16+

ISSN 1028-4427 (Print)
ISSN 2542-131X (Online)

Гений Ортопедии
Orthopaedic Genius

Том 30
№ 4
2024

Научно-теоретический и практический журнал
Основан в память академика Г.А. Илизарова

РЕДАКЦИОННАЯ КОЛЛЕГИЯ

Бурцев А.В. (Россия, Курган) – **главный редактор**
Аранович А.М. (Россия, Курган) – **заместитель главного редактора**
Samchukov M.L. (США) – **заместитель главного редактора**
Баиндурашвили А.Г. (Россия, Санкт-Петербург)
Борзунов Д.Ю. (Россия, Екатеринбург)
Волокитина Е.А. (Россия, Екатеринбург)
Губин А.В. (Россия, Санкт-Петербург)
Дьячкова Г.В. (Россия, Курган)
Котельников Г.П. (Россия, Самара)
Кутепов С.М. (Россия, Екатеринбург)
Мироманов А.М. (Россия, Чита)
Линник С.А. (Россия, Санкт-Петербург)
Попков А.В. (Россия, Курган)
Попков Д.А. (Россия, Курган)
Рябых С.О. (Россия, Москва)
Скрябин Е.Г. (Россия, Тюмень)
Тихилов Р.М. (Россия, Санкт-Петербург)
Birch J.G. (США)
Catagni M.A. (Италия)
Chaudhary M.M. (Индия)
Dubousset J.F. (Франция)
Glatt V. (США)
Hosny G.A. (Египет)
Kirienko A. (Италия)
Lascombes P. (Швейцария)
Madan S. (Великобритания)
Monsell F. (Великобритания)
Paley D. (США)
Pinzur M.S. (США)
Podeszwa D.A. (США)
Weiss H.-R. (Германия)

Борзунова О.Б. – ответственный секретарь
Беляева М.А. – технический секретарь
Марченкова Л.О. – редактор

THE EDITORS

A.V. Burtsev (Russia, Kurgan) – **Editor in Chief**
A.M. Aranovich (Russia, Kurgan) – **Deputy Editor**
M.L. Samchukov (USA) – **Deputy Editor**
A.G. Baindurashvili (Russia, St. Petersburg)
D.Yu. Borzunov (Russia, Ekaterinburg)
E.A. Volokitina (Russia, Ekaterinburg)
A.V. Gubin (Russia, St. Petersburg)
G.V. Diachkova (Russia, Kurgan)
G.P. Kotel'nikov (Russia, Samara)
S.M. Kutepov (Russia, Ekaterinburg)
A.M. Miromanov (Russia, Chita)
S.A. Linnik (Russia, St. Peterburg)
A.V. Popkov (Russia, Kurgan)
D.A. Popkov (Russia, Kurgan)
S.O. Ryabykh (Russia, Moscow)
E.G. Skryabin (Russia, Tyumen)
R.M. Tikhilov (Russia, St. Petersburg)
J.G. Birch (USA)
M.A. Catagni (Italy)
M.M. Chaudhary (India)
J.F. Dubousset (France)
V. Glatt (USA)
G.A. Hosny (Egypt)
A. Kirienko (Italy)
P. Lascombes (Switzerland)
S. Madan (UK)
F. Monsell (UK)
D. Paley (USA)
M.S. Pinzur (USA)
D.A. Podeszwa (USA)
H.-R. Weiss (Germany)

O.B. Borzunova – Executive Secretary
M.A. Beliaeva – Technical Secretary
L.O. Marchenkova – Editor

Курган

Учредитель и издатель журнала:

федеральное государственное бюджетное учреждение «Национальный медицинский исследовательский центр травматологии и ортопедии имени академика Г.А. Илизарова» Министерства здравоохранения Российской Федерации

Издание журнала осуществляется при поддержке Ассоциации по изучению и применению метода Илизарова России (A.S.A.M.I. Россия)

Журнал включен в перечень научных специализированных изданий ВАК, в которых могут публиковаться основные результаты диссертационных работ на соискание ученой степени кандидата наук, ученой степени доктора наук (3.1.8 – травматология и ортопедия)

Журнал включен в Реферативный журнал и Базы данных ВИНИТИ

Сведения о журнале ежегодно публикуются в международной справочной системе по периодическим и продолжающимся изданиям «Ulrich's Periodicals Directory»

Журнал включен в библиографические и реферативные базы данных РИНЦ и SCOPUS

Журнал включен в электронные информационные ресурсы базы данных EBSCO

Электронная версия журнала размещена на сайтах

http://ilizarov-journal.com
http://elibrary.ru
http://cyberleninka.ru

Контент журнала доступен под лицензией Creative Commons – Attribution 4.0 International, CC-BY.

Адрес: 640014, Россия, г. Курган, ул. М. Ульяновой, 6
Телефоны: (3522) 43-06-94 – редакция
(3522) 23-42-60 – реклама
Интернет: http://ilizarov-journal.com/
Email: genius@ilizarov.ru

Оригинал-макет изготовлен ОИАиВР ФГБУ «НМИЦ ТО имени академика Г.А. Илизарова» Минздрава России

Журнал зарегистрирован Федеральной службой по надзору в сфере связи, информационных технологий и массовых коммуникаций ПИ № ФС77-68207 от 30 декабря 2016 года

Территория распространения: Российская Федерация, зарубежные страны

Язык: русский, английский

Издается 6 раз в год

Цена свободная

© Федеральное государственное бюджетное учреждение «Национальный медицинский исследовательский центр травматологии и ортопедии имени академика Г.А. Илизарова» Министерства здравоохранения Российской Федерации, 2024

Dear colleagues,

Welcome to the new issue of the journal Genij Ortopedii!

