DOI 10.18019/1028-4427-2020-26-3-313-318

Prevention of minimally invasive plate osteosynthesis (mipo) complications in diaphyseal humerus fractures: a cadaveric topographic anatomical study

D.V. Volchenko[1], A.Yu. Terskov[1], I.F. Akhtiamov[2], Yu.D. Udalov[1], O.A. Sozonov[1], M.N. Velichko[1], E.Ya. Shpiz[1], E.I. Sidoruk[2]

[1]Russian State Research Center Burnasyan Federal Medical Biophysical Center of Federal Medical Biological Agency, Moscow, Russian Federation
[2]Kazan State Medical University, Kazan, Russian Federation

Background Minimally invasive plate osteosynthesis (MIPO) corresponds to the modern principles of "biological" fixation as it implies closed reduction and plate insertion causing minimal iatrogenic trauma. However, the lack of direct visualization increases the risk of damage to important anatomical structures. **Purpose** To develop recommendations in the use of MIPO for diaphyseal fractures of the humerus from anterolateral approaches to prevent possible complications and improve the results. **Methods** 16 shoulders of fresh cadavers were included in the study. In all cases, MIPO was performed with a straight plate (10–12 holes) and screws (2 proximal and 2 distal) using two anteriolateral approaches. Complete revision of the shoulder area was carried out in order to determine the accuracy of plate location and the relationship between the implant, neurovascular structures and bone landmarks. **Results** No damage or compression of the neurovascular and tendomuscular humerus structures was revealed. The average distance from the acromion to n. axillaris was 5.8 ± 0.66 mm (range from 4.9 to 6.9 mm). The average distance from the lateral epicondyle of the humerus to n. musculocutaneus was 56.5 ± 4.66 mm (from 49 to 63 mm). We observed the difference in location at the extreme pronation (5.1 ± 0.33 mm, from 4.5 to 5.7 mm) and supination positions of the forearm (5.8 ± 0.6 mm, from 5.1 to 6.1 mm) measuring the distance between the edge of the plate and n. radialis. The average distance between the distal medial edge of the plate and a. brachialis, n. medianus was 17.1 ± 2.7 mm (from 13 to 21 mm). **Conclusions** Based on the obtained data, we offer MIPO recommendations for anterolateral accesses in diaphyseal fractures of the humerus. Compliance with the proposed recommendations will reduce the risk of iatrogenic damage and improve the results of humeral fractures treatment.

Keywords: minimally invasive plate osteosynthesis (MIPO), humerus, fracture, diaphysis, plate

INTRODUCTION

The incidence of humerus diaphysis fractures is 1–5 % of all skeletal fractures [1, 2]. Conservative and surgical methods of treating such injuries have their merits and shortcomings. Long-term plaster or adequate immobilization, as a rule, leads to frequent contractures of the elbow and shoulder joints, deformities of the humerus, delayed consolidation and worsens patients' quality of life [3, 4]. Surgical treatment enables to more accurately restore the anatomical structure, predict the restoration of the function of the upper limb, and reduce the risk of secondary displacement and malunion [5, 6].

Variants of surgical interventions for fractures of the humerus are intramedullary, extramedullary, extrafocal osteosynthesis [7, 8, 9]. The choice of one or another fixation method is made taking into account the nature of the injury, concomitant damage to soft tissues, bone quality, fracture location, etc.

The shortcomings of open reduction and internal osteosynthesis are trauma, impaired blood supply to the fracture area, and incidence of infectious complications [10, 11, 12]. To reduce the volume of iatrogenic injury, B. Livani and W.D. Belangero proposed a method of minimally invasive plate osteosynthesis (MIPO) of the humerus from anterolateral approaches, involving the implantation of straight plates for bridge fixation [13]. However, there is a risk of conflict between the implant and the long head of the biceps brachii by using this method for fractures in the upper third of the humerus. To prevent this complication, A.A. Fernandez Dell'Oca proposed an original technique of osteosynthesis with helical plates, allowing the placement of implants distally along the anterior and proximally along the lateral surface of the humerus [14].

