DIGEST AND REVIEWS

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Surgical treatment of the proximal humerus fractures in patients with osteoporosis. Problematic issues and development prospects

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Fractures of the proximal part of the humerus (FPPH) are the third most common in the elderly after fractures of the femur and radius. Objective. On the basis of analysis of the literature to identify problematic issues of surgical treatment of patients with FPPH and osteoporosis and prospects for improving implants and algorithms treatment. Methods. The material of the study was the scientific papers available in Google search engines, PubMed, Medline, published in specialized sources. Results. It is shown that are used today there are Neer and AO/OTA classifications of FPPH. Conservatively manage of FPPH in 80 % of patients with two-fragmentary fractures according to Neer or type A2/A3 according to AO/OTA. The remaining 20 % patients have three- and four-segment FPPH (types B and C according to AO/OTA), the conservative treatment of which consists of problem, especially in patients with osteopenia and osteoporosis. Surgical treatment of FPPH is recommended in case of fractures types 11B2-3, 11C2-3 in young patients or in the elderly age that requires significant functionality of the upper extremity. Positive results of treatment of FPPH types 11B3, 11C2-3 on the background of osteoporosis obtained after installation LCP-plates with allo- or autograft from the fibula bones, as well as support screws, filling of cavities in the humerus head fragments with bone cement, or using free bone implants are most often used. These methods achieve and support to enable stable repositioning of even complex type fractures 11C2-3. Blocked intramedullary nails of the third generation have improved mechanisms for attaching proximal screws and specific fixation of bone fragments, as well as straight geometry. Primary reverse shoulder arthroplasty in case of type 11C2, 11C3 fractures according to AO/OTA enables to obtain positive results in most patients. Conclusions. Surgical treatment of patients with FPPH is advisable for active patients, it is possible to improve functional results compared to conservative manage and avoid the most complications of it.

Переломи проксимального відділу плечової кістки (ППВПК) є третіми за поширеністю в людей похилого віку після переломів стегнової та променевої кісток. Мета. На підставі аналізу літератури визначити проблемні питання хірургічного лікування пацієнтів із ППВПК та остеопорозом і перспективи вдосконалення імплантатів і алгоритмів лікування. Методи. Матеріалом дослідження були відповідні наукові роботи, доступні в пошукових системах Google, PubMed, Medline, опубліковані в спеціалізованих джерелах. Результати. Показано, що сьогодні використовуваними є класифікації ППВПК Neer та AO/OTA. Консервативно лікують ППВПК у 80 % пацієнтів із двофрагментарними переломами за Neer або типу A2/A3 за AO/OTA. У решти 20 % хворих трапляються три- та чотирифрагментарні ППВПК (типи B і C за AO/OTA), консервативне лікування яких є складною проблемою, особливо на фоні остеопенії та остепорозу. Хірургічне лікування ППВПК рекомендовано в разі переломів типів 11B2-3, 11C2-3 у молодих пацієнтів або в осіб похилого віку, яким необхідна значна функціональність верхньої кінцівки. Позитивні результати лікування ППВПК типів 11B3, 11C2-3 на фоні остеопорозу отримані після встановлення LCP-пластин і ало- або автоімплантатів із малогомілкової кістки. Медіальні опорні гвинти, заповнення порожнин у кістці й аугментація наконечника гвинта кістковим цементом, застосування кісткових імплантатів є найчастіше застосовуваними методами. Вони дають змогу досягти та підтримувати стабільну репозицію навіть складних переломів типу 11C2-3. Блоковані інтрамедулярні цвяхи третього покоління мають удосконалені механізми кріплення проксимальних гвинтів і специфічну фіксацію фрагментів кістки, а також пряму геометрію. Первинне реверсивне ендопротезування плечового суглоба в разі переломів типів 11C2, 11C3 за AO/OTA дає змогу отримати позитивні результати в більшості пацієнтів. Висновки. Хірургічне лікування пацієнтів із ППВПК доцільне, можна покращити функціональні результати порівняно з консервативним і уникнути післяопераційних ускладнень. Ключові слова. Перелом проксимального відділу плечової кістки, відкрита репозиція та внутрішня фіксація, пластини з кутовою стабільністю, інтрамедулярні блоковані цвяхи, аугментація цементом, алоімплантат із малогомілкової кістки

Key words. Proximal humerus fracture, open reduction and internal fixation, plates with angular stability, LCP, intramedullary locking nails, cement augmentation, fibula allograft and autograft

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Introduction

Proximal humerus fractures (PHFs) make up 5–6 % of all fractures [1, 2]. This is the third most common fracture in the elderly [3]. As a result of demographic changes in developed countries, the number of PHFs will continue to increase sharply, especially in women [1]. In southern Europe, the incidence rate was 89.3 per 100,000 compared to 28.2 in men [4]. In Australia, the frequency of PHFs increased from 28.5 per 100,000 people in 2008 to 45.7 in 2017 [5]. In Australia, women over 85 years of age had the highest incidence of PHFs in 2017 at 711.8 cases per 100,000 [5], while the US averaged 600 cases per 1,000,000 annually. The increased incidence of PHFs is associated with the growth of the elderly and senile population [2, 4, 6–9].

PHF is usually diagnosed in young people as a result of high-energy trauma or in elderly and senile people after low-energy trauma against the background of osteopenia and osteoporosis [10]. The number of PHFs is expected to increase with the aging of the population, and it is the third most common type of fracture [11]. The tactics of treating patients with PHFs depends on many factors, including the type of fracture, the level of activity of the individual, concomitant diseases, age, and presence of osteopenia or osteoporosis [12, 13].

Most patients older than 65 years with PHFs undergo conservative treatment [14]. If there are indications, patients undergo surgical treatment, such as open reduction and internal fixation (ORIF), closed reduction and percutaneous fixation, blocked intramedullary osteosynthesis (BIOS), hemiarthroplasty (HA), total anatomic shoulder arthroplasty (TSA) and reversible total shoulder arthroplasty (RSA) [15, 16].

Purpose: based on the analysis of the literature, to determine the problematic issues of surgical treatment of patients with fractures of the proximal part of the humerus and osteoporosis and prospects for improving implants and treatment algorithms.

Material and methods

The material of the investigation comprised relevant scientific studies available in the search engines Google, PubMed, Medline, published in specialized sources. The search depth was 10 years.

Results and their discussion

The classification of PHFs was first proposed in 1934 by Codman, who defined fractures based on four anatomical parts: the diaphysis of the humerus, the articular surface, the greater and lesser tubercles [17]. However, displacement of the fracture was not taken into account, surgical and anatomical fractures of the neck of the humerus were not distinguished [18, 19].

The most widely used and generally recognized system is Neer (1970), according to which fractures are divided into six groups: I — minimal displacement, less than 1 cm or at an angle of less than 45º; II — displacement of the proximal part (anatomical neck of the humerus); III — displacement at the level of the surgical neck of the humerus; IV — movement of the greater tubercle of the humerus, which is divided into two parts without displacement at the level of the surgical neck, into three parts — with displacement, four — with fracture and displacement of the lesser tubercle; V — displacement of the small tubercle, which has the same signs as IV group with division into two, three or four parts; VI — fractures associated with dislocation of a part of the head, which are also divided into two, three or four parts [18–20].

According to AO/OTA (formerly AO/ASIF), PHFs are classified on the basis of damage to the articular surface, anatomical location, and dislocation [21, 22]: 11A — extra-articular, single-focal, two-fragmented; 11A1 — a large hump; 11A 2 — surgical neck; 11A3 — vertical; 11B — extra-articular bifocal three-fragmentary; 11B1 — surgical neck; 11C — intra-articular or four-fragmented; 11C1 — anatomical neck; 11C3 — anatomical neck combined with a metaphyseal fracture.

The Codman concept was further developed in the works of R. Hertel et al. [23, 24]. They took as a basis the fracture planes, not the number of fragments. As a result of the combination of these planes, the authors identified 12 main types of PHFs (Fig. 1).

It is known that the frequency of avascular necrosis of the humeral head (ANHH) after comminuted three- and four-fragment fractures according to Neer or types 11B and 11C according to AO/OTA reaches 77 % [25]. The blood supply of most of the head of the humerus comes from the anterior circumflex artery of the shoulder, a branch of the axillary artery on the lower edge of the subscapular bone (Fig. 2) [25]. The anterior circumflex brachial artery passes laterally to form an arcuate artery that runs deep to the long head of the biceps tendon. Therefore, it is important to limit additional tissue dissection in order not to injure its branches [26]. Taking into account the peculiarities of the displacement of the fragments and the blood supply of the humeral head, the factors affecting its ischemia after intra-articular PHFs (Fig. 3) [26, 27] were identified, namely: the transition of the fracture line to the metaphysis; violation of the medial wall (calcar) of the proximal part of the humerus; type B

or C fracture; splitting the head into fragments (more than 20 % of the volume of its damage); its angular displacement of the head is more than 45°; movement of hilliness by more than 10 mm; fracture heads.

Another similar classification scheme focuses mainly on valgus and varus fractures [28]. According to calculations, the Hertel-Codman system has the highest inter-rater reliability regarding the choice of treatment method and prognosis, followed by Neer, then Resch, and finally AO/OTA [23]. Despite recent modifications, the AO/OTA classification system of PHFs is more scientific than others, but it is more complicated due to the division of fractures into 27 types [21, 22].

The recently proposed classification of Mayo [29] for PHFs is aimed at identifying specific fracture patterns and applying displacement criteria to each of them. It contains 7 general fracture patterns:

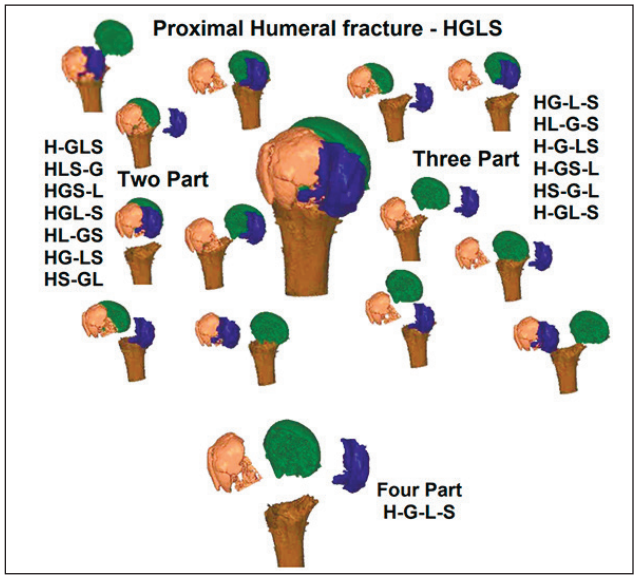

Fig. 1. HGLS classification for PHFs (according to [23, 24])

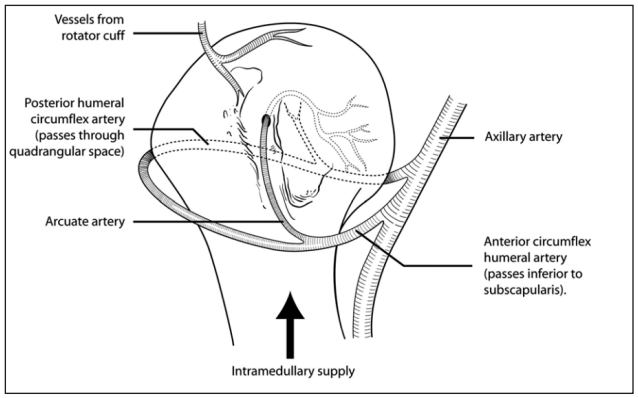

Fig. 2. Blood supply of the proximal part of the humerus. Most often, the arcuate artery in the bicipital groove is injured [25–27]

isolated greater or lesser humerus, surgical neck, compression with rotation of the head in varus and posteromedial or valgus directions, with dislocation of the head of the humerus (dislocation of the head), bifurcation (split of the head) or depression (compression of the head). It is proposed to perform surgical intervention in categories with a red background, and conservative with a green one (Fig. 4).

Conservative treatment of PHFs is used in case of minimal displacement of fragments (up to 2–3 mm) [32, 33] or a high threat to life under the conditions of surgical intervention. Short-term immobilization in such patients is effective with positive clinical results [34]. A general approach is immobilization with a Dezo bandage followed by early and progressive physical therapy rehabilitation [35]. Early mobilization (14 days after the fracture) provides significantly better results (based on pain, function, and range

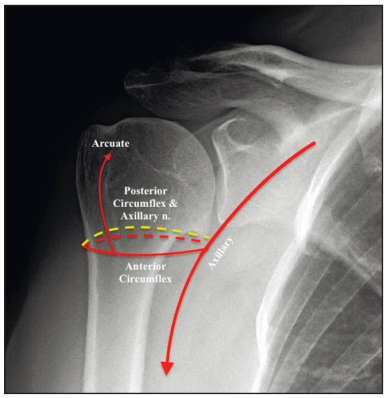

Fig. 3. Radiographs of the right shoulder joint in anteroposterior projection: the arcuate artery is a branch of the anterior circumflex artery of the shoulder and rises along the intertuberous groove to the entrance to the head of the humerus. The posterior circumflex artery of the shoulder passes together with the axillary nerve [25–27]

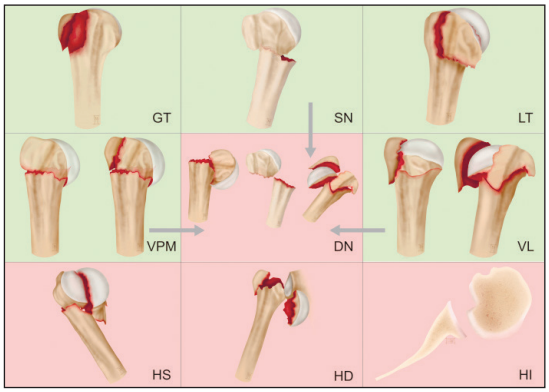

Fig. 4. Classification of PHFs according to Mayo [29]: GT — isolated greater tubercle; SN — surgical neck; LT — lesser tubercle; VPM — varus posteromedial; DN — at the level of the surgical neck; VL — valgus; HS — head splitting; HD — head splitting and dislocation; HI — impression fracture of the head

of motion) compared to later mobilization [36–38]. However, some experts believe that there is no significant difference in the results of surgical and conservative treatment in people older than 65 years with two- and three-fragment fractures according to Neer [38]. Meta-analysis, which included 7 randomized controlled studies and 15 observational studies, confirmed that the functional result did not depend on the method (surgical or conservative) of treatment [39]. Improper consolidation and, as a result, the development of contracture and arthrofibrosis, dysfunction of the rotator cuff of the shoulder, and sometimes non-union [40] are among the complications of the conservative treatment of PHFs. Thus, the effectiveness and indications for conservative treatment of PHFs remain a matter of debate.

Surgical treatment of PHFs may be recommended with 11B2-3, 11C2-3 type shift, which occurred in young patients or in older patients in the case of high functional status [41]. Open repositioning and internal fixation of type B and C (AO/OTA) ACLs, despite the development of fixation methods and implants, may be ineffective due to osteoporosis [42]. The «gold standard» in most patients with PHFs, especially in the case of tubercle displacement, is fixation with various types of LCP plates [43–45]. But their biomechanical characteristics and configuration, as well as screw design, are constantly being discussed and improved. For example, some authors consider the use of two types of LCP plates (Fig. 5) with an increased number of screws, placement of posterior screws in combination with calcar screws to be equally biomechanically justified [46], but the modeling results require clinical confirmation [47].

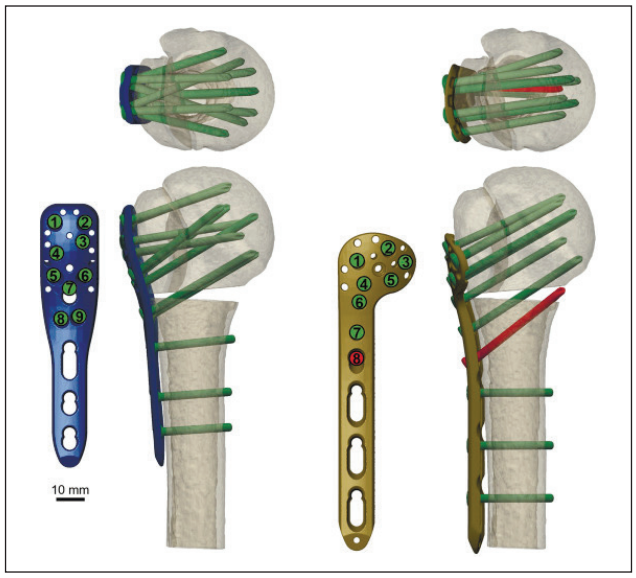

Fig. 5. Two types of LCP-plates for surgical treatment of three-fragmented PHFs [46, 47]

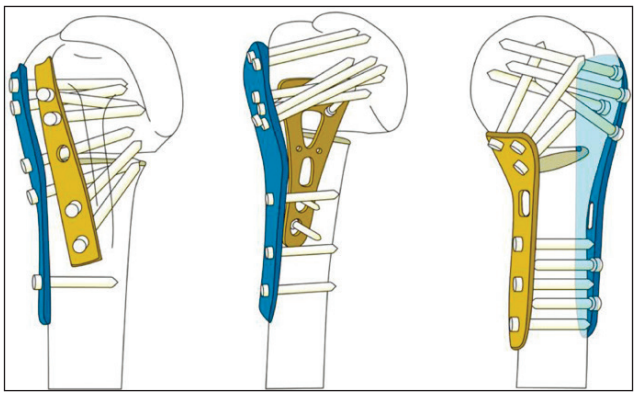

Fig. 6. Fractures of PHF type 11C2-11C3. Restoration of the medial support with fixation with two blocked plates (according to [48])

In complex PHFs and a displacement of more than 8–10 mm, it is suggested to use calcar screws, bone graft, augmentation with bone cement, double fixation with plates to maintain the stability of the fixation of the blocked plate and restore the medial support (Fig. 6) [48, 49].

