Original Article
https://doi.org/10.17816/2311-2905-1683

Shoulder Arthrodesis: A New Technique

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Background. The replacement of fusion by arthroplasty in terminal shoulder arthropathies has led to the emergence of cases contraindicated for revision arthroplasty. Performing fusion by traditional methods in such cases is extremely risky because of unfavorable conditions: absence of the humeral head, thinning of the metaphysis walls, and defects of the glenoid. Thus, the creation of a new shoulder fusion technique is necessary.

The study aimed to show the possibilities of a new shoulder fusion technique in treating arthroplasty complications and terminal shoulder arthropathies.

The surgical procedure includes the resection of the shoulder joint and internal fixation with a special device containing a scapular fork with four locking screws and a bone plate. The fork was put on the scapular spine from the side of its notch and was blocked by four tightening screws, which clamped the scapular spine in the fork. The bone plate fixed the diaphysis of the humerus. The fixator form set the scapulohumeral ratio for the formation of ankylosis in a functional position. Bone grafting was performed with a graft from the wing of the iliac bone according to the special technique after endoprosthesis removal or with the resected head of the humerus in case of arthrosis.

Conclusions. The developed technique can be used as a standard revision option for contraindications to shoulder arthroplasty and for any traditional indications for its fusion, such as oncological resections, consequences of open and gunshot trauma, lesions of the brachial plexus, and terminal arthropathies in persons engaged in heavy physical labor when it is impossible to change profession.

Keywords: shoulder arthrodesis, shoulder ankylosis, shoulder arthropathy, complications of shoulder arthroplasty, bone grafting.

Cite as: Voronkevich I.A., Varfolomeev A.P., Geraschenko N.I. [Shoulder Arthrodesis: A New Technique]. *Travmatologiya i ortopediya Rossii* [Traumatology and Orthopedics of Russia]. 2022;28(1):100-109. (In Russian). https://doi.org/10.17816/2311-2905-1683.

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Submitted: 15.10.2021. Accepted: 22.11.2021. Published Online: 07.02.2022.

Научная статья
УДК 616.727.2-089.881
https://doi.org/10.17816/2311-2905-1683

Артродез плечевого сустава: новая технология

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Актуальность. Вытеснение артродеза эндопротезированием при терминальных артропатиях плечевого сустава привело к появлению пациентов, которым противопоказано ревизионное эндопротезирование. Выполнение артродеза традиционными методами у таких пациентов оказывается крайне рискованным вследствие неблагоприятных условий: отсутствия головки, истончения стенок метафиза и дефектов суставного отростка лопатки. Это потребовало создания новой техники артродеза плечевого сустава.

Цель исследования — показать возможности новой методики артродеза плечевого сустава при последствиях осложнений эндопротезирования и терминальных стадиях артропатии плечевого сустава. ***Техника операции*** включает резекцию плечевого сустава, внутреннюю фиксацию специальным устройством, содержащим лопаточную вилку с четырьмя блокирующими винтами и накостную пластину. Вилка надевается на лопаточную ость со стороны ее вырезки и блокируется четырьмя стягивающими винтами, которыми зажимают лопаточную ость в вилке. Накостной пластиной фиксируют диафиз плечевой кости. Форма фиксатора задает плечелопаточные соотношения для формирования анкилоза в функционально выгодном положении. Костную пластику выполняют трансплантатом из крыла подвздошной кости по специальной методике после удаления эндопротеза или утильной головкой плечевой кости при артрозе.

Заключение. Разработанная методика может применяться в качестве стандартной ревизионной опции при противопоказаниях к эндопротезированию плечевого сустава, а также при любых традиционных показаниях к его артродезу, таких как онкологические резекции, последствия открытой и огнестрельной травмы, поражения плечевого сплетения и терминальные стадии артропатии у лиц, занимающихся тяжелым физическим трудом при невозможности смены профессии.

Ключевые слова: артродез плечевого сустава, плечелопаточный анкилоз, артропатия плечевого сустава, осложнения эндопротезирования плечевого сустава, костная пластика.

Воронкевич И.А., Варфоломеев А.П., Геращенко Н.И. Артродез плечевого сустава: новая технология. *Травматология и ортопедия России*. 2022;28(1):100-109. https://doi.org/10.17816/2311-2905-1683.

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Рукопись получена: 15.10.2021. Рукопись одобрена: 22.11.2021. Статья опубликована онлайн: 07.02.2022.

Background

The shoulder fusion is an operative intervention consisting in resection of the joint and fixation of the humerus to the scapula for the formation of ankylosis, providing painless functioning of the upper limb in new anatomical and functional conditions. Thirty years of experience in shoulder joint arthroplasty has shown low survival rate of modern systems, which in 7-12 years in some cases results in an inoperable condition for revision arthroplasties [1, 2, 3, 4, 5]. In cases of contraindications to revision arthroplasty of the shoulder joint in such patients, arthrodesis is increasingly required. Most of orthopedic surgeons have begun to forget the shoulder fusion, or, avoid it due to the imperfection of traditional surgical techniques. Traditional techniques happened to be untenable in the consequences of shoulder joint arthroplasty complications [6]. In addition, it has become clear that primary arthroplasty are usually contraindicated for people engaged in heavy physical labor [7, 8, 9, 10]. The new reality has led to the look for other solutions to the problem of terminal stages of osteoarthritis by means of revival of shoulder fusion surgery at new technological level, which can ensure successful ankylosing in conditions of combined bone defects of the shoulder head and the glenoid. To do this, we have modified the surgical technique and created a brand new special internal scapulohumeral fixator with standardized angles of 3D alignments for ankylosis formation in a functionally favorable position [11]. With contraindications to arthroplasty, this turned out to be a high-tech option for surgical restoration of upper limb function.

The aim of the study was to show the possibilities of shoulder fusion new technique in the consequences of complications of arthroplasty and terminal stages of osteoarthritis of the shoulder joint. A new technique and special internal fixator for the formation of ankylosis, with standardized angles of humeroscapular ratios, created at the R.R. Vreden NMIC, is updated option for surgical restoration of upper limb function for all known indications to shoulder fusion, and a highly effective method for contraindications to revision arthroplasty.

The device is a bridge-like structure combining a scapular fork with locking screws for attachment to the scapular spine and a bone plate for fixing the humeral diaphysis. For the external looking like, the device was called "The Camerton" [11]. The combination of proximal locking unit and compression plate in the implant provides a long time rigid inter-fragment fixation that resists loosening and maintains optimal mechanical conditions for the consolidation between the glenoid and the humerus after its head resection.

They are responsible for relative comfort of the patient and the optimal range of upper limb motions. The surgeon is responsible for correct rotational position. Bending along the contour of the humerus head makes it possible to bypass the resected remains of the proximal end of the humerus with the glenoid (Fig. 1a). This also helps exact reposition, to free up space around the joined surfaces to accommodate grafts fitting that increase local bone mass and completeness of interfragmental contact. After removal of the stem of the shoulder component or spacer, there is always high probability of delayed consolidation due to decreased reparative potential of the bone adjacent to them. This requires long-term resistance of the fixator to fatigue fractures of the plate at the level of screw hole. Therefore, the transition zone of the implant above the resected shoulder joint is made without screw holes which migt be stress concentrators. The scapular fixing unit is made so that when put on the scapular spine, the fork of the "Camerton" imbraced it with branches in front, in the supraspinatus fossa, and behind, in the infraspinatus fossa. Fixation is carried out with three or four tightening screws that pass through the scapular spine, block it and clamp it tightly, bringing the fork branches closer (Fig. 1 b, c). Such fixation successfully resists loosening in the scapular spine and ensures the reliability of compression for a long time. There are three types of screw holes in the diaphyseal part of the plate: longitudinal groove for one-time static compression by the contractor, oval compression holes for dynamic compression and round holes for final fixation of the humerus.

Surgical technique

The surgery can be performed from two positions of the patient: "beach chair", patient sitting with a raised trunk, which is traditional for shoulder joint surgery, or lying on a healthy (opposite) side. When laying a "beach chair" for the shoulder joint fusion, it is necessary to hang the operated scapula over the edge of the table by the

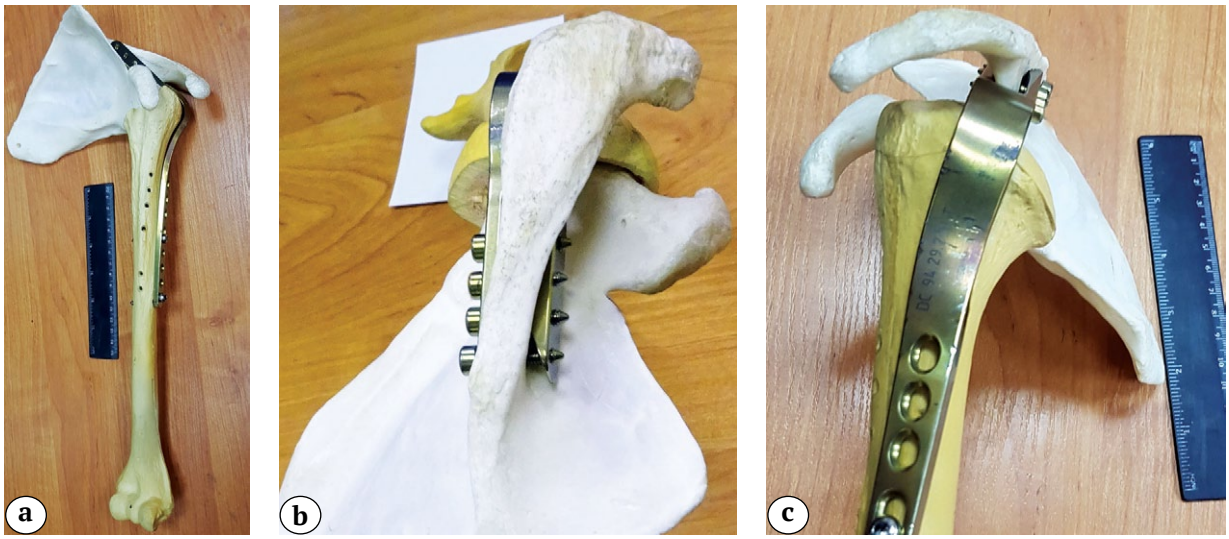

Fig. 1. The location of the fixator on the bone and the coverage of the scapular spine with locking screws on a training plastic bones: a — general view; b — view from the scapular spine; c — side view

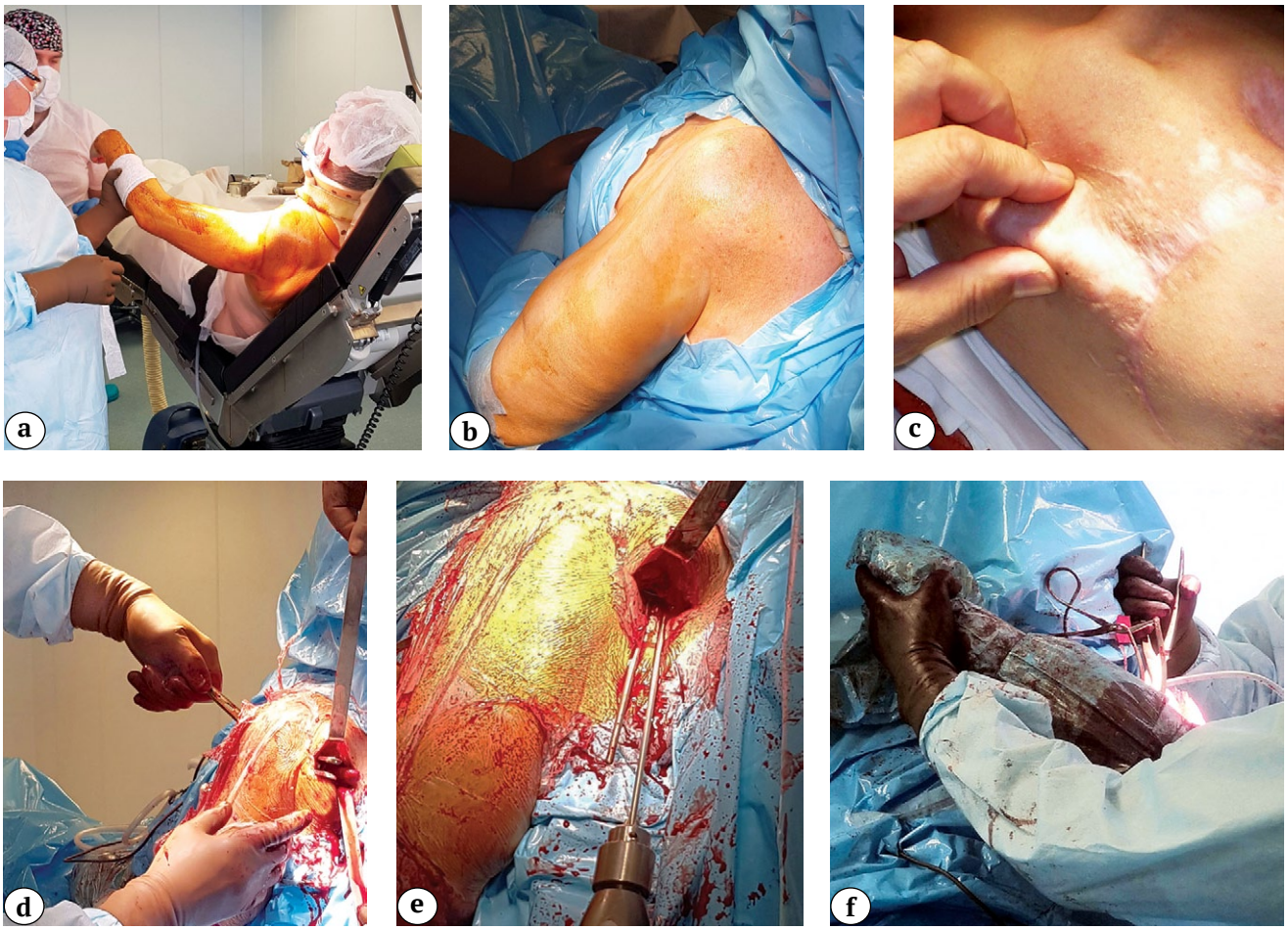

Fig. 2. Patient's position "the beach chair" for shoulder fusion: a — general view; b — the operating field includes all of the scapula and provides approach to the scapular spine; c — palpation of the scapular spine in correct positioning; d — the fork placement; e — fork screw-locking to the scapular spine; f — setting the correct rotation, when the hand of the operated arm reaches the patient's nose

width of the scapula (Fig. 2). In this position, it is comfortable for surgions to resect the joint and remove the scapular component of the endoprosthesis. It is inconvenient for surgeons to implant the “Camerton” fork on the spatula. It is also impossible to take a large autograft from the iliac wing, which is required in the absence of humeral head, that is common for indications to revision surgery for an endoprosthesis failure with simultaneous contraindications to revision shoulder arthroplasty. First we have put the patient on his opposite side to harvest the autograft, then shift it to a "beach chair", and the surgeon is forced to lock the screws in the scapular fork without visual control - "by touch", with the risk of errors and with significant loss of time.

We use the patient's position "on the side" more often now. It allows without shifting the patient simultaneously (by two surgeons) to perform all stages of the surgery from harvesting a large iliac wing autograft to removing the endoprosthesis, blocking the scapular fork with visual control, osteosynthesing and bone grafting (Fig. 3). In such way the duration of the surgery is reduced by 40-50 minutes.

Removal of components and joint resection in such “side position” require spatial rethinking and updating of the skill of shoulder joint surgeons. To reduce blood loss, the incision is performed step by step: each approach is done for one of the stages of the surgery. The first incision is a straight anterior arthrotomy 10-12 cm long between the anterior and middle portions of the deltoid muscle from the acromion to the lower border of the humerus neck. It is performed for resection of the shoulder joint. Surgeons remove the cartilaginous lip, cartilage from the glenoid and resect 2/3 of the humerus head(if head is not

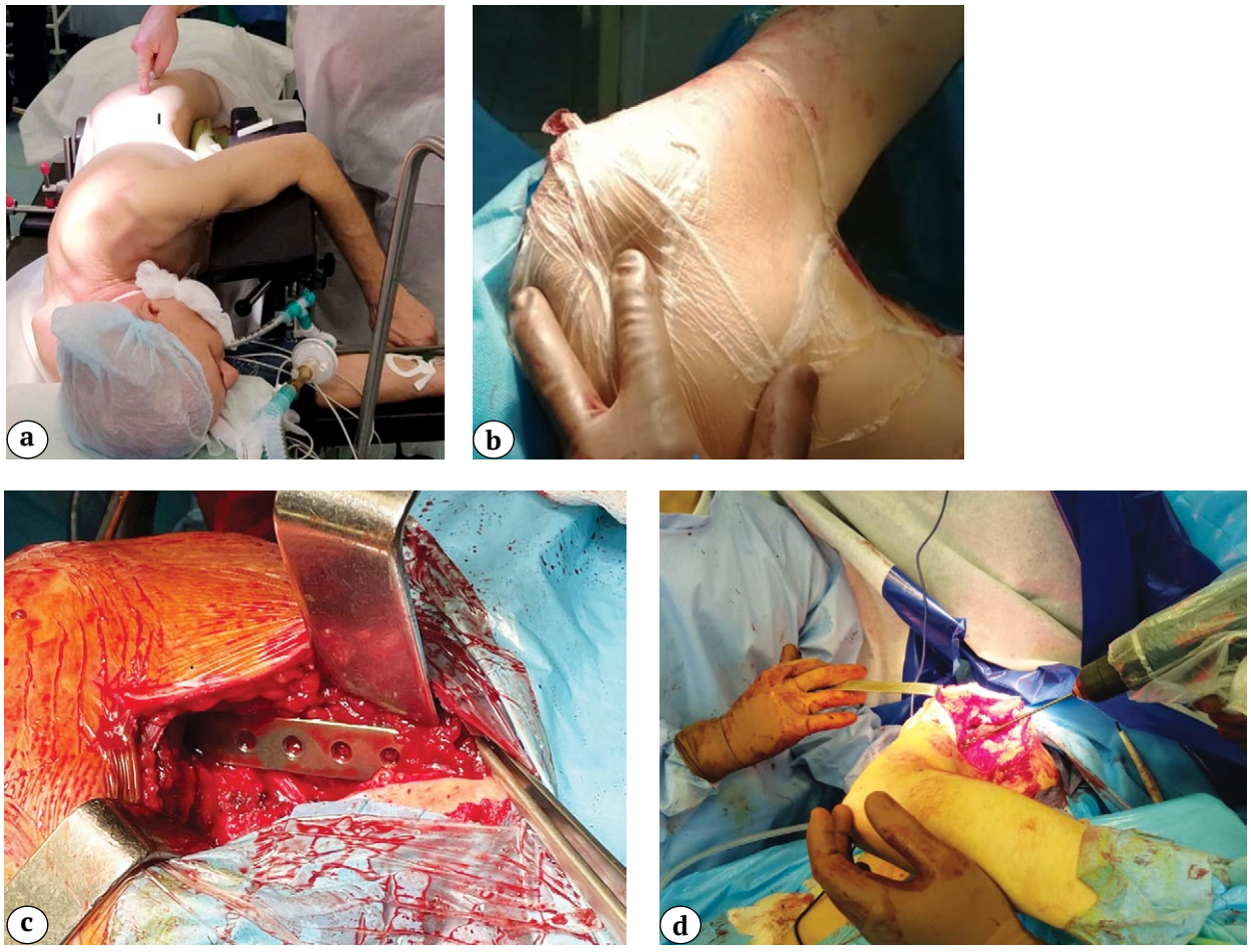

Fig. 3. Patient’s position “on the intact side”: a — convenience of bone harvesting from iliac wing; b — palpation for planning approach to the spine of the scapula; c — visualization of the scapular branch of the “The Camerton” for it’s screw locking; d — convenience of inserting screws into the plate

removed) along the anatomical neck. It is cut with an oscillating saw parallel to the anatomical neck, forming disc-shaped fragments 5-8 mm thick, which will be used as autografts for bone grafting.

To fix the fork to the scapula, an incision 4-5 cm long is made parallel to the scapular spine, steping distally from it by 3-7 cm, depending on the thickness of soft tissues (in case of obesity, the distance is increased). Longitudinally dissect the infraspinatus muscle, reach the back surface of the scapula to the edge of its insisura, put a fork on the spine and block it with tightening screws. Next, the arthrotomic incision is extended in the distal direction by the length of the diaphyseal plate part of the implant. The incision is spirally shifted medially to step off the radial nerve. The biceps muscle in the distal part of the incision is also displaced medially and, pushing the fibers of the shoulder muscle, they reach the bone. In the lower corner of the wound in short patients, the radial nerve is visible or palpated, in tall patients it remains distal.

During reposition, the resected proximal end of the humerus is put on the resected glenoid, controlling the completeness of contact with optimal humerus rotation placement. The shape of the implant is responsible for the angular relationship between the humerus and the scapula (abduction and deviation), and the surgeon controls only the rotational alignment: the hand of the operated limb must reach the patient's nose (see Fig. 2 f). If the contact surfaces do not match perfectly, they are fitted by modeling resection. With a preserved head after resection, we sometimes make a depression in the shape and size of the glenoid for putting cave on it, which significantly increases the contact area of the fragments. When the proximal end of the shoulder is thinned, we insert the tip into the prepared groove in the center of the glenoid. In the latter case, the volume of the bonegraft should be increased.

In the absence of the humerus head, the contact between the humerus and the scapula is always minimal, so it requires extensive bone grafting, which requires a large autograft from the iliac wing. Therefore, we begin the surgery by harvesting the graft in the estimated volumes. Joint resection is always completed by anterior and posterior decortication of the glenoid to surround the consolidation zone with blood-supplied cortico-spongious fragments. Under the decorticated fragments of the glenoid on the anterior and posterior surfaces, we put autografts in a volume that obviously exceeds the expected size of the formed callus, and we put them with an impactor to a tight fit. To improve the side contact of the grafts, we press them against the humerus and glenoid with compression screws. Such bone grafting with massive bonegrafts around the zone of questionable consolidation provides optimal conditions for the formation of ankylosis. In long-lasting dislocations, we met bone defects of the head of the humerus (Hill-Sachs and McLaughlin) and the anterior or posterior edges of the glenoid. In these cases, we processed the docking zone with Z-shaped «step-cut» counter resections with compression fixation with lag screws.

Thorough hemostasis is required at each stage of approach. Particular attention should be paid to the vessels: a. circumflexa humeri posterior, which may be responsible for bleeding in time of the head of the humerus dissection. A. et v. suprascapulartis, passing along the lower edge of incisura scapulae and which may be damaged if the locking fork is incorrectly implanted on the spine. With anterior dislocations, a long-term history brings the axillary artery in close contact to the head of the humerus. Therefore, before the surgery angiocontrast CT is necessary. In the case of close contact of the artery with the head, it was necessary to perform a resection of the head, using a decortication technique, leaving part of the the dislocated head – subchondral bone with cartilage in place adjacent to the artery.

The second-generation fixator, which was used in 82 patients from 2013 to the present, was universal, independent of the side of the shoulder joint lesion, and always required preoperative individual bending, sometimes with the use of heating up to 600-700°, at which titanium becomes thermoplastic and allows it to take any shape without loss of strength. From the neutral form, the fixator was bent in three planes before sterilization: for the side of the lesion and for the surgical task. They started by bending the plate posteriorly by 25-30°, turning the fixator into a right or left option. In the case of a preserved head of the humerus or minor anatomical changes in the bones of the shoulder joint, with such preparation of the fixator, the offset was not changed, but only the diafiseal plate of the fixator was spirally

twisted around the axis of the humerus to avoid contact with the radial nerve. For the right, the plate is twisted counterclockwise, for the left — clockwise by 30-50 °, depending on the patient's height. Height determines the distance from the joint to the exit of the radial nerve to the anterior surface of the humerus. In a tall patient with a preserved head, the twist is lesser. With a decrease in the length of the humerus in a short patient with a head defect, for example after arthroplasty or tumor destruction, the twist was increased, bringing the distal end of the plate almost to the anterior surface of the humerus. In the absence of the head, and especially after removal of the endoprosthesis or spacer, it was necessary to reduce the offset by the difference between the diameter of the head and the diameter of the proximal end of the diaphysis, which were determined by CT data. To do this, the main bend of the fixato going around the conditional head was changed (there is no head, therefore it is necessary to bring the conditional axis of the humerus closer to the center of the glenoid remnants by the difference between the diameter of the head and the diameter of the metadiaphysis of the humerus), that is, from 50-55 mm to 25-30 mm.

At the time of article writing, 100 patients underwent surgery according to the above-mentioned indications in the clinic of the R.R. Vreden NMIC TO according to the described technique. Over the past 5 years, the ratio of revision indications together with the contraindications to arthroplasty to all other indications has increased to 3:2. In 95% of patients, ankylosis of the shoulder joint was formed, and consolidation in the absence of the head and defects of the glenoid led to the formation of a sufficiently strong bone callus (Fig. 4). In some patients without final callus remodeling, clinical consolidation is observed with a positive tendency to bone fusion. All patients note the pain relief, physical strength increasing and consistency of the result with a tendency to improve by the 5th-6th year after surgery without a tendency to deterioration for 10 years.

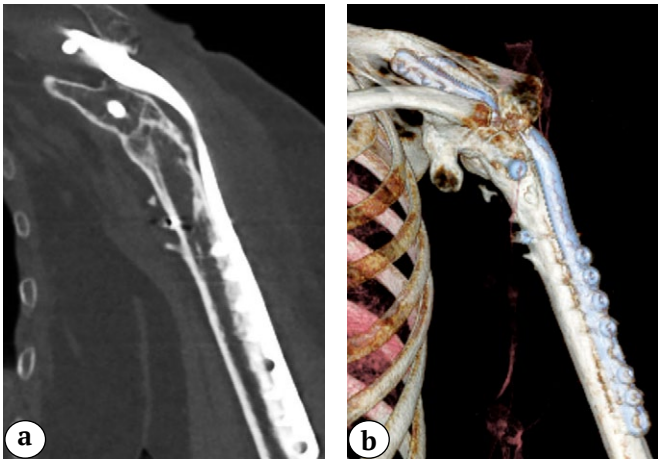

Fig. 4. Consolidation quality after left shoulder fusion for recurrent dislocations after the revision reverse arthroplasty (7 years of anatomical endoprosthesis survival, & 4 years after the reverse shoulder arthroplasty complicated by recurrent dislocations): a — CT-scan frontal section; b — CT-scan, 3D reconstruction, frontal view

Discussion

The arthrodesis surgery according to the described method has been used in our institution since 2005. The first such interventions were performed using individually manufactured implants made of bayonet-shaped intramedullary nails of CITO, which were significantly transformed. The accumulated experience had been used for manufacturing the second-generation design (NPO DEOST, "DC Implant Production", Pushchino, Moscow), which we used for this operation since 2012 to 2021. Currently, the third generation of the device is prepared for release at the "Altermedica Enterprise" (St. Petersburg). The experience of working with the second generation allowed us to formulate new medical and technical requirements for the third generation implant, which is planned to be released since 2023. During the final refinement of the new third-generation device, the disadvantages typical for previous generations were eliminated. The main drawback — the need for preoperative implant bending to the side of the injury and its anatomical variant – were eliminated by the

manufacturer. Fixators will be produced with high level of implant 3D shaping and in special standard sizes.

Almost all the bends of the implant are imbodied in new done forms: a refined contour around the joint, longitudinal spiral twists and a posterior deviation of the diaphyseal plate. This resulted in appearance of the right and left versions of the third generation fixator and new standard offset sizes. For extensive resections of the proximal humerus, mainly for arhtroplasty and oncological indications, appaired short revision-resection offset and wide offset for the preserved humeral head. We consider the most important advantage of third-generation devices to minimize the individual modeling of the fixator, together with the material (plastic titanium) now allows for easy minimal individualization right in the operating room with plate bender wrenches.

The improvement of the technique of shoulder arthroplastics resulted in the almost complete refusion of the shoulder arthrodesis everywhere [8, 10, 12]. This surgery in the coming months after the correct implantation of an anatomical or reversible endoprosthesis leads to the restoration of painless shoulder movements with sufficient amplitude. We found few cases reports with artroplastics after shoulder ankylosis osteotomy, performed for special indications (apparently with a functionally unfavorable fusion) [13, 14]. However, the experience gained over more than 30 years has revealed a number of negative trends, which requires rethinking the problem of treating terminal stageos of the shoulder joint osteoarthritis. The first negative phenomenon was a relatively short period of successful functioning of shoulder joint endoprostheses in a significant part of patients with a tendency to a gradual decrease in the amplitude of movements and the appearance of pain, which eventually trends to become an indication for revision surgery [8, 15].

Of the revision options, the conversion from anatomical to reverse endoprosthesis is currently more often used [2, 7, 15]. Indications for the transition from endoprosthesis to arthrodesis [6, 16] have not yet been found in modern publications, that, in our opinion, could be explained by the lack of a reliable technique available. However, the gained experience has shown that after a reverse arthroplasty performed as a revision, indications for the second revision surgery occur almost twice as quickly as after the primary one [2, 17]. Currently, according to various authors, from a quarter to a third of patients who need in second revision surgery face contraindications to performing shoulder joint replacement due to the lack of a sufficient bone bed for implantation (especially the scapular component), recurrent dislocations of the reversive implant, periprosthetic fractures or pseudoarthrosis at the tip of the unstable humerus component, deltoid muscle dysfunction, or a spacer after a deep infection. Another reason is the misunderstanding of the patient the strict load restrictions in professions espessially for those associated with heavy physical labor when it is impossible to change professions [17, 18, 19].

A patient with a "painful floating shoulder" after repeated attempts to replace the joint has the only chance to restore the painlessness and strength of the upper limb with a diminished range of movements. This is the shoulder joint fusion against the background of extremely unfavorable conditions for the formation of ankyloses: a combination of a total defect of the head with a subtotal defect of the glenoid [18, 19, 20, 21, 22]. In addition to the new problems that have arisen due to the increase in the number of arthroplasties, the traditional, long-known indications for arthrodesis, which have no alternative solutions, have not disappeared anywhere.

Currently, the indication to shoulder fusion are: the consequences of fractures and fractures of the proximal humerus with irreversible loss of axillary nerve function, unreduced dislocations of the humerus with a long-term history, which are accompanied by complete degeneration of the elements of the rotator cuff muscles with deep impression defect of the humerus head, damage to the brachial plexus (for shoulder stabilization to increase the effectiveness of revision neurosurgical intervention on the nerves forming the plexus), the consequences of severe open and gunshot fractures of the shoulder joint, the consequences of repeated unsuccessful revision interventions for complications of osteosynthesis, resection of tumors of the shoulder joint area, after which arthroplasty with an acceptable functional result is impossible [21, 22, 23, 24, 25]. Separately, degenerative-dystrophic diseases of the shoulder joint should be mentioned in persons with heavy physical labor when it is impossible to change their profession. Heavy physical labor results in rapid development of mechanical

complications of arthroplasty: aseptic loosening, periprosthetic fractures, instability, dislocations [18, 21, 22].

The remaining techniques of the shoulder joint fusion, as a rule, are designed to use compression transarticular fixation of the head of the humerus after the cartilage removal to the similarly processed glenoid in combination with extra-articular humerus to the scapula fixation with one or two plates or external fixation devices. However, even with a preserved head, they do not always allow to achieve consolidation: instead of ankylosis of the shoulder joint, pseudoarthrosis develops in 10-25% of patients after arthrodesis [20, 26, 27, 28]. After removal of the humeral head for any indications, among which endoprosthesis-related ones prevail, these arthrodesis techniques happenes to be practically ineffective. In this regard, the technique described in this article has clear and undeniable advantages and is an effective option for contraindications to shoulder joint replacement.

Conclusions

Thus, the proposed technique of the shoulder joint fusion is an effective option for irreparable damage to the shoulder joint, which allows to achieve consolidation in more than 90% of cases, including cases after removal of the endoprosthesis or spacer, which significantly exceeds the effectiveness of known techniques. It is a reliable revision option in unfavorable biomechanical conditions with contraindications to shoulder joint arthroplasty, and can serve as an alternative to known techniques.

Disclaimers

Authors' contributions

All authors made equal contributions to the study and the publication.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

Funding source. This study was not supported by any external sources of funding.

Competing interests. The authors declare that they have no competing interests.

Ethics approval. The study was approved by the local ethics committee of Vreden National Medical Research Center of Traumatology and Orthopedics.

Consent for publication. Written consent was obtained from the patients for publication of relevant medical information and all of accompanying images within the manuscript.

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