In most cases, the MIPO for fractures in the middle and lower third of the humerus can be performed with straight plates from two small anterolateral surgical approaches without exposing the fracture area. It prevents damage to the periosteum, does not impair blood circulation, and allows preserving hematoma between bone fragments. However, the insertion of the plate without direct visualization has the risk of damaging important anatomical structures. In this regard,

Volchenko D.V., Terskov A.Yu., Akhtiamov I.F., Udalov Yu.D., Sozonov O.A., Velichko M.N., Shpiz E.Ya., Sidoruk E.I. Prevention of minimally invasive plate osteosynthesis (mipo) complications in diaphyseal humerus fractures: a cadaveric topographic anatomical study. *Genij Ortopedii*, 2020, vol. 26, no 3, pp. 313-318. DOI 10.18019/1028-4427-2020-26-3-313-318

the aim of our study was to clarify the recommendations and technical nuances of minimally invasive plate osteosynthesis of the humerus to simplify the surgical procedure and avoid possible complications.

In accordance with the aim, the following tasks were set: to conduct a topographic and anatomical study in order to clarify the interposition of the anatomical structures of the upper arm with an increased risk of injury in the minimally invasive technique of humerus osteosynthesis with straight on-bone implants from anterolateral approaches and to determine technical nuances for prevention of possible complications.

MATERIAL AND METHODS

A topographic and anatomical study of 16 segments of the intact upper limbs (average length of the humerus 287.4 ± 5.4 mm) was conducted on 8 unfixed corpses (5 men, 4 women, average age 68.1 ± 5.8 years, from 61 years to 82 years old). MIPO of the humerus was performed with a straight plate (10–12 holes) and screws from two anterolateral approaches.

Proximal mini-approach: a skin incision about 4 cm long along the anterolateral surface of the humerus in its upper third at a distance of about 6 cm from the coracoid process. Approach to the anterior surface of the humerus is performed in the space between the medial edge of m. deltoideus and lateral edge of the proximal m. biceps brachii (Fig. 1 a, b, c, d).

Distal approach (Fig. 2): a skin incision about 5 cm long along the anterolateral surface of the humerus in its lower third, 5 cm proximal to the bending of the elbow (Fig. 1 a, b). The approach was made between the lateral edge of the biceps muscle and m. brachialis with mandatory visualization of n. musculocutaneus (Fig. 2 d). Further on, the fibers of m. brachialis were bluntly separated in the longitudinal direction in the middle third to create the exposure to the anterior surface of the humerus. Thereby, the medial portion of the muscle protects n. musculocutaneus, a. brachialis and n. medianus, and the lateral portion protects n. radialis from direct compression with instrumentation (Fig. 2 e, f).

To position the plate on the anterior surface of the humerus, we formed an axillary extraperiosteal canal using raspatory. This step can be performed from the proximal (antegrade) or distal (retrograde) approach.

The peculiarities of installing plates using a minimally invasive method include certain difficulties in creating an extraperiosteal canal in the area of the tendon attachment of m. deltoideus (in the upper third, anterolateral surface) and m. brachialis (in the middle third along the anterior surface). Thus, a sharp raspatory was used to detach the tendon fibers from the periosteum in the locations indicated above.

In a comparative assessment of the antegrade and retrograde techniques for creating an extraperiosteal canal, we should note the following. From the proximal approach, there is a difficulty in detaching the tendon attachment m. brachialis with a tendency to displacement of the raspatory along its anterior surface. Therefore, it is necessary to carefully monitor the location of the instrument and avoid its lateralization (risk of damage to n. radialis) and excessive medialization (risk of damage to a. brachialis, n. medianus).

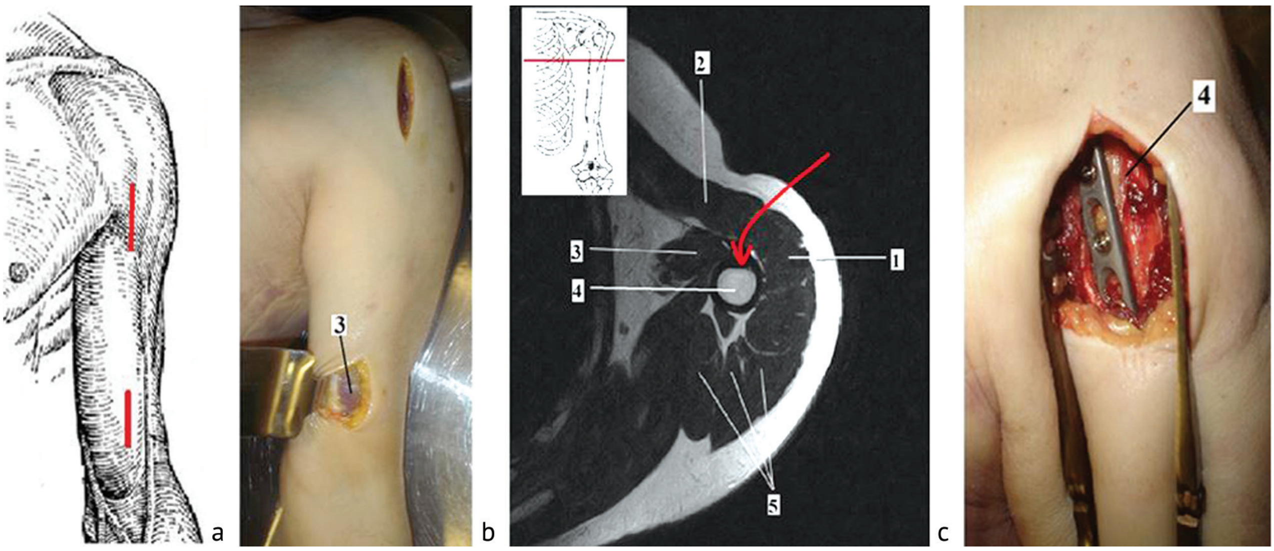

Fig. 1 Proximal and distal anterolateral approaches for minimally invasive plate osteosynthesis of the left humerus: a, b skin incisions; c proximal anterolateral approach: MRI axial slice in the region of the proximal humerus, red arrow – surgical approach; d implanted plate in the proximal part of the left humerus; 1 – m. deltoideus; 2 – m. pectoralis major; 3 – m. biceps brachii; 4 – os humerus; 5 – m. triceps brachii

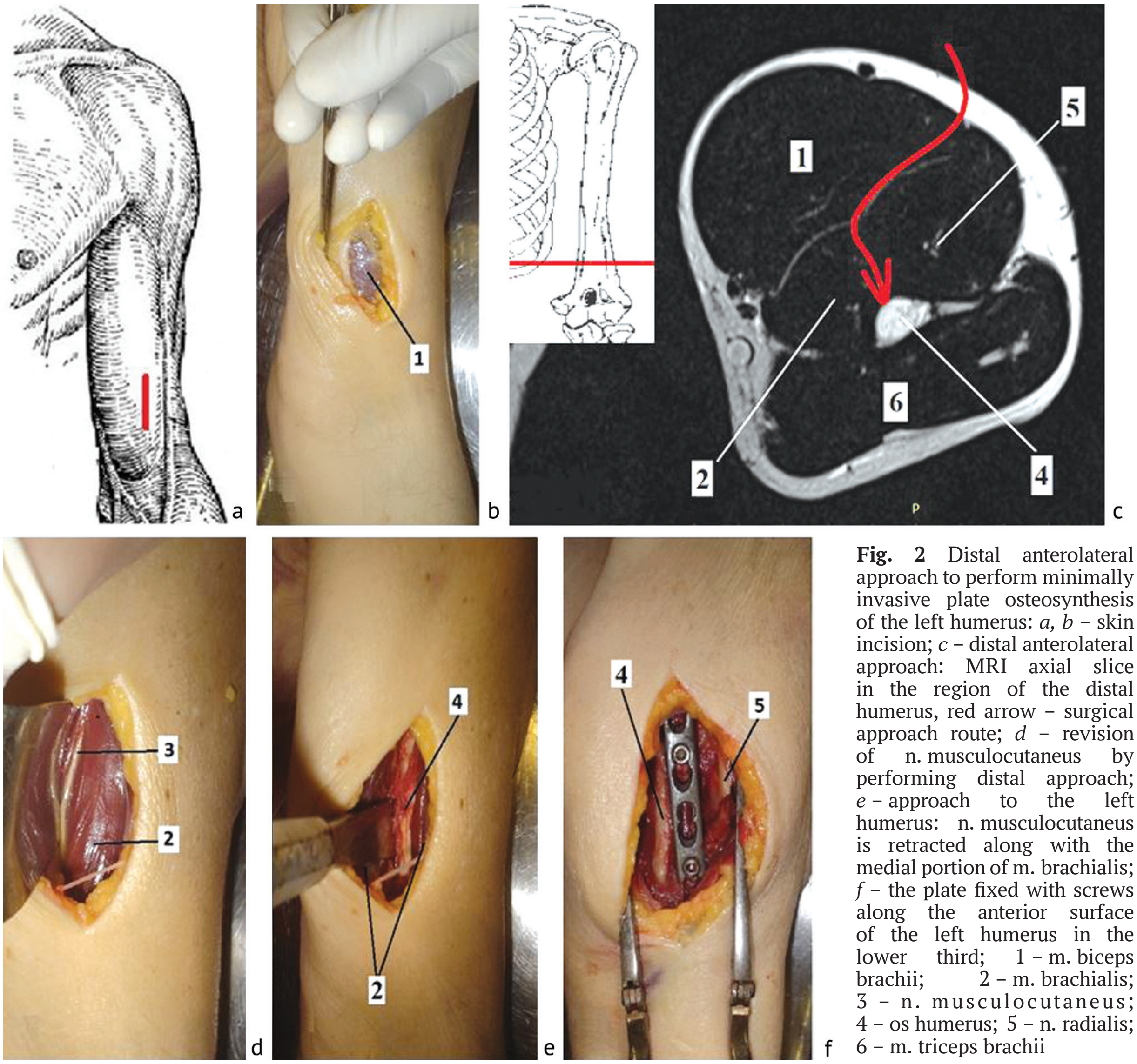

Fig. 2 Distal anterolateral approach to perform minimally invasive plate osteosynthesis of the left humerus: *a, b* – skin incision; *c* – distal anterolateral approach: MRI axial slice in the region of the distal humerus, red arrow – surgical approach route; *d* – revision of n. musculocutaneus by performing distal approach; *e* – approach to the left humerus: n. musculocutaneus is retracted along with the medial portion of m. brachialis; *f* – the plate fixed with screws along the anterior surface of the left humerus in the lower third; 1 – m. biceps brachii; 2 – m. brachialis; 3 – n. musculocutaneus; 4 – os humerus; 5 – n. radialis; 6 – m. triceps brachii

When the axillary extraperiosteal canal is formed in the retrograde direction in the region of the attachment point of m. brachialis to the humerus, the raspatory should rest on the tendon fibers that run in the opposite direction. It simplifies their detachment from the periosteum and provides better control over the position of the instrument on the surface of the humerus. Based on the above, the safest way is to create the canal from the distal anterolateral mini-approach in the proximal direction.

At the next step of the surgical intervention, a plate was inserted into the formed axillary extraperiosteal canal and positioned along the anterior surface of the humerus. After installing the implant coaxially with the diaphysis, the distal and proximal ends were fixed with screws.

Further, a complete layer-by-layer revision of the upper arm area was performed. The accuracy of the plate location was assessed, the distance between the distal lateral edge of the plate and n. radialis was measured (in positions of extreme pronation and supination of the forearm), a. brachialis and n. medianus, distances from the acromion to n. axillaris and between the lateral epicondyle of the humerus and n. musculocutaneus and the presence of damage to anatomical structures.

Statistical processing of the data was carried out using the IBM SPSS Statistics v.23 program. All results are presented as mean distances (μ), standard deviation (σ), maximum and minimum values were also determined.

RESULTS

In all cases, a coaxial position of the plate with the humerus was achieved. We did not identify a single case of compression of the shoulder muscles located in the area of surgical intervention. The implants were placed on the anterior surface of the humerus.

The main anatomical structures at increased risk of injury while performing MIPO of the humerus with a minimally invasive technique from anterolateral approaches are listed in Table 1.

None of the cases showed compression of n. radialis with the plate; however, when using elevators and with rough mechanical manipulations, it may be compressed in the area of the distal approach lateral to the plate (Fig. 2 f). It should be noted that the distance between the radial nerve and the plate changes depending on the position of the forearm with a tendency to increase in supination. This fact should be taken into account while performing this surgical intervention.

The data on mean distances between implants and anatomical structures of the upper arm are given in Table 2.

Revision of the proximal approach did not reveal any lesions to n. axillaris and a. circumflexa humeri posterior et anterior. No compression of the tendon of the long head of the biceps brachii was detected. In each case, visual control was used for n. musculocutaneus while performing the distal approach.

Based on the observations made, we specified the areas of increased risks of the damage to the main neurovascular and tendon-muscle formations of the upper arm, which are presented in Table 3.

Table 1

Anatomical structures at risk of being injured

Proximal approach	Distal approach
n. axillaris	n. radialis
a. circumflexa humeri posterior, anterior	n. musculocutaneus
caput longum musculus biceps brachii	n. medianus
v. cephalica	a. brachialis

Table 2

Mean distances between anatomical structures of the humerus and implants

	Distance between the plate end and n. radialis		Distance between the distal medial edge of the plate and a. brachialis and n. medianus	Distance from acromion to n. axillaris	Distance between lateral epicondyle of the humerus and n. musculocutaneus
	Pronation	Supination			
Mean (μ ± σ mm)	5.1 ± 0.33	5.8 ± 0.6	17.1 ± 2.7	5.7 ± 0.69	56.5 ± 4.66
Minimum (mm)	4.5	5.1	13	4.9	49
Maximum (mm)	5.7	6.1	21	6.9	63

Table 3

Anatomical regions at higher risks of injuries around the humerus

Anatomical formation	Area of increased risk of surgical injury
n. axillaris, a. circumflexa humeri posterior et anterior	• 5–7 cm distal of the acromion while performing the proximal approach
n. musculocutaneus	• 5–7 cm lateral of the humerus epicondye while performing distal approach
n. radialis	• Middle third of the humerus along the posterior surface (by drilling and screw insertion from anterior to posterior) • Lower third by the use of elevators
caput longum musculus biceps brachii	• By performing proximal approach • If plate is located at the level of the greater tubicle, the mechanical conflict is possible with the edge of the implant
n. medianus, a. brachialis	• By performing the distal approach
v. cephalica	• By performing the proximal approach • By performing the distal approach

DISCUSSION

The MIPO technique with the use of modern instrumentations becomes popular. The number of works devoted to it for fractures of the humerus has been growing.

Topographic and anatomical investigations studied most often separate anatomical structures.The work of T. Apivatthakakul et al. (2005) paid particular attention to the interposition of n. radialis and plates. The authors performed MIPO of the humerus from anterior approaches on 10 cadaver preparations. None of the cases showed compression of n. radialis. The distance between the nerve and the plate was also measured in the positions of extreme supination and pronation of the forearm, which was 2.0–4.9 mm (average, 3.2 mm) and 0–3 mm (average, 0.82 mm), respectively. Based on the data obtained, the researchers concluded that it is possible to perform MIPO of the humerus from the anterior approaches and proposed to perform the distal approach with complete supination of the forearm. In our study, we also evaluated the change in the distance between n. radialis and an implant in extreme pronation and supination of the forearm. Despite the absence of a significant difference in our results (Table 2), the described technical nuance, undoubtedly, should be taken into account to reduce the likelihood of iatrogenic nerve damage.

The next study of T. Apivatthakakul et al. (2010) evaluated the likelihood of injury to n. musculocutaneus in plating. According to the data obtained, the zone of an increased risk during screw placement is located at a distance of 5.46–12.86 cm from the lateral epicondyle of the humerus [16]. M.J. Gardner et al. (2005) identified areas of increased risks of n. musculocutaneus injury in osteosynthesis with simulated plates. It was found that its damage is most likely at an average distance of 13.5 cm from the greater tubercle of the humerus (from 12.2 to 14.8 cm) [17]. Our results on the location of n. musculocutaneus in relation to the humerus are consistent with previous studies. Performing a distal approach in the course of the operation, its compression with instruments and damage is prevented by direct visualization and a medial portion of m. brachialis.