It was determined that the overall rate of complications after ORIF in patients older than 60 years was 44 %; unsatisfactory results, which led to repeated surgery, comprised 34 % (regardless of the use of bone allograft). Improvement of the technique of fixation and indications for PHFs operation using various metal structures (Fig. 7) is relevant [50].

An assessment of the anterior-posterior radiographs of the shoulder showed significant variations in the lateral angle of the proximal part of the humerus, which did not correlate with the angle between the neck and the diaphysis of the humerus. This humeral angle was greater than the plates and prone to varus reduction and medial collapse.

The average lateral angle on plain radiographs was 12.9° ± 2.2°, and the height from the most proximal point to the angular (GT) — (44.4 ± 4.7) mm. The bending angles of the three plates were equal to 8° and 10°, the height from the proximal edge of the plate to the bending point was 42.4; 42.0; 43.8 mm. In 98 % of cases, the lateral angle was greater than the bending angle of the plates. In 43 % of cases, the height of the GT was less than the height of the plates, and when applied to the 3D model, the average gap between the GT and it was (4.8 ± 2.8) mm [51].

LCP plates have been developed with threaded pins through which cross screws are orthogonally passed to create a three-dimensional framework for bone engagement. The biomechanical model proved that cross elements significantly increased the ability of pins to resist axial displacement

of osteoporotic bone (Fig. 8). That is, they contribute to the stability of proximal fixing plates in osteoporotic bone [52].

In the case of type 11C2-11C3 fractures secondary to osteoporosis, reversible primary total endoprosthesis of the shoulder joint is the most appropriate option for surgical treatment. However, it has disadvantages in patients aged 40–60 years due to a higher level of activity and the possible need for revision surgery. These patients are offered the use of an intramedullary nitinol cage with the installation of additional screws through it and tubercles, if necessary (Fig. 9) [53, 54].

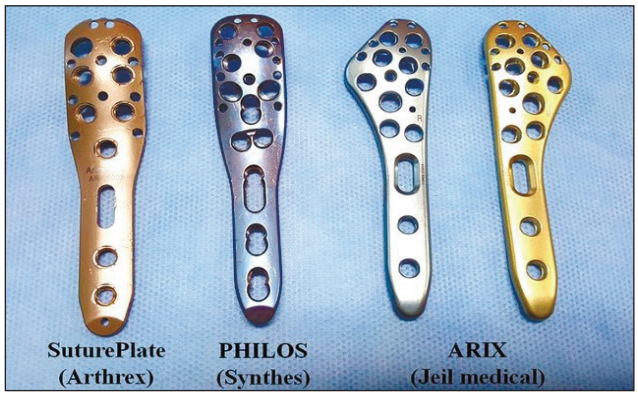

Fig. 7. Types of fixing plates for the treatment of PHF (according to [51])

Fig. 8. LCP-plate with threaded pins, through which cross-threaded screws (yellow) pass orthogonally to create a three-dimensional framework and increase the ability of threaded pins to resist axial displacement under conditions of osteoporosis (according to [52])

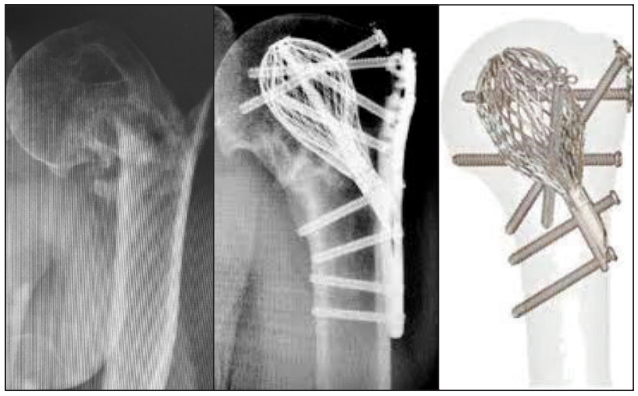

Fig. 9. Employment of an intramedullary nitinol cage for reconstruction of the PHF (according to [53–56])

After one year of observation, a low percentage of re-displacement of the fracture and excision of the screw was found (no more than 11 %). However, a higher-than-expected level of avascular necrosis was noted compared to other studies using a similar fixation design (4–14 %), so determination of the advantages and disadvantages of its use requires additional studies with a longer follow-up period [55, 56].

Some authors [57, 58] believe that successful surgical treatment of 11B3, 11C2-3 fractures using LCP-plates secondary to osteoporosis during ORIF is possible due to the use of an endosteal implant. An allograft or autograft from the fibula bone is relatively easy to implant in the diaphysis of the humerus and plays the role of a support, which improves the stability of the reconstruction. This minimizes the most common complications — secondary displacement, threading and migration of screws, impression of fragments and, as a result, the development of avascular necrosis of the humeral head (Fig. 10).

Thus, the LCP plate combined with an intramedullary cortical bone scaffold can provide nearly twice the mechanical stability and strength for constructs than alone. The bone implant provides support for the medial column and reduces the varus moment of the humeral head, prevents the migration of fragments and reduces deformations under conditions of early mobilization [58].

The calcaneal screw plays a key role in providing medial support and improving varus stability regardless of the use of allografts or autografts. PHFs in elderly and senile patients are mostly observed in the case of a fracture with a greater tubercle (GT). Fragments of this localization are sometimes difficult to use as an anatomical reference for the correct position of the plate and screw. Placement of the pectoralis major tendon is an alternative guide for the appropriate position of the plate and ring screw. The highest probability of placing the calcar screw in the correct place (72 %) has been proven under the conditions of placing the elongated combined hole of the PHILOS plate 3 mm above the upper edge of the pectoralis major tendon attachment [59].

In order to reduce the percentage of unsatisfactory results of ORIF with LCP plates in patients with PHFs secondary to osteopenia and osteoporosis, it is suggested to use them in combination with osteoplastic material (calcium sulfate) and osteosynthesis of the greater tubercle with the help of high-strength sutures [60]. Quite often, valgus PHF type 11C is accompanied not only by displacement, but also by com-

pression of the cancellous bone of the humeral head, which makes it impossible to achieve anatomical reposition without filling the cavity in the central part of the head. Therefore, it is suggested to fill defects of the humeral head with cement based on polymethyl methacrylate (PMMA) or a mixture of PMMA and calcium phosphate [61, 62]. However, PMMA inhibits the processes of consolidation of bone fragments due to the high temperature of polymerization and the subsequent development of scar tissue at the bone-cement border. For this purpose, bioactive cements (calcium phosphate) were developed, which showed positive results in vitro [63]. But they lose their mechanical properties too quickly, so some researchers decided to combine ß-tricalcium phosphate (26 %) with PMMA [64, 65]. This combination of materials will make it possible both to prevent early postoperative migration of humeral head fragments and to increase the stability of plate fixation [65].

From the above, it can be concluded that there is no completely satisfactory OIRF technique. The most important and critical movement task for a patient with PHF after successful surgery is to rise from a sitting position with support on the injured arm. This action produces a peak load force approximately 1.8 times greater than body weight [66]. A force under different vectors of 1413 N is applied to the proximal part of the humerus for a patient weighing 80 kg. Thanks to the use of innovative cement technology, the destructive force for the bone-implant system was 1,686 N, while the standard technique can withstand only 471 N. It stands to mention that when the straight arm is raised to an angle of 90°, the resulting force in the shoulder joint is about 600 N, and when lifting a weight of 1.1 kg — 2,070 N [67]. The combined cement (26 % ß-tricalcium phosphate with PMMA) cannot be easily removed, but can be drilled to accommodate screws. This makes it possible to use the usual PHILOS technique. In addition, the specific properties of this bone substitute contribute to bone formation [63, 64].

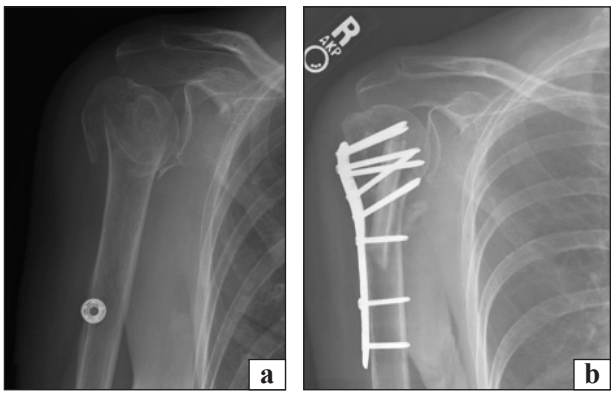

Fig. 10. Radiograph of a type 11C3 fracture (a) and after ORIF with the installation of an LCP plate and a fibula allograft (according to [57])

PMMA cement augmentation in elderly patients with PHF secondary to osteoporosis has been shown to demonstrate clinically equivalent short-term results of up to 6 months compared with augmentation with a bone implant or no augmentation, despite older age and a higher incidence of more serious fractures. The technique appears to be safe with no specific side effects and can be added to the surgeon's arsenal for the treatment of these fractures [68, 69].

The addition of bone cement to augment forward-facing screws has been shown not to increase stiffness and damage load, but to reduce movement at the bone-implant interface. Thus, the authors consider it appropriate to use this technique to reduce the risk of secondary displacement of head fragments [70, 71].

The use of computer technologies (ANSYS software) allows at the stage of preclinical studies to test hypotheses for improving the reliability of fixation in case of PHFs.

For example, using the finite element method, it has been shown that placement of calcaric screws in combination with good medial cortical contact in varus fixation with a locking plate in the medial spaced PHF position can provide optimal fixation stability [72]. In the case of PHF fixation with a plate, the calcar is an important fulcrum for the screws, which provides the necessary support for the medial column. Proximal placement of screws on the calcar is undesirable, and distal placement of the implant may improve the stability of the construct. Successful reconstruction of the PHF is an integral part of anatomical repositioning in combination with support of the medial column. On the basis of anatomical features, it is possible to accurately identify the corresponding bone structures of the proximal part of the humerus and mark the location of the pin on the 3D model, which is a simple, practical and individual approach [73–75].

Medial abutment screws, filling of bone defects and augmentation of the screw tip with bone cement, as well as the use of bone grafts are currently the most commonly used methods. All of the mentioned strategies have a positive effect on achieving and maintaining stable repositioning, even in complex fractures. Further clinical studies with a larger number of patients and a higher level of evidence are needed to develop a standardized treatment algorithm for cement augmentation and bone grafting. Although these measures are likely to have a stabilizing effect

on plate fixation, their general use cannot yet be recommended [76].

Surgical treatment of PHFs by the method of closed reposition and percutaneous fixation

Minimally invasive techniques, including closed reduction and percutaneous pinning, may have advantages over conventional open fixation. However, the percutaneous technique carries the risk of injury to important anatomical structures around the shoulder. Lateral needles should be placed distally to avoid damage to the anterior branch of the axillary nerve and penetration into the cartilage of the humeral head. There is a risk of injury of *v. cefalica*, the tendon of the biceps brachii muscle and the musculocutaneous nerve during the anterior needles. Needles passing through the greater tubercle should be placed so that the hand rotates outward, directed to a point located 20 mm from the lower side of the head of the humerus without excessive penetration into the cortical layer of the humerus [77]. Closed repositioning and percutaneous fixation of PHF is a technically difficult procedure, but it can be successful if 5 conditions are met: normal bone mineral density; minimal fragmentation; stable closed contraction of no more than 5 mm; intact medial calcar (medial wall of the proximal part of the humerus), good psycho-emotional contact with the patient to perform rehabilitation measures and care for needles. Contraindications to this technique for PHF are the low quality of the bone and the fragmentary nature of the 11C2-11C3 fracture [78, 79]. The use of these techniques has recently fallen out of favor as most surgeons prefer open reduction internal fixation in younger patients where surgery is recommended [80].

Surgical treatment of PHFs by the method of closed reduction and pins with fixation in the humerus block (Humerusblock) is a relatively new concept [81]. The ideology of the bone block in the proximal part of the humerus consists in semi-rigid fixation of needles or pins, which will be optimal for the consolidation of simple two-fragment metaphyseal 11CA3-11B1-B2 fractures (Fig. 11).

The implant consists of two 2 mm needles, which are inserted into the metaphyseal zone after the reposition of the fragments of the PHF from the side in the direction of the humerus diaphysis and blocked in it (Humerusblock) [81–83].

Surgical treatment of PHFs with a blocked intramedullary nail

Historically, blocked intramedullary osteosynthesis (BIOS) was rarely used for the surgical treatment of PHFs due to the risk of additional injury to the rotator cuff tendons and muscles, iatrogenic fracture, and proximal screw migration [84]. However, modern intramedullary interlocked nails (IINs) incorporate improved proximal screw fixation mechanisms with

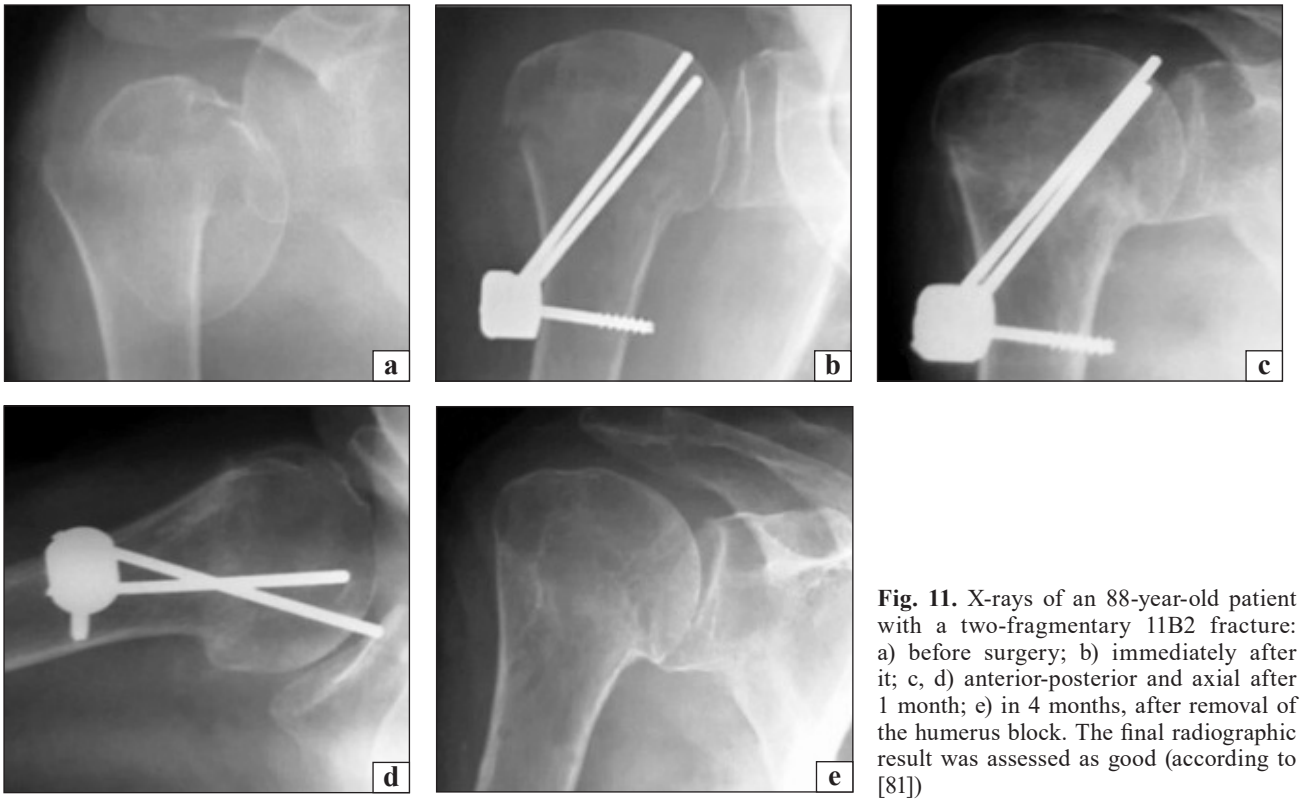

Fig. 11. X-rays of an 88-year-old patient with a two-fragmentary 11B2 fracture: a) before surgery; b) immediately after it; c, d) anterior-posterior and axial after 1 month; e) in 4 months, after removal of the humerus block. The final radiographic result was assessed as good (according to [81])

specific fragment fixation, as well as a straight geometry that allows the nail to be inserted medial to the supraspinatus tendon attachment. The improvement of the design of IINs led to the restoration of their use for fixation of PHF [85, 86].

The treatment of fractures with a significant displacement of types 11C2–11C3 remains controversial.

Under the conditions of the use of first and second generation antegrade nails, high rates of repeated operations and complications, especially iatrogenic injuries of the rotator cuff of the shoulder, were found. Therefore, experts do not recommend IINs for the treatment of three- and four-fragment fractures secondary to osteoporosis [87]. Antegrade fixation of the third generation of IINs with a short format of a smaller-diameter nail with an entry point in the muscular part of the supraspinatus bone has been developed, which provides a high rate of consolidation, good clinical results, and a low level of complications (Fig. 12) [87].

It should be noted that there are no objective criteria to help surgeons choose between IINs and plate

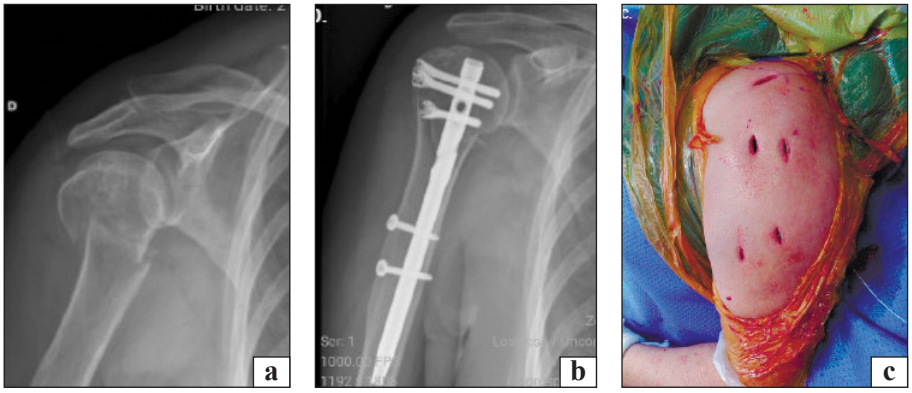

Fig. 12. Radiographs (a, b) and external intraoperative view (c) of the shoulder of a patient with a type 11B2 fracture: a) before surgery; b) BIOS (according to [87])

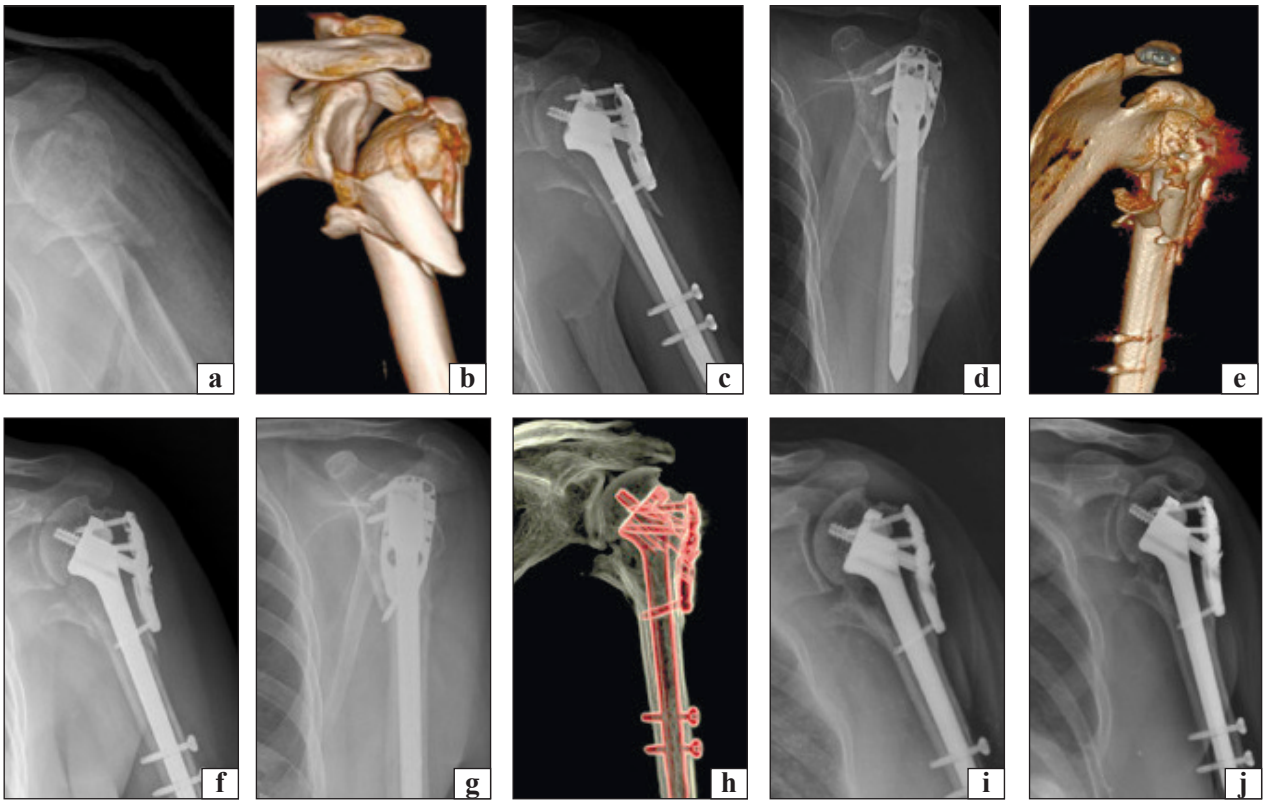

Fig. 13. X-rays and CT scans of the patient's shoulder using the ISNP device: a) preoperative front-back projection; b) three-dimensional CT scan, shoulder reconstruction, 11C3 fracture with comminuted medial wall; c, d) postoperative radiographs; e) three-dimensional CT, alignment of the head and diaphysis, despite the reduced medial cortical plate; f, g) radiographs 3 months after surgery; i) three-dimensional CT, fracture consolidation without loss of reposition; k) radiographs in 6 months; l) in 12 months, consolidation of the displaced medial cortical plate to the diaphysis of the humerus (according to [90])

fixation for three- or four-fragmentary PHFs. Some researchers recommend using LCP-plates in the case of an intact medial calcar, and in others — any technique provided that the general rules of internal fixation are followed (reposition of the tubercles, varus correction of the head and stabilization of the calcar region) [88].

As a result of a comparative study using the Constant and ASES system of the clinical effects of surgical treatment of PHFs, no difference was found between the use of the MultiLoc IMC and the Philos plate in elderly patients. However, the authors believe that the use of the MultiLoc nail is better due to less blood loss, the duration of the operation, the frequency of complications and reoperations with a change to RSA [89].

Anatomical repositioning of the medial column and cusps, as well as metaphyseal support, have been recognized as key elements of fixation to achieve positive functional outcomes in patients with PHFs and osteoporosis. The authors propose a combined ISNPs device for surgical treatment of type 11C2, 11C3 fractures with low bone quality (Fig. 13) [90].

Despite encouraging first clinical results, ISNP design improvements are needed. For example, multiple ISNP models should be produced for different body sizes or fracture types. Further randomized controlled trials with larger sample sizes are also needed.

Biomechanical studies of different types of IINs have shown conflicting results, but most of them have demonstrated better IIN properties in the case of simple PHF type 11A2. It has been proven that the use of curved locked nails causes a higher risk of complications [91]. Current research suggests that fixation plates and intramedullary nails have similar efficacy in terms of functionality and overall complication rate. No advantages of these devices over each other in case of displaced proximal fractures of the humerus were found. Blocked anterograde intramedullary osteosynthesis in osteoporosis is not recommended for complex fractures and has a significant disadvantage associated with additional damage to the supraspinatus muscle [92, 93]. Post-traumatic arthrofibrosis, nonunion, osteonecrosis, early failure of fixation, and infection are the most common complications after IIN placement in patients with PHFs [94, 95].

When choosing a treatment method for PHF, the surgeon should focus on the type of fracture, the patient's activity level, concomitant diseases or injuries, the presence of osteopenia and osteoporosis, and social factors. Usually, conservative treatment is recommended for stable fractures with minimal displacement [96]. In addition, surgical intervention in PHFs is inappropriate for elderly and senile patients, with subcompensated or decompensated abnormalities of internal organs or significant cognitive impairment.

The greatest risks of complications during surgery in patients with PHFs are associated with severe systemic osteoporosis secondary to endocrine disorders, diabetes, immunodeficiency, chronic use of steroids, malignant neoplasms, abuse of tobacco, alcohol, and drugs, and in the presence of rheumatoid arthritis [97, 98]. Thus, the following factors should be taken into account when planning the surgical treatment of a patient with PHF: type of fracture, physiological and mental state, concomitant disorders, the presence of osteopenia and osteoporosis, the possibility of improving functional results compared to conservative treatment. In addition, it is necessary to avoid possible complications of surgical intervention in PHFs, among which ANHH is one of the most severe (in open reposition and internal fixation). Primary endoprosthesis of the shoulder joint for the treatment of four-fragment fractures according to Neer or 11C2, 11C3 according to AO/OTA allows physicians to obtain positive results in the majority of patients [94–98]. A prospective, blind, randomized, controlled, parallel study

Table

Algorithm for choosing a treatment method for patients with PHFs

Type of fracture, according to Neer	Patient's age, years		
	18–60	61–70	over 70
Fracture of the greater tubercle	LCP	LCP	LCP
Two-fragmented	LCP/BIOC	LCP	LCP
Three-fragmented	LCP	LCP	LCP
Four-fragmented	If technically possible:		
	LCP / anatomical endoprosthesis	LCP / reversible endoprosthesis	LCP / reversible endoprosthesis
Multifragmentary fracture dislocations	LCP / anatomical endoprosthesis	reversible endoprosthesis	

questioned the superiority of both ORIF and hemiarthroplasty over conservative treatment in patients older than 60 years with three- and four-fragment fractures without dislocations. On the contrary, the superiority of ORIF compared to hemiarthroplasty was determined in studies of the level of evidence I and II. That is, the results turned out to be contradictory, emphasizing the need to create unified approaches to choosing a treatment method. In particular, the proposed algorithm for the treatment of PHFs, taking into account the Neer classification and the age of the patient (Table) [99–101].

Conclusions

Neer and AO/OTA systems are used among the above PHFs classifications, the Hertel-Codman and Mayo classifications require further clinical confirmation.

Conservative treatment of PHFs is carried out in 80% of patients with two-fragmented fractures according to Neer or types A2/A3 according to AO/OTA. In the remaining 20 % of people, three- and four-fragment PHFs (types B and C according to AO/OTA) occur, when the use of their technique leads to complications, especially secondary to osteopenia and osteoporosis, i. e., to improper consolidation and, as a result, the development of contracture and arthrofibrosis, dysfunction of the rotator cuff of the shoulder, sometimes to non-union.

Surgical treatment of PHFs is recommended in case of type 11B2-3, 11C2-3 fractures in young patients or in elderly people who need significant functionality of the upper extremity. The «gold standard»treatment of most patients with PHFs, especially in the case of tubercle displacement, is fixation with various types of LCP-plates. However, their biomechanical characteristics, screw configuration and design are constantly being improved. Positive results of surgical intervention of PHF types 11B3, 11C2-3 secondary to osteoporosis were obtained after installation of LCP-plates and allo- or auto-implants from the fibula bone.

In valgus PHF type 11C2-3, which are accompanied not only by displacement, but also by compression of the cancellous bone of the humeral head, filling bone defects with PMMA-based cement or a mixture of PMMA with calcium phosphate is a clinically effective method of treatment.

Medial support screws, bone cavity filling and screw tip augmentation with bone cement, as well as the use of bone grafts are currently the most commonly used methods. Although the evidence is insufficient, all of the strategies mentioned are capable of achieving and maintaining stable reduction of even complex type 11C2-3 fractures.

Third-generation intramedullary interlocked nails have improved proximal screw anchoring mechanisms and specific fixation of bone fragments, as well as a straight geometry that allows the nail to be placed medial to the fixation of the supraspinatus tendon. However, surgical treatment of type 11C2-11C3 PHF with significant displacement using IBC remains controversial.

Surgical treatment of patients with PHFs should be performed when functional results can be improved compared to conservative treatment and postoperative complications can be avoided. Aseptic necrosis of the head of the humerus is the most difficult of them after open reposition and internal fixation.

Primary reversal shoulder arthroplasty for the treatment of four-fragmented fractures according to Neer or 11C2, 11C3 according to AO/OTA allows physicians to obtain positive results in most patients.

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

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SURGICAL TREATMENT OF THE PROXIMAL HUMERUS FRACTURES IN PATIENTS WITH OSTEOPOROSIS. PROBLEMATIC ISSUES AND DEVELOPMENT PROSPECTS

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