The Clinical Studies section opens this issue and comprises 7 works.

An algorithm for surgical treatment of patients with diaphyseal defects of the forearm bones after gunshot injuries is presented in the work of Davydov et al. (Moscow, Ingushetia). The authors used the developed algorithm to treat 178 patients with gunshot fractures of the forearm, including accompanied by extensive defects, and came to the conclusion that the algorithmt allows considering anatomical changes, drawing up an operation plan based on the reconstruction vector and choosing optimal surgical techniques.

The authors from Kurgan (Kuttygul et al.) show the results of using a modified technique for resection of the proximal row of carpal bones in adaptive wrist collapse in eight patients. Analysis of the immediate results of using the modified PRC technique showed that it decreases the invasiveness of the operation, improves its esthetic result, and provides pain relief, satisfactory range of motion and grip strength.

The results of a prospective comparative study on the use of two approaches in total knee arthroplasty in 60 patients are presented in the work of the authors from Egypt (Badawi et al.). Having analyzed the outcomes, the authors came to the conclusion that the advantage of the subvastus approach over the parapatellar approach is the preservation of the integrity of the quadriceps muscle and intact extension mechanism after surgery. Moreover, the subvastus approach causes less intensive pain, less intraoperative blood loss and fewer complications.

The effect of elastic intramedullary nailing on the lengthening of lower limbs with acquired shortenings was studied by authors from Kurgan (Tropin et al.). Having analyzed the results of treatment of 64 patients, the authors came to the conclusion that in the conditions of lower limb shortening of acquired etiology, the use of a combined technique of bone lengthening (an external fixator in combination with elastic intramedullary nailing) provides good and excellent results without serious complications.

Vlasov and Musikhina (Nizhny Novgorod) discuss risk factors associated with congenital clubfoot in children in their work. The authors note that the greatest sensitivity, specificity and causal relationship with the congenital clubfoot development were risk factors associated with the unfavorable impact of external factors during pregnancy, such as nicotine addiction in women; along with family heredity for congenital foot pathology in blood relatives.

A comparative analysis of the results of surgical treatment of osteoporotic burst fractures of vertebral bodies of the thoracolumbar spine with conventional methods and an original method was carried out by the authors from Novosibirsk (Sinyavin and Rerikh). The authors note that the method of correction of local kyphotic deformity developed for treatment of osteoporotic burst fractures of vertebral bodies in comparison with circular and hybrid stabilization demonstrates satisfactory correction of local kyphosis, reduces the risks of complications and poor outcomes.

Peri-implant infection in patients with rheumatoid arthritis is a topic for discussion in the work of the authors' team from Cheboksary (Lyubimova et al.). The results of treatment of 35 patients were studied. The studies showed that culture-negative infection is the leader in the cases of peri-prosthetic infection in this patient’s group. Outcomes of surgical treatment were positive after two-stage management. Markers of ESR, CRP and D-dimer at the stages of diagnosis and surgical debridement of the infection focus did not reach normal values, which indicates the inapplicability of standard diagnostic criteria of peri-prosthetic infection in patients with rheumatoid arthritis.

Experimental studies are presented in two works of this issue. Korobeynikov et al. (Kurgan) assessed the effect of osteosynthesis wires on the structural reorganization of the metaepiphyseal cartilage in 18 lambs. Kirschner wires, titan wires, and poly-L-lactic acid pins were used. Histomorphometric

characteristics of the growth zone reliably showed that the insertion of wires/pins, regardless of their material, was not accompanied by inhibition of the bone-forming function of the distal metaepiphyseal cartilage of the femur.

The features of regeneration of the Achilles tendon after its transverse tenotomy with preservation of the peritenon and its structures were studied in an experiment on 20 rabbits by Vlasov et al. (Nizhny Novgorod). The authors note that the processes of reparation of the Achilles tendon after its dissection with preservation of the peritenon and its vessels and nerves occur under optimal conditions, under which the tendon tissue is formed in a short term (already 3 months after the intervention), which has maximum similarity with the original.

Two case reports presented in the issue are dedicated to the peculiarities of fixation of the rotator cuff tendons in case of complete lysis of the greater tubercle of the humerus (Makovsky et al., Moscow) and the use of a multidisciplinary approach in the treatment of complicated intra-articular fractures of the distal radius (Khromov et al., St. Petersburg).

The two literature reviews cover current trends in the diagnosis and treatment of nerve injuries during shoulder surgery (Tuturov et al., Moscow) and the influence of non-surgical factors on the treatment outcomes of patients with idiopathic scoliosis according to SRS-22 data (Molotkov; Kurgan, Moscow, St. Petersburg).

We hope that you will find this issue interesting and useful. We invite to submit your studies.

A.V. Burtsev, MD
Chief Editor of Genij Ortopedii

Original Articles

Case report

Literature review

Оригинальные статьи

Случай из практики

Обзор литературы

Original article
https://doi.org/10.18019/1028-4427-2024-30-4-487-501

Algorithm of surgical treatment for diaphyseal defects of the forearm bones due to gunshot injuries

D.V. Davydov[1], L.K. Brizhan[1], A.A. Kerimov[1], A.A. Maksimov[1], I.V. Khominets[1], A.V. Lychagin[2], A.A. Gritsyuk[2]✉, A.Z. Arsomakov[3]

[1] Burdenko Main Military Clinical Hospital, Moscow, Russian Federation
[2] First Moscow State Medical University (Sechenov University), Moscow, Russian Federation
[3] Ingush State University, Magas, Republic of Ingushetia, Russian Federation

Corresponding author: Andrey A. Gritsyuk, drgaamma@gmail.com

Abstract

Introduction In the current system of providing medical aid to wounded servicemen, along with the conservative primary surