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Iatrogenic Damage to the Radial Nerve During Osteosynthesis of the Humerus. Prevention, Diagnosis and Treatment

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THE RELEVANCE is determined by the significant frequency of iatrogenic injuries of the radial nerve during internal osteosynthesis of the humerus, long-lasting functional disorders, a large number of unsatisfactory results, as well as the lack of a unified approach to diagnosis and treatment.
MATERIAL AND METHODS The causes of iatrogenic damage to the radial nerve were studied in 22 patients who underwent internal fixation during fractures of the humeral diaphysis. The ultrasound examination was used to visualize the radial nerve. In 13 patients (59.1%), a pathogenetic treatment was used, including medication, physical and mechanical therapy.
RESULTS AND DISCUSSION In plate osteosynthesis, a greater number of iatrogenic damage to the radial nerve was observed than during osteosynthesis with screws. The ultrasound method had high diagnostic values to determine the continuity of the nerve trunk and identify conflicts with solid structures. The use of pathogenetic therapy of neuropathy led to a more rapid clinical recovery of limb function.
CONCLUSION To prevent iatrogenic injuries and avoid gross manipulations, the access with sufficient visualization of the radial nerve is necessary in plate osteosynthesis and distal blocking outside the projection of the radial nerve is necessary in intramedullary osteosynthesis. Indications for early revision after iatrogenic damage are neurotmesis and a nerve conflict with bone fragments or an implant.
Keywords: diaphyseal fracture of the humerus, internal osteosynthesis, iatrogenic neuropathy, ultrasound, revision of the radial nerve
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AO — (Arbeitsgemeinschaft für Osteosynthesefragen) Association for the Study of Internal Fixation
CI — confidence interval
ENMG— electroneuromyography
MD — mean deviation

INTRODUCTION

According to various sources, iatrogenic damage to the radial nerve during surgical treatment of diaphyseal fractures of the humerus occurs in 8–19% of cases [1–3]. Such injuries are often (up to 46% of cases) accompanied by long-lasting, up to 9-14 months, motor and sensory disorders [4]. Persistent dysfunction of the upper limb remains in 22% [5, 6] and causes disability in 15% of patients [7].

Iatrogenic neuropathies can be associated with the use of both external fixation [2, 8] and internal osteosynthesis [9, 10]. The causes of damage are caused by direct and indirect effects on the nerve such as injury, traction, compression and contusion, or their combination. Nerve damage can be either complete (neurotmesis), or only involving a part of the axial cylinders, with the neural membranes intact (axonotmesis), or not accompanied by structural abnormalities (neuropraxia or functional block of conduction). As in the case of primary nerve injuries, the pathogenesis of iatrogenic traumatic neuropathy is associated with combination of denervation and regenerative processes [11].

There is no single approach to the diagnosis of traumatic neuropathies, including iatrogenic ones. The clinical method, allowing to reliably identify the fact of nerve injury and determine the level of damage, does not make it possible to establish the type of this damage, since in most cases in the acute period any nerve damage, from neurotmesis to a functional block, manifests itself as a detailed picture of sensory-motor deficit. Some specialists use electroneuromyography (ENMG) to determine the treatment tactics [11, 12], however, in the early stages after nerve injury, ENMG may be uninformative due to false positive and false negative results [13, 14]. For visualization of the radial nerve, magnetic resonance imaging and ultrasound examination are used. Each of them has its own advantages, but in practice ultrasound is used more often [15–20].

The subject of discussion is also therapeutic tactics, which main issues are the need for primary revision of the radial nerve and postoperative treatment.

Various authors suggest both obligatory revision of the nerve within a short period of time after surgery [8] and expectant tactics for several months after injury in order to restore hand function [21]. At the same time, the authors do not take into account the importance of instrumental diagnostic data for the choice of surgical tactics.

Therapeutic treatment of neuropathy after the performed revision of the radial nerve is not discussed in foreign specialized publications [3, 8, 12], and in the works of domestic authors there is no unity of views on such treatment [4, 5, 11, 22-24].

Thus, iatrogenic damage to the radial nerve is a significant medical, social and legal problem [15, 23], which can be approached only by using the set of modern diagnostic capabilities and treatment methods.

Aim of study: to optimize the diagnostic and therapeutic tactics on the ground of the analysis of the causes of iatrogenic damage to the radial nerve during internal osteosynthesis of the diaphysis of the humerus.

MATERIAL AND METHODS

The obtained data were statistically processed using Microsoft Excel 2010 and Statistica 13 programs.

To describe the statistical characteristics of the sample, the format M (min; max; MD; 95% CI) was used, where M is the mean value for the sample, min and max are the minimum and maximum values, MD is the mean deviation, and CI is the confidence interval. When evaluating the characteristics of the diagnostic value of research methods, the accuracy, sensitivity and specificity were calculated. When determining the statistical significance, Pearson's χ^2 test and Student's t-test were used (data on the timing of recovery of limb function corresponded to a normal distribution). The level of statistical significance was taken as $p \leq 0.01$.

The work was carried out in the Department of Emergency Traumatology of the N.V. Sklifosovsky Research Institute. In 2008–2019, 599 patients with uncomplicated fractures of the humerus diaphysis were operated on. Iatrogenic damage to the radial nerve was observed in 22 patients (3.7%). There were 12 men (54.5%) and 10 women (45.5%). The average age of the patients was 41.2 years (min 24; max 79; MD 14.8; 95% CI 4.85).

All patients underwent internal osteosynthesis. Table 1 shows information about the applied methods of surgical treatment and the number of complications.

Table 1
Distribution of patients by treatment methods in which iatrogenic neuropathy developed

Type of osteosynthesis	Number of patients (*)	Number of iatrogenic damage to the radial nerve
Plate osteosynthesis	196	11 (5.6%)
Screw fixation	55	1 (1.8%)
Locking screw fixation	348	10 (2.9 %) (**)
Total:	599	22 (3.7%)

Notes: * — Column “Number of patients” shows the total number of patients with uncomplicated closed fractures of the diaphysis of the humerus who were treated in this period, who were treated using various methods. The number of iatrogenic injuries of the radial nerve is indicated as a percentage of the number of patients who were treated using each method; ** — In one case, the direct cause of iatrogenic damage was wire cerclage, used in combination with locking screw fixation

It should be noted that the use of non-locking screws refers to the early study period. Despite the low percentage of iatrogenic damage to the radial nerve when using this method, it is currently not used due to the fact that it does not meet the requirements of modern osteosynthesis.

The presence of iatrogenic damage to the radial nerve was established according to clinical data. Since 2011, after the introduction of the method of ultrasound of the peripheral nerves in our clinic, the same method has been used to assess the continuity of the nerve trunk and identify the conflict of the nerve with bone fragments and the implant. Investigations were carried out on days 1–2 after the operation, according to the standard method, on ultrasound scanners Esaote MyLab 70 (Italy) with a linear sensor and scanning frequency range of 5–10 MHz, Esaote MyLab Class C (Italy) with a linear sensor and scanning frequency range of 5 –13 MHz and convex probe 1–8 MHz. ENMG was used for instrumental verification of clinical data and assessment of the dynamics of radial nerve restoration.

After confirmation or restoration of the continuity of the nerve trunk, the therapeutic treatment of neuropathy began with measures aimed at reducing the edema of the injured segment. The patients continued their treatment on an outpatient basis or in rehabilitation hospitals. In 13 patients (59.1%), a pathogenetic treatment regimen was used, including drug, physiotherapy and mechanotherapy. The main directions of therapy were both a direct effect on the restoration of the structure and function of the damaged nerve, and improvement of trophism of the damaged segment, elimination of pain, as well as prevention of atrophy of immobilized and denervated tissues.

To assess the data of the clinical study we used scales of O. Nickolson, H. Seddon, 1957, modified at the Leningrad Research Institute of Neurosurgery [K.A. Grigorovich, 1981], where score 0 is the absence of sensitivity (S) or motor function (M), and score 5 is the norm.

RESULTS AND DISCUSSION

Comparing the number of complications in osteosynthesis with locking screws and plates, a greater number of iatrogenic injuries of the radial nerve during osteosynthesis with plates can be noted. Despite the fact that no statistically significant difference was obtained (χ^2; p = 0.127), a significant difference was observed in percentage (Table 1).

Table 2 presents data on the direct causes of iatrogenic damage to the radial nerve, diagnostic and therapeutic tactics and functional results.

Table 2
Causes of iatrogenic complications, tactics and treatment results (study group, n=22)

	Implant	Ultrasound scan	Cause of damage	Revision	Scope of operation	With rock	Result	Follow-up period
1	plate	no	plate compression	Yes	re-ostosynthesis, neurolysis	4 months	S4 M4	18 months
2	plate	no	not identified	Yes	mobilization	2	S4 M5	13 months
3	locking screw	no	distal locking screw compression	Yes	decompression screw removal	3 months	S4 M4	14 months
4	non-locking screw	no	not identified	not	-	-	S5 M5	5 months
5	plate	no	plate compression	Yes	re-ostosynthesis, neurolysis	5 months	unknown	unknown
6	locking screw	no	partial damage by distal locking	Yes	screw removal, neurolysis	6 months	S3 M4	18 months
7	locking screw + cerclage	yes	compression cerclage	Yes	fixation removal, decompression, subsequent tendon transposition	8 months, 12 months.	-	19 months
8	locking screw	no	traction	no	-	-	S4 M5	5 months
9	plate	no	not identified	no	-	-	S5 M5	8 month
10	locking screw	no	traction	no	-	-	S5 M5	11 months
11	plate	no	not identified	no	-	-	S4 M4	11 months

12	plate	yes	compression / tool traction	no	-	-	S4-5 M 4	12 months
13	locking screw	yes	traction	no	-	-	S5 M5	6 months
14	locking screw	yes	contusion with fragment	no	-	-	S5 M5	3 months
15	plate	yes	screw compression	yes	decompression screw removal	4 days	S4 M5	3 months
16	locking screw	yes	traction	no	-	-	unknown	unknown
17	locking screw	yes	contusion with fragment	no	-	-	S2 M1	2 months, observation continues
18	plate	yes	traction	no	-	-	S5 M5	6 months
19	plate	yes	compression / tool traction	no	-	-	unknown	lost
20	plate	yes	tightening screw contusion	no	-	-	S 0-1 M 3	1 month, observation continues
21	locking screw	yes	complete break with distal locking	yes	screw removal, nerve suture	5 days	S4 M0	2 months, observation continues
22	plate	yes	compression / tool traction	not	-	-	S0-1 M1-2	2 month observation continues

All operated patients underwent clinical assessment of the radial nerve function on the 1st day after surgery. Excluding false-positive results due to prolonged anesthesia, the sensitivity, specificity, and accuracy of the clinical method for detecting iatrogenic damage to the radial nerve was 100%.

Ultrasound examination (since 2011) was performed in 12 patients, of whom the results were verified in 10 cases with repeated intervention or by the dynamics of function recovery. The unimpaired nerve trunk was detected in 9 cases (90.0%) — truly negative results. In one case (10.0%), ultrasound revealed iatrogenic neurotmesis, which was confirmed intraoperatively (truly positive result). There were no false positive or false negative results. Thus, the indicators of sensitivity, specificity and accuracy were 100%. When determining the conflict of the radial nerve with the implant, 2 true positive results, 7 true negative and one false negative results were obtained. There were no false positives. Thus, the sensitivity of the method was 67%, specificity — 100%, and accuracy — 90%. We associate obtaining a false negative result with the difficulties in visualizing the radial nerve against the background of significant scars. The probability of error, although it was revealed in a small sample, prompted us to use not only imaging studies, but also ENMG, which made it possible to assess the dynamics of nerve recovery more objectively.

When performing plate osteosynthesis, there were no cases of iatrogenic neurotmesis. The most severe complication was compression of the radial nerve between the implant and the bone. We observed 2 such cases (18.2%), and before the ultrasound examination was introduced into the examination protocol, we had no opportunity to identify this conflict. In this regard, the revision was performed at a later date, 5 and 6 months after the operation, in the absence of both clinical improvement and positive dynamics of ENMG. The availability of ultrasound would allow timely detection of a conflict between the radial nerve and the implant and eliminate compression of the nerve trunk.

In one more case (9.0%), when performing osteosynthesis with a locking screw for reposition of fragments of the humerus, a wire cerclage was additionally used, which was superimposed over it as a result of insufficient visualization of the radial nerve, and led to the development of iatrogenic neuropathy. When performing a series of ultrasounds, a conflict with the implant was not detected (false-negative result), as a result, the revision was performed 8 months after the operation. Due to the unsatisfactory result of limb function restoration, the patient underwent tendon transposition.

One case of iatrogenic neuropathy of the radial nerve (9.0%) with plate osteosynthesis was associated with the compression of the nerve trunk with a screw inserted from the inside outward, with insufficient isolation of the radial nerve from the surrounding tissues. A conflict of the nerve with the implant was detected by ultrasound (Fig. 1). The screw was removed, and the radial nerve function was fully restored.

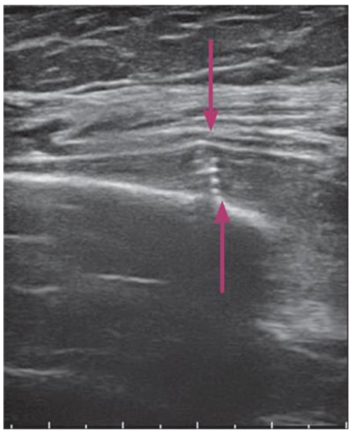


Fig. 1. Echogram, longitudinal scan. A screw extending beyond the humerus () compresses the radial nerve (↓)

In 5 cases (45.5%), ultrasound did not reveal a conflict between the radial nerve and the implant. These patients were treated conservatively. At the same time, in 2 cases, good and excellent results of recovery were obtained, in 2 cases the follow-up period was insignificant, one patient failed to follow-up.

Clinical example

A 30-year-old female patient B. fell from a height of about 1 m, got a closed comminuted fracture of the right humerus in the lower third with displacement of fragments (AR 12-B1) — Fig. 2.

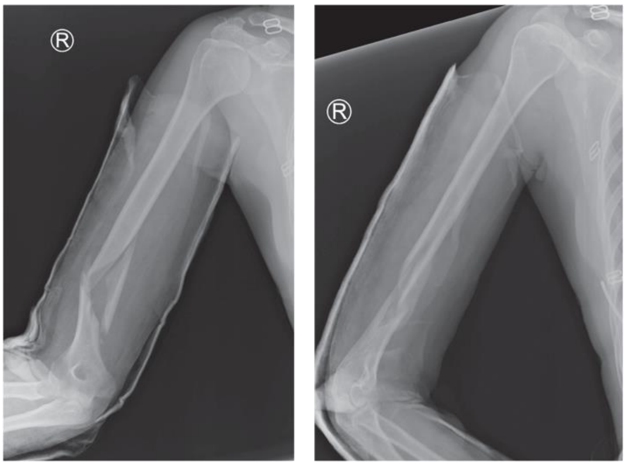


Fig. 2. X-ray images of patient B., front and lateral views

Two days after admission to the hospital, the operation was performed: plate osteosynthesis of the right humerus with angular stability (Fig. 3).

