < 0.001$) than in the case of MIHPO or LIO (6 patients (18.2 %) and 4 patients (12.1 %), respectively). The residual angular deformity of the bone fragments was assessed according to three degrees: up to 5°, from 5° to 10°, and more than 10°. In the MIHPO group, they were seen in 69.7 %, 15.2 %, 15.2 % of patients, in LIO group in 66.0 %, 12.1 % and 21.2 % of patients, and in the CPO group in 92.3 %, 3.9 % and 3.9 % of patients, respectively. Translation was also evaluated as three grades: less than 1/3 of the diaphysis width, in the interval from 1/3 to 2/3 of the diaphysis width and more than 2/3 of the diaphysis width. The results of such an assessment are shown in the diagram (**Fig. 1**).

Thus, the minimum angular deformity and the minimum displacement of fragments along the width were significantly more frequently observed in the CPO group ($p < 0.05$). It should also be noted that there were some advantages in the group MIHPO as compared with the group of LIO on the studied efficiency of reduction. However, these differences did not reach the level of statistical significance ($p > 0.05$).

Function recovery of the injured upper limb in the postoperative period was assessed at follow-up examinations in dynamics using the functional scales DASH and Constant. The average scores for these scales in the three groups of our patients within 24 weeks of follow-ups are shown in **Table 2**.

The data obtained indicate that the average scores on both scales used (DASH and Constant) changed significantly for the better ($p < 0.001$) thoughout 24 weeks of follow-ups after surgical treatment. At the same time, there were no significant differences in their values between the three groups of patients in any of the studied periods ($p > 0.05$).

The process of fracture union was assessed in AP and lateral radiographs performed in dynamics. The key criteria were the presence of a distinct bone callus and /or the disappearance of the fracture line in two projections. X-ray signs of fracture union were revealed already by the 6th week of the postoperative period in 7.1 % of the patients in the MIHPO group, in 3.6 % of the LIO group and in 4.0 % of the CPO group. Over time, the proportion of patients with signs of consolidation significantly increased ($p < 0.001$) and reached 100 % in the MIHPO group, 91.7 % in the LIO group and 100 % in the CPO group by the 24th week (**Fig. 2**).

Postoperative complications were detected in patients of all three groups. They were observed in 4 (12.1 %) patients of the first group, in 10 (30.3 %) of the second group, and in 8 (30.8 %) patients of the third group. One can state with a reliability of 92 % ($p = 0.08$) that the incidence of complications in the MIHPO group was lower. Types of complications and their incidence in patients of the three clinical groups are presented in Table 3. It should be noted that they differed significantly and depended on the method of osteosynthesis.

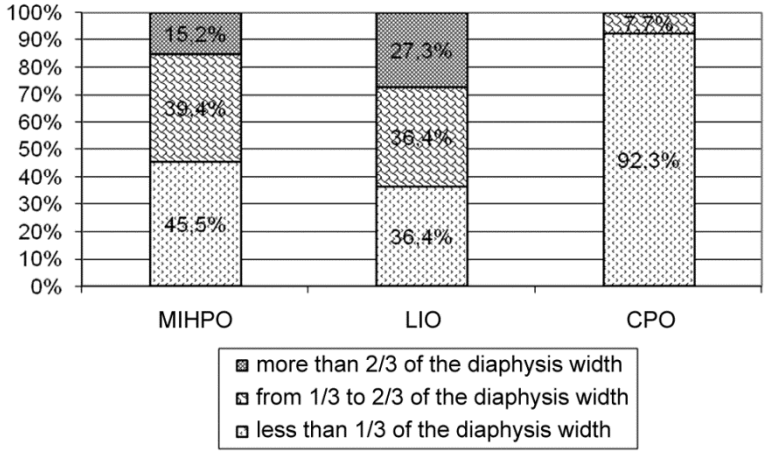

Fig. 1 Residual translation deformity after reduction in all three methods

Table 2

Mean DASH и Constant scores in three groups at follow-ups

Scale	Groups	1 week	6 week	12 week	18 week	24 week
DASH	MIHPO	66.5 ± 2.3	49.8 ± 2.5	36.1 ± 2.6	27.0 ± 2.7	18.0 ± 2.7
	LIO	66.5 ± 2.3	50.9 ± 2.5	39.0 ± 2.6	29.3 ± 2.7	21.1 ± 2.7
	CPO	71.6 ± 2.6	55.9 ± 2.7	42.1 ± 2.9	33.1 ± 2.9	21.0 ± 3.0
Constant	MIHPO	22.7 ± 2.1	36.2 ± 2.3	50.6 ± 2.4	62.8 ± 2.4	73.3 ± 2.4
	LIO	22.4 ± 2.1	36.3 ± 2.3	47.5 ± 2.4	59.2 ± 2.5	71.5 ± 2.5
	CPO	20.5 ± 2.4	37.0 ± 2.5	53.2 ± 2.6	62.4 ± 2.6	73.4 ± 2.7

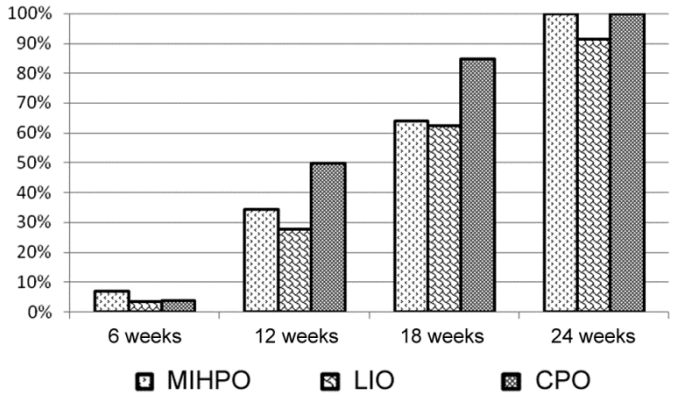

Fig. 2 Dynamics of fracture consolidation manifestation in the postoperative period in three groups

Table 3

Postoperative complications in patients of the groups studied

Complication	MIHPO (n = 33)		LIO (n = 33)		CPO (n = 26)	
	Number	%	Number	%	Number	%
Neuropathy	0	0 %	3	9 %	4	15 %
Bone break	0	0 %	3	9 %	0	0 %
Infection	0	0 %	1	3 %	0	0 %
Instability	4	12 %	2	6 %	3	12 %
Impingement	2	6 %	4	12 %	2	8 %
Non-union	0	0 %	2	6 %	0	0 %
Total	6	18 %	15	45 %	9	35 %

Four patients of MIHPO group had 6 complications of different types such as fixation instability (4 cases) and impingement due to a limited migration of the plate (2 cases). Combination of these complications was detected in two patients at week 6 post-surgically and was manifested as pain in the proximal humerus as well as abduction and anterior flexion limitation in the shoulder joint. In our opinion, they were caused by diaphyseal fracture multi-fragmentation (type C) and mistakes in the technical implementation (insufficient number of screws in the proximal fragment). Additional fixation with a cravat bandage for 12 weeks and avoidance of exercise therapy were administered. Re-operation was not required. Plates were removed in two patients at 18 weeks after the osteosynthesis due to distinct radiographic signs of fracture union. However, at a 24-week follow-up, they showed a worsened function and the final outcome was rated as fair.

In the LIO group, 15 complications of six types were noted in 10 patients. They were 3 cases of iatrogenic radial nerve neuropathy, 3 iatrogenic fractures of the humerus, one wound infection, two cases of fixation instability and two non-unions, and 4 cases of impingement. Three cases of transient iatrogenic neuropathy of the radial nerve had the greatest clinical significance. It was associated with the distal blockage of the intramedullary nail which was performed in the frontal plane from the outside inwards by the free arm method without revision of the radial nerve. It should be noted that the function of the radial nerve recovered in all patients at 6 months post-surgery after a conservative treatment.

Splitting of the humerus by the introduction of the nail was observed in 3 cases (9 %). The cause of this complication was an incorrect choice of the nail thickness in a narrow intramedullary canal. In one female patient, this affected the timing of fracture union. She also had a case of infection with peri-fractural hemato-

ma, revealed on the 5th day after the operation. Upon opening and draining the hematoma, the subsequent postoperative period proceeded without any events, the wound healed by secondary tension after 14 days, and the recurrence of infection was not observed.

Instability of the intramedullary nail in four of our patients developed due to an inadequate locking (one locking screw or fixation in one plane), which resulted in an impingement due to nail migration (4 cases) and non-union (2 cases). These patients complained of pain and limitation of abduction in the shoulder joint. In one patient at 24 weeks after the operation, the intramedullary nail was removed after the fracture union and pathological symptoms relieved. The remaining patients needed additional treatment measures after the end of the observation period in this study

In the CPO group, 9 complications of three types were seen in 8 patients: iatrogenic radial nerve neuropathy (4 cases), fixation instability (3 observations), and impingement (2 cases). The largest proportion of neuropathy (15.4 % of cases) in patients in this group was observed. In our opinion, it happened due to the mobilization and revision of the radial nerve during the operation of osteosynthesis, although this nerve trunk was withdrawn to a safe distance and protected during manipulations with bone fragments. Further on, two patients recovered the function of the radial nerve completely at 4 months after surgery with conservative treatment. One patient required a second operation with neurolisis of the radial nerve which ensured the restoration of his function within 2 months after neurolysis and by a six-month period after osteosynthesis. Another patient with a pronounced neuropathy of the radial nerve was expecting a similar operation when this study was written.

Instability of humeral fragments fixation was observed in three CPO group patients. The fracture line on their control radiographs was detected that extended above the fixation zone with a plate. Given the absence of significant displacement of bone fragments, all of these patients underwent additional immobilization of the injured humerus with a plaster cast for a period of 6 to 8 weeks which ensured the fracture consolidation in all these observations by week 24 after osteosynthesis. The impingement syndrome that happened in the group under discussion in two cases, was due to the high position of the plate (above the tip of the large tubercle of the humerus). The reasons for the incorrect position of the implants were inadequate selection of plates and the absence of intraoperative fluoroscopic control.

DISCUSSSION

The study of the available scientific publications on the topic conducted by us showed that at present there is no uniform opinion of specialists on the choice of the optimal method for surgical treatment of patients with diaphyseal fractures of the humerus [2]. The most frequently used methods for fixation of bone fragments in such patients have their merits and shortcomings. It has been also confirmed by our study. In particular, we have shown that the duration of the operation, dynamics of functional restoration and final treatment outcomes after 24 weeks are quite comparable in the three groups studied. This agrees with the data of other authors [7, 18]. Certain differences were noted only in the degree of anatomy restoration of the humerus as well as in the nature and types of complications. Therefore, the results of our study do not give grounds for recognizing one of the three methods of osteosynthesis that we have studied is a priority in the surgical treatment of patients with humeral shaft fractures.

The data obtained by us show that conventional bone osteosynthesis with plates (CPO) provides the best results of bone fragments reduction and allows maximum restoration of the anatomy of the humerus. However, bone instability incidence associated with the impossibility of fixing the humerus all over and the impingement syndrome with this method of osteosynthesis are similar to those encountered in the MIHPO and LIO groups while the proportion of patients with severe neuropathy of the radial nerve is the greatest. This is in complete agreement with the publications of other authors [9, 10].

We obtained a relatively large number of complications (15) in 10 out of 33 patients (30.3 %) in the LIO group. Such complications as splitting of the humerus and deep infection of the wound were not observed in two other our groups (CPO and MIHPO). In addition, the LIO methodology is a high-tech intervention requiring a careful pre-operational planning, strict adherence to the operation technology and mandatory use of an image intensifier [9, 10].

Clinical results of the minimally invasive osteosynthesis method proposed by us with a helical plate (MIHPO) showed that the outcomes of treatment and dynamics of recovery of lost functions were quite comparable with other studied methods (CPO and LIO). At the same time, the number of complications in the MIHPO group (33 patients) was the least in both the types (2 kinds) and the total number (6 complications). It should also be noted that all the cases of unstable fixation (4 cases) were managed with conservative therapy that ensured fracture consolidation by the maximum observation period (24 weeks) and achieved acceptable functional results. It is also important that no cases of neuropathy of the radial nerve were noted in

any of the observations by the use of our method. As shown by the topographic anatomical studies [20], it was always behind the helical plate and did not contact with it. Moreover, it was shown that the average time of the operation with the use of the three studied osteosynthesis techniques does not differ significantly but the operating time of the image intensifier is significantly ($p < 0.001$) less (more than twice) with the use of the MIHPO method than in LIO.

It should also be noted that the new method of minimally invasive plating osteosynthesis (MIHPO), in our view, is especially indicated for high humeral shaft fractures as well as for the combination of diaphyseal fractures with fractures of the surgical neck of the humerus. In such clinical cases, minimally invasive osteosynthesis with straight plates is either technically impossible or can lead to a conflict between the implant and the tendon of the long head of the biceps brachii. Our method of minimally invasive osteosynthesis with a helical plate is devoid of these drawbacks and can be successfully applied in the clinical situations indicated, as evidenced by a number of our clinical observations.