An interesting study by A.Yu. Kochish et al. (2016) was dedicated to the possibility of performing osteosynthesis with spirally curved modeled plates in fractures of the humerus diaphysis from anterolateral approaches. The authors assessed the relative position of such plates with the main anatomical structures of the upper arm. Their topographic and anatomical studies found that the installation of implants according to the proposed method avoids damage to the axillary, radial, musculocutaneous and median nerves, brachial and deep arteries and the tendon of the long head of the biceps brachii [18]. It should be noted that, in our opinion, the need for modeling structures arises in the osteosynthesis of fractures in the upper third of the humerus and the location of the implant at the level of the sulcus intertubercularis; in other cases, fixation is possible with straight plates with installation along the anterior surface.

Despite a large number of studies confirming the possibility and safety of MIPO of the humerus, it cannot be denied that the likelihood of traumatizing important anatomical structures in this area is extremely high. Severe edema and deformity of the limb, in many cases, make it difficult to accurately determine the location of anatomical landmarks. There is also a significant variability in anthropometric data, which has a great influence on the results of measuring the distances between the implant, neurovascular and tendon-muscle formations [19]. Therefore, the identification of areas in which the likelihood of damage to important anatomical structures is highly relevant. It will enable to propose measures for the prevention of iatrogenic damage.

In our study, in addition to previously published works, we tried to determine the main features of minimally invasive placement of plates on the anterior surface of the humerus, to offer recommendations and to focus on technical nuances that might simplify the surgical procedure and avoid possible complications.

CONCLUSIONS

Based on the data of the topographic and anatomical study and the analysis of available publications on this topic, we propose to the following recommendations in the performance of MIPO for diaphyseal fractures of the humerus.

1. In the area of distal approach, the anatomical structures of the upper arm at high risk of injury are n. musculocutaneus and n. radialis; the area of increased risk of damage to n. musculocutaneus is located at a distance of 5–7 cm from the lateral epicondyle of the humerus.

2. To prevent an intraoperative iatrogenic damage to n. musculocutaneus, its direct visualization and protection with the help of the medial portion of m. brachialis by dissecting it along the midline with the formation of a lateral and medial portions.

3. By performing the distal anterolateral mini-approach, it is advisable to obtain maximum supination of the forearm, which reduces the likelihood of injury to n. radialis while executing the distal approach.

4. Use of elevators and rough mechanical manipulations to widen the wound in distal approach (especially lateral) should be avoided due to an increased risk of compression n. radialis.

5. In the area of the proximal approach, the anatomical structures of the upper arm at high risk of injury are n. axillaris and aa. circumflexa humeri posterior et anterior circumflexa humeri posterior et anterior, zone of increased risk of damage to n. axillaris is located 5-7 cm distal to the acromial process of the scapula; direct visualization of the n. axillaris with associated vessels will make the manipulation safe.

6. The safest is to create an axillary extraperiosteal canal in the proximal direction from the distal approach.

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Received: 29.01.2020

Information about the authors:

1. Denis V. Volchenko, M.D., Ph.D.,
Burnasyan Federal Medical Biophysical Center FMBA, Moscow, Russian Federation,
Email: den4099@yandex.ru
2. Aleksandr Yu. Terskov, M.D., Ph.D.,
Burnasyan Federal Medical Biophysical Center FMBA, Moscow, Russian Federation,
Email: terskov72@mail.ru
3. Ildar F. Akhtyamov, M.D., Ph.D., Professor,
Kazan State Medical University, Kazan, Russian Federation,
Email: yalta60@mail.ru
4. Yuri D. Udalov, M.D., Ph.D.,
Burnasyan Federal Medical Biophysical Center FMBA, Moscow, Russian Federation,
Email: udalov@fmbcfmba.ru
5. Oleg A. Sozonov, M.D.,
Burnasyan Federal Medical Biophysical Center FMBA, Moscow, Russian Federation,
Email: brachio@gmail.com
6. Maksim N. Velichko, M.D.,
Burnasyan Federal Medical Biophysical Center FMBA, Moscow, Russian Federation,
Email: maxveldoc@yandex.ru
7. Evgeny Ya. Shpiz, M.D.,
Burnasyan Federal Medical Biophysical Center FMBA, Moscow,
Email: shpiz@inbox.ru
8. Egor I. Sidoruk, M.D.,
Kazan State Medical University, Kazan, Russian Federation,
Email: ego7@list.ru