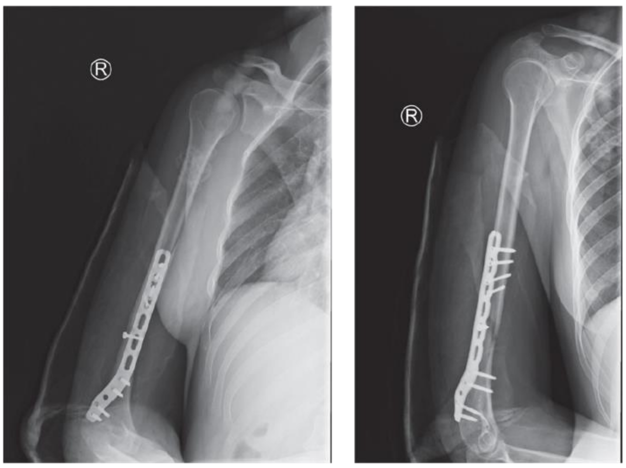


Fig. 3. X-ray images of patient B., front and lateral views. Plate osteosynthesis of the humerus. Satisfactory position of fragments and fixator

Intraoperatively, the radial nerve was mobilized throughout the entire surgical approach. After performing the osteosynthesis, the nerve was positioned over the proximal part of the plate. In the postoperative period, clinical signs of iatrogenic neuropathy of the radial nerve (S0-1; M0) were revealed. Ultrasound revealed no conflict between the radial nerve and the implant and bone fragments (Fig. 4).

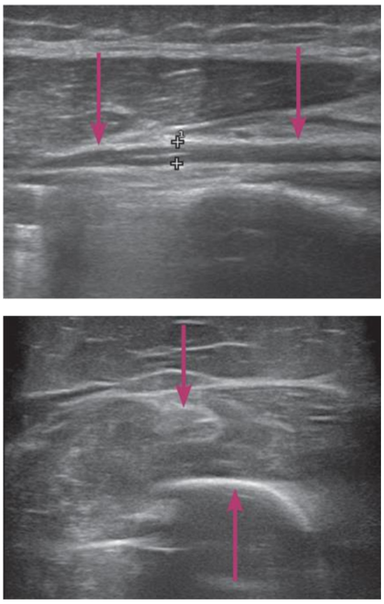
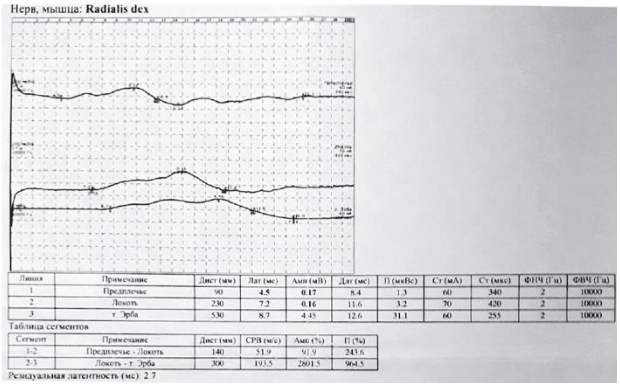


Fig. 4. Echograms of patient B., longitudinal and transverse scanning. The radial nerve is revealed (↓), signs of neuropathy are determined: differentiation into bundles and echogenicity are reduced. Conflict with fragments () and plate is not detected

The treatment was initiated to reduce soft tissue edema. Upon discharge from the hospital on the 4th day after the operation, the neurological deficit S0-1 persisted; M0.

The patient refused rehabilitative treatment in a rehabilitation hospital. Upon the control examination 2 months after the operation, the previous level of neurological deficit (S0-1, M0) remained.

Eight months after the operation, a positive trend was revealed. According to the patient, the restoration of radial nerve function began 5 months after the operation. At the time of examination, the level of sensitivity in the zone of autonomous innervation S4, extension of the hand M3-4, abduction of the 1st finger of the hand M3 were noted. At the same time, the results of ENMG revealed the persistence of significant neuropathy of the radial nerve (Fig. 5).



Нерв, мышца: Radialis dex

Линия	Примечание	Дист (мм)	Лат (мс)	Амп (мВ)	Длт (мс)	П (мкВс)	Ст (мА)	Ст (мкс)	ФНЧ (Гц)	ФВЧ (Гц)
1	Предплечье	90	4.5	0.17	8.4	1.3	60	340	2	10000
2	Локоть	230	7.2	0.16	11.6	3.2	70	420	2	10000
3	т. Эрба	530	8.7	4.45	12.6	31.1	60	255	2	10000

Таблица сегментов

Сегмент	Примечание	Дист (мм)	СРВ (м/с)	Амп (%)	П (%)
1-2	Предплечье - Локоть	140	51.9	91.9	243.6
2-3	Локоть - т. Эрба	300	193.5	2801.5	964.5

Резидуальная латентность (мс): 2.7

Fig. 5. The result of ENMG of patient B., 8 months after the injury. The significant axonal-demyelinating lesion of the right radial nerve is determined distal to the middle third of the humerus

Upon follow-up examination 1 year after the operation, the level of sensitivity in the zone of autonomous innervation S4-5, extension of the hand M4, abduction of the 1st finger of the hand M3-4 were noted (Fig. 6).

X-ray examination revealed a consolidated fracture of the humerus (Fig. 7).

Fig. 6. The photo. The clinical result of the treatment of patient B., 12 months after trauma

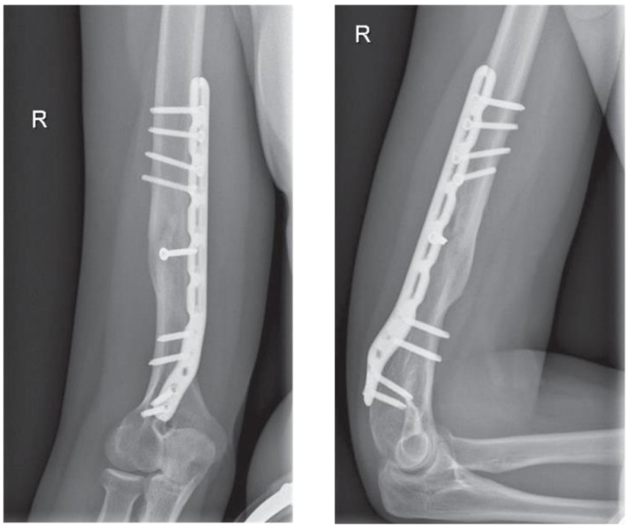


Fig. 7. X-ray images of patient B., front and lateral views. The consolidation of a fracture of the right humerus after osteosynthesis

This clinical example confirms the reasonability of refusing to revise the radial nerve in the absence of a conflict between the nerve trunk and the fragments and the implant, visually determined and confirmed by ultrasound data. We explain the relatively long period of restoration of function by the refusal of the patient to undergo comprehensive rehabilitation treatment. The dissociation of physical examination data and ENMG emphasizes the need to take into account both clinical and instrumental data when assessing the restoration of limb function.

In 3 cases (27.3%), the cause of iatrogenic damage remained unclear, since ultrasound had not yet been used in that period of the study. In one of these cases, a revision of the radial nerve was performed, and no damage was visually detected. In 2 cases, the revision was not performed. In all 3 cases, limb function recovered to the level of S4-5, M4-5.

As a result of further application of the approach with the mobilization of the radial nerve, which ensures its visualization throughout the contact of the implant with the bone, we did not receive a single case of a conflict between the radial nerve and the plate.

The main risks in closed osteosynthesis with locking screws are traction and contusion lesions during the reposition of fragments and the introduction of the screw, as well as nerve injury when performing distal locking from the outside inward. Of 9 cases of iatrogenic injuries, in 6 cases (66.7%) ultrasound examination revealed no conflict between the radial nerve and the fragments and the implant. Radial nerve revision was not performed in these cases. Functional recovery to S4-5, M4-5 levels occurred in 4 patients, one patient failed to follow-up, in one case, recovery to S2, M1 levels took place, follow-up continues.

To prevent such complications, it is necessary to avoid rough manipulations with closed reduction and advancement of the screw in the fracture area.

In 3 cases (33.3%), damage to the radial nerve occurred during distal locking. In 2 cases, with local marginal damage and compression with a screw after removal of the screw and performing neurolysis, a good functional result was obtained. In one case, iatrogenic neurotmesis occurred with distal locking. It should be noted that in all 3 cases the length of the screw was less than the length of the medullary canal of the humerus, and when performing distal locking, access to the drilling point corresponding to the projection of the hole in the screw was in the projection of the radial nerve.

Clinical example

A 76-year-old male patient M. received a closed fracture of the right humerus at the border of the upper and middle thirds with displacement of fragments (AO 12-A1) as a result of a fall on a flat surface. Closed intramedullary osteosynthesis of the humerus with a locking screw was performed (Fig. 8).

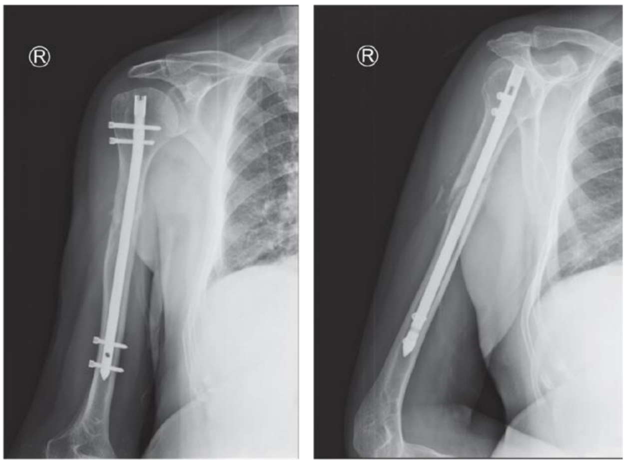


Fig. 8. X-ray images of patient M., front and lateral views. Osteosynthesis of the right humerus with a locking screw. The position of the fragments and the implant is satisfactory

According to X-ray images, it was determined that the length of the screw was 3.7 cm less than the length of the medullary canal. Distal locking was performed with two screws from the outside inward.

In the postoperative period, clinical manifestations of radial nerve neuropathy were noted, and against the background of complete loss of motor function (M0), the decrease in sensitivity was insignificant (S4).

Ultrasound revealed a break in the radial nerve at the level of the distal locking screw (Fig. 9).

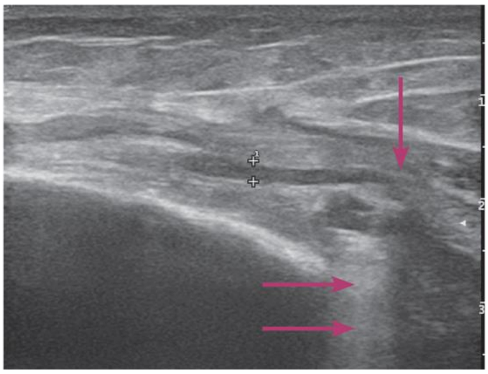


Fig. 9. Echogram, longitudinal scan. At the level of the locking screw (→), the radial nerve (++) is interrupted (↓)

The ultrasound results became the basis for revision of the radial nerve; intraoperatively, neurotmesis of the deep branch of the radial nerve with a diastasis between the ends of 0.7 cm was confirmed (Fig. 10). An abnormally high junction of the superficial branch of the radial nerve (proximal to the injury) was also revealed, which explains the impaired sensitivity.

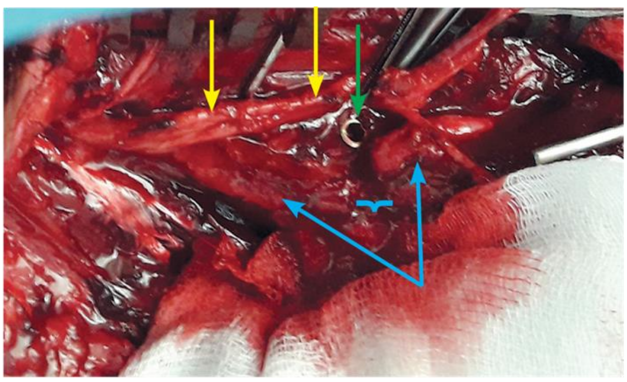


Fig. 10. Intraoperative photo. A break of the deep branch of the radial nerve ({) at the level of the locking screw (the green arrow) is determined, the proximal and distal stumps are indicated by blue arrows. The continuity of the superficial branch of the radial nerve (yellow arrows) is preserved

Mobilization, epi-perineural suture of the deep branch of the radial nerve, removal of the distal locking screw were performed (Fig. 11).

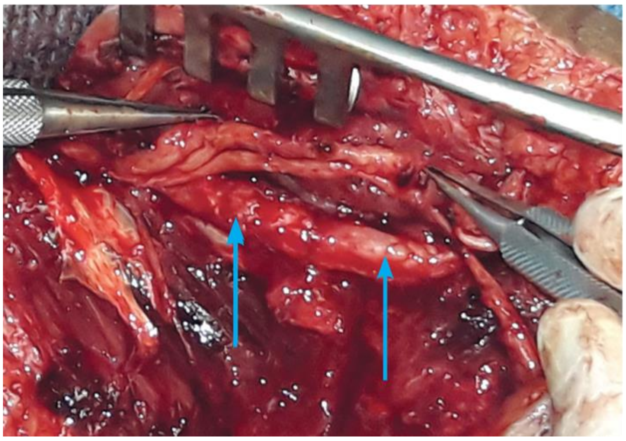


Fig. 11. Intraoperative photo. The deep branch of the radial nerve is sutured ()

Thus, postoperative ultrasound diagnostics made it possible to reliably identify the type and cause of damage to the radial nerve and to determine the indications for immediate reconstructive surgery.

To exclude such complications, it is necessary to use screws with the ability to lock outside the projection of the radial nerve. When using screws with distal locking from outside inward, we selected the length of the screw in accordance with the length of the medullary canal of the humerus. In this case, the access for locking is displaced more distally, where the radial nerve is located closer to the anterior surface of the humerus and the risk of damage to it during external access is less. Nevertheless, taking into account the possible individual characteristics of the trajectory of the radial nerve, it is necessary to access the bone before drilling the hole, making sure that there is no radial nerve in the projection of the drilling.

Of 10 patients who did not undergo early revision of the radial nerve, in 6 cases (60%) limb function recovered, in 3 cases (30%) it began to recover (with continued observations). In one case (10%), the late diagnosis of the conflict between the radial nerve and the implant led to late revision with an unsatisfactory functional outcome (Table 2). Thus, in the presence of a clinical picture of damage to the radial nerve, but the continuity of the nerve trunk determined by ultrasound and the absence of conflict with bone fragments and the implant, early revision of the nerve is not indicated due to the high probability of restoration of limb function.

In 3–18 months after the nerve injury, the results of treatment were studied in 14 patients with preserved radial nerve continuity, who had complete restoration of function. Those who received pathogenetic therapy for neuropathy (group 1, n = 7) showed a faster clinical recovery of the radial nerve function. So, the average period of initial recovery of sensitivity and movements to the level of S1-2, M1-2 points on the H. Seddon - O. Nickolson - K.A. Grigorovich was 1.20 (min 0.75; max 3.50; MD 0.30; 95% CI 0.10) months. In patients who did not undergo staged complex treatment (group 2, n = 7), this period was 2.13 (min 1.25; max 4.25; MD 0.58; 95% CI 0.20) months (Fig. 12). The average time to complete recovery to the level of S4-5, M5 in groups 1 and 2, respectively, was 3.55 (min 3.00; max 6.50; MD 0.43; 95% CI 0.13) and 5.10 (min 4.50; max 7.75; MD 0.38; 95% CI 0.12) months (Fig. 13).

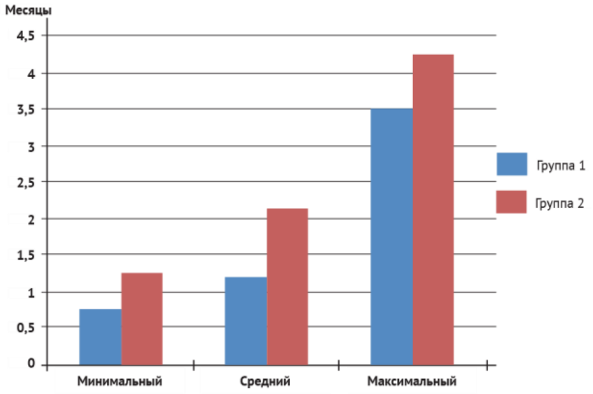


Fig. 12. Terms of the initial recovery of radial nerve function

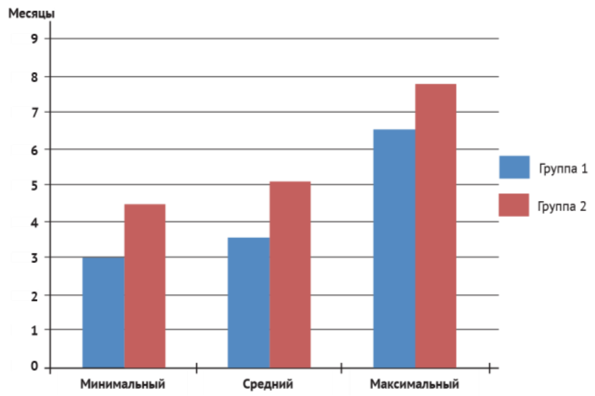


Fig. 13. Terms of complete radial nerve function recovery

Thus, a significantly faster recovery of the radial nerve function can be noted in patients who underwent complex pathogenetic treatment (Student's t-test; p = 0.004).

CONCLUSION

When performing osteosynthesis of the humerus, a significant number of iatrogenic injuries of the radial nerve are caused by compression and traction effects during reposition of fragments and manipulations with soft tissues. To prevent such damage, gross manipulations should be avoided.

In addition, in bone osteosynthesis, the cause of iatrogenic injuries is compression of the radial nerve between the bone and the plate, as well as injuries when using locking screws, therefore, it is necessary to use access to the humerus, which provides visualization of the radial nerve throughout the plate, especially in the proximal parts of it when using posterior access for distal fractures.

A specific complication when performing osteosynthesis with a screw is damage to the radial nerve during distal locking from the outside inward. Prevention consists in the selection of a screw that exactly matches the length of the medullary canal. If there is a risk of damage to the radial nerve, it is necessary to expand the access to the place of locking of the screw and perform drilling, making sure visually that there is no nerve in the operating wound or having previously taken it to the side.

Ultrasound data on the state of the radial nerve are decisive for resolving the issue of the need for its early revision after iatrogenic injury, since the ultrasound method has high diagnostic value for determining the continuity of the nerve trunk and identifying its conflict with bone fragments and an implant.

The indications for early revision of the radial nerve after iatrogenic injury are:

- neurotmesis. The purpose of the revision is to restore the integrity of the nerve;

- conflict of the radial nerve with an implant or bone fragments (interposition, compression or traction). The purpose of the revision is to eliminate the traumatic effect on the nerve.

If the continuity of the nerve trunk is preserved and there is no conflict with the implant or bone fragments, it is impractical to perform an early revision of the radial nerve, since there is a high probability of restoring the function of the limb with conservative treatment.

The use of pathogenetic therapy for neuropathy in the early stages after iatrogenic damage can accelerate the recovery of the function of the radial nerve.

REFERENCES

1. Zolotova YuA. *Profilaktika yatrogennykh povrezhdeniy luchevogo nerva pri lechenii perelomov plecha: cand. med. sci. diss. synopsis*. Yakutsk; 2016. (In Russ.)
2. Sholomova EI, Romanenko VYu, Ninel' VG, Arutyunyan TR, Sholomov II, Shul'dyakov AA. Subclinical forms of neuropathy with diaphyseal fractures of the humerus. *Saratov Journal of Medical Scientific Research*. 2012;(2):556–560. (In Russ.)
3. Shoji K, Heng M, Harris MB, Appleton PT, Vrahas MS, Weaver MJ. Time from injury to surgical fixation of diaphyseal humerus fractures is not associated with an increased risk of iatrogenic radial nerve palsy. *J Orthop Trauma*. 2017;31(9):491–496. PMID: 28459772 https://doi.org/10.1097/BOT.0000000000000875
4. Kkhir Bek M. *Kompleksnaya diagnostika i optimal'nyy podkhod k lecheniyu travmaticheskikh povrezhdeniy luchevogo nerva: cand. med. sci. diss. synopsis.* Moscow; 2009. (In Russ.)
5. Zhivolupov SA. *Travmaticheskie nevropatii i pleksopatii (patogenez, klinika, diagnostika i lechenie): dr. med. sci. diss. synopsis*. Saint Peterburg; 2000. (In Russ.)
6. Skoroglyadov AV, Sokov EL, Afanas'ev DS, Al'zamnl' Khalil M. Novoe v diagnostike i lechenii patsientov s nevrologicheskimi oslozhneniyami pri zakrytykh perelomakh i vyvikhakh plecha. *Russian Medical Journal*. 2006;(1):20–23. (In Russ.)
7. Gubochkin NG, Ivanov VS, Tkachenko MV. Struktura povrezhdeniy dlinnykh vetvey plechevogo spleteniya i otdalennye rezul'taty nevroliza u patsientov s zastarelymi travmami verkhney konechnosti. *Traumatology and Orthopedics of Russia*. 2006;2(40):89. (In Russ.)
8. Schwab TR, Stillhard PF, Schibli S, Furrer M, Sommer C. Radial nerve palsy in humeral shaft fractures with internal fixation: analysis of management and outcome. *Eur J Trauma Emerg Surg*. 2018;44(2):235–243. PMID: 28280873 https://doi.org/10.1007/s00068-017-0775-9
9. Claessen FM, Peters RM, Verbeek DO, Helfet DL, Ring D. Factors associated with radial nerve palsy after operative treatment of diaphyseal humeral shaft fractures. *J Shoulder Elbow Surg*. 2015;24(11):307–311. PMID: 26341025 https://doi.org/10.1016/j.jse.2015.07.012
10. Neverov VA, Chernyaev SN, Shinkarenko DV. Therapeutic Approach to Humeral Bone Fractures Complicated by Peripheral Nerve Trauma. *Grekov's Bulletin of Surgery*. 2015;174(6):42–45. (In Russ.) https://doi.org/10.24884/0042-4625-2015-174-6-42-45
11. Odinak MM, Zhivolupov SA. *Zabolevaniya i travmy perifericheskoy nervnoy sistemy (obobshchenie klinicheskogo i eksperimental'nogo opyta)*. Saint Peterburg: SpetsLit Publ.; 2009. (In Russ.)