CONCLUSION

In general, our comparative clinical study allows us, in our opinion, to conclude that the new method of minimally invasive osteosynthesis with a helical plate (MIHPO), proposed by us, is safe enough and effective. It is quite comparable in this respect with the known methods of conventional plating (CPO) and locked intramedullary osteosynthesis (LIO). The data obtained by us substantiate the possibility to recommend a new method of minimally invasive osteosynthesis with helical plates (MIHPO) to a wider clinical use. It should be taken into account that the method of osteosynthesis proposed by us can be successfully used in the treatment of patients with fractures of the humeral shaft in its upper and middle thirds. It is also suitable for their combination with fractures of the surgical neck of the humerus.

REFERENCES

1. Apaguni A.E., Arzumanov S.V., Vorotnikov A.A., Ul'ianchenko M.I. Anatomo-funktsional'nye iskhody operativnogo lecheniia bol'nykh s perelomami diafiza plechevoi kosti [Anatomic-and-functional outcomes of surgical treatment of patients with humeral shaft fractures]. *Med. vestn. Sever. Kavkaza*, 2010, vol. 20, no. 4, pp. 32-35. (In Russ.)
2. Belen'kii I.G., Maiorov B.A., Li S.Kh. Operativnoe lechenie perelomov diafiza plechevoi kosti. Sovremennyi vzgliad na problemy i puti ikh resheniia [Surgical treatment of humeral shaft fractures. Modern view on problems and ways to solve them]. *Fundam. issled*., 2014, no. 10-9, pp. 1849-1857. (In Russ.)
3. Donchenko S.V., Lebedev A.F., Cherniaev A.V., Simonian A.G. Maloinvazivnyi osteosintez plechevoi kosti iz perednego dostupa: anatomicheskoe obosnovanie, pokazaniia, pervye rezul'taty [Little invasive osteosynthesis of the humerus through an anterior approach: anatomical substantiation, indications, early results]. *Moskov. khirurg. zhurn*., 2013, no. 2 (30), pp. 38-43. (In Russ.)
4. Erokhin A.N., Tarchokov V.T. Osobennosti konsolidatsii pereloma diafiza plechevoi kosti u bol'nykh pri chreskostnom osteosinteze metodom Ilizarova [Characteristics of humeral shaft fracture consolidation for transosseous osteosynthesis by the Ilizarov method]. *Travmatologiia i ortopediia Rossii*, 2017, no. 1, pp. 70-80. (In Russ.)
5. Kupkenov D.E. Sposob osteosinteza segmentarnogo pereloma plechevoi kosti sterzhnevym apparatom [Osteosynthesis technique for a segmental humeral fracture using a rod device]. *Travmatologiia i ortopediia Rossii*, 2010, no. 4 (58), pp. 73-77. (In Russ.)
6. Litvinov I.I., Kliuchevskii V.V., Ryzhkin A.A. Nakostnyi osteosintez perelomov nizhnei treti diafiza plechevoi kosti [Internal osteosynthesis of humeral fractures in the lower shaft third]. *Travmatologiia i ortopediia Rossii*, 2011, no. 1 (59), pp. 117-120. (In Russ.)
7. An Z., Zeng B., He X., Chen Q., Hu S. Plating osteosynthesis of mid-distal humeral shaft fractures: minimally invasive versus conventional open reduction technique. *Int. Orthop*., 2010, vol. 34, no. 1, pp. 131-135. Doi: 10.1007/s00264-009-0753-x.
8. Castoldi F., Blonna D., Assom M., eds. Simple and complex fractures of the humerus. A guide to assessment and treatment. Italia, Springer-Verlage Mailand, 2015, 337 p. Doi: 10.1007/978-88-470-5307-6.
9. Canale S.T., Beaty J.H. Campbell's Operative Orthopaedics. 12th ed. Mosby Elsevier, 2013, vol. 1, 4664 p.
10. Rüedi T.P., Buckley R.E., Moran C.G. AO Principles of Fracture Management. 2nd expanded ed. Stuttgart, Thieme, 2007, 1106 p.
11. Tong G.O., Bavonratanavech S. Minimally Invasive Plate Osteosynthesis (MIPO): Concepts and cases presented by AO East Asia (AO Manual of fracture management). 1st ed. Switzerland, AO Publishing, 2007, 381 p.
12. Lin J., Shen P.W., Hou S.M. Complications of locked nailing in humeral shaft fractures. *J. Trauma*, 2003, vol. 54, no. 5, pp. 943-949. Doi: 10.1097/01.TA.0000032252.57947.47.
13. Blum J., Janzing H., Gahr R., Langendorff H.S., Rommens P.M. Clinical performance of a new medullary humeral nail: antegrade versus retrograde insertion. *J. Orthop. Trauma*, 2001, vol. 15, no. 5, pp. 342-349.
14. Kobayashi M., Watanabe Y., Matsushita T. Early full range of shoulder and elbow motion is possible after minimally invasive plate osteosynthesis for humeral shaft fractures. *J. Orthop. Trauma*, 2010, vol. 24, no. 4, pp. 212-216. Doi: 10.1097/BOT.0b013e3181c2fe49.
15. Dzhodzhua A.V. Retrogradnyi osteosintez bedrennoi i plechevoi kostei [Retrograde osteosynthesis of the femur and humerus]. *Vestn. Nats. mediko-khirurg. tsentra im. N.I. Pirogova*, 2008, vol. 3, no. 2, pp. 25-27. (In Russ.)
16. Zhiquan A., Bingfang Z., Yeming W., Chi Z., Peiyan H. Minimally invasive plating osteosynthesis (MIPO) of middle and distal third humeral shaft fractures. *J. Orthop. Trauma*, 2007, vol. 21, no. 9, pp. 628-633. Doi: 10.1097/BOT.0b013e31815928c2.
17. Livani B., Belangero W.D. Bridging plate osteosynthesis of humeral shaft fractures. *Injury*, 2004, vol. 35, no. 6, pp. 587-595. Doi: 10.1016/j.injury.2003.12.003.

18. Hu X., Xu S., Lu H., Chen B., Zhou X., He X., Dai J., Zhang Z., Gong S. Minimally invasive plate osteosynthesis vs conventional fixation techniques for surgically treated humeral shaft fractures: a meta-analysis. *J. Orthop. Surg. Res.*, 2016, vol. 11, no. 1, pp. 59. Doi: 10.1186/s13018-016-0394-x.
19. Fernández Dell'Oca A.A. The principle of helical implants: unusual ideas worth considering. Case studies. *Injury*, 2002, vol. 33, no. Suppl. 1, pp. SA29-SA40.
20. Kochish A.Iu., Maiorov B.A., Belen'kii I.G. Original'nyi sposob maloinvazivnogo nakostnogo osteosinteza spiral'no izognutymi plastinami pri perelomakh diafiza plechevoi kosti [An original technique of little invasive internal osteosynthesis with spirally bent plates for humeral shaft fractures]. *Travmatologiia i ortopediia Rossii*, 2016, no. 3 (81), pp. 99-109. (In Russ.)
21. Kochish A.Iu., Maiorov B.A., Belen'kii I.G. Klinicheskaia aprobatsiia novogo sposoba maloinvazivnogo nakostnogo osteosinteza u patsientov s perelomami diafiza plechevoi kosti [Clinical testing of the new technique of low invasive osteosynthesis in patients with humeral shaft fractures]. *Sb. nauch. st., posviashch. 110-letiiu RNIITO im. R.R. Vredena "Aktual'nye problemy travmatologii i ortopedii"*[Proc. dedicated to 110th anniversary of the Vreden RSRITO "Problems of current interest in traumatology and orthopaedics"]. SPb., RNIITO im R.R. Vredena, 2016, pp. 140-146. (In Russ.)

Received: 02.05.2017

Information about the authors:

1. Boris A. Maiorov, M.D., Vsevolozhsk Clinical Interdistrict Hospital, Vsevolozhsk, Leningrad region, Russia, Head of Department of Traumatology and Orthopaedics No 2; Pavlov First Saint Petersburg State Medical University, St. Petersburg, Russia, Department of Traumatology and Orthopaedics, assistant; Email: bmayorov@mail.ru
2. Igor' G. Belen'kii, M.D., Ph.D., Pavlov First Saint Petersburg State Medical University, St. Petersburg, Russia, Department of Traumatology and Orthopaedics, associate professor
3. Aleksandr Iu. Kochish, M.D., Ph.D., Professor, Vreden Russian Research Institute of Traumatology and Orthopedics, St. Petersburg, Russia, Deputy Director on scientific and educational work