12. Reichert P, Wnukiewicz W, Witkowski J, Bocheńska A, Mizia S, Gosk J, Zimmer K. Causes of secondary radial nerve palsy and results of treatment. *Med Sci Monit*. 2016;22:554–562. PMID: 26895570. https://doi.org/10.12659/MSM.897170
13. Kasatkina LF, Gil'vanova OV. *Elektromiograficheskie metody issledovaniya v diagnostike nervno-myshechnykh zabolevaniy. Igol'chataya miografiya*. Moscow: Medika Publ.; 2010. (In Russ.)
14. Aleynikova IB, Sachkov AV, Kasatkin DS, Mazhorova II, Grin' AA. Povrezhdeniya perifericheskikh nervov. In: Krylov VV (ed.) *Neyrokhirurgiya i neyroreanimatologiya*. Moscow: ABV-press Publ.; 2018. (In Russ.)
15. Peer S, Bodner G, Meirer R, Willeit J, Piza-Katzer H. Examination of postoperative peripheral nerve lesions with high-resolution sonography. *AJR Am J Roentgenol*. 2001;2:415–419. PMID: 11461873 https://doi.org/10.2214/ajr.177.2.1770415
16. Toros T, Karabay N, Ozaksar K, Sugun TS, Kayalar M, Bal E. Evaluation of peripheral nerves of the upper limb with ultrasonography: a comparison of ultrasonographic examination and the intraoperative findings. *J Bone Joint Surg Br*. 2009;91(6):762–765. PMID: 19483229 https://doi.org/10.1302/0301-620X.91B6.22284
17. Alaqeel A, Alshomer F. High resolution ultrasound in the evaluation and management of traumatic peripheral nerve injures: review of the literature. *Oman Med J*. 2014;29(5):314–319. PMID: 25337305 https://doi.org/10.5001/omj.2014.86
18. Maletskiy EY, Korotkevich MM, Butova AV, Alexandrov NY, Itskovich IE. Measurements of Peripheral Nerves: Comparison of Ultrasound, MRI and Direct Intraoperative Data. *Medical Visualization*. 2015;(2):78–86. (In Russ.)
19. Martel II, Meshcheryagina IA, Mitina YuL, Rossik OS, Mikhailova EA. MR-Image Diagnostics of Injuries of Peripheral Nerves. *Acta Biomedica Scientifica*. 2011:4(80):119–123. (In Russ.)
20. Kim S, Choi JY, Huh YM, Song HT, Lee SA, Kim SM, et al. Role of magnetic resonance imaging in entrapment and compressive neuropathy—what, where, and how to see the peripheral nerves on the musculoskeletal magnetic resonance image: part 2. Upper extremity. *Eur Radiol*. 2007;17(2):509–522. PMID: 16572333 https://doi.org/10.1007/s00330-006-0180-y
21. Niver GE, IIyas AM. Management of radial nerve palsy following fractures of the humerus. *Orthop Clin North Am*. 2013;44:419–424. PMID: 23827843 https://doi.org/10.1016/j.ocl.2013.03.012
22. Sholomova EI, Arutyunyan TR, Salina EA, Sholomov II. Neyroprotektsiya v lechenii posttravmaticheskikh neyropatiy. *Poliklinika*. 2012;(1–2):45–47. (In Russ.)
23. Bogolyubsky YA, Klyukvin IY, Slastinin VV. Current State of Diagnosing and Treatment of Closed Dyaphiseal Fractures of the Humerus Complicated by Radial Nerve Palsy. *Russian Sklifosovsky Journal Emergency Medical Care*. 2015;(4):30–38. (In Russ.)
24. Schetkin VA, Chukina EA, Vorontsov YA. An Exercise Therapy in Patients With Intra-Articular Fractures in the Distal Part of Humerus. *Russian Sklifosovsky Journal Emergency Medical Care*. 2013;(4):35–38. (In Russ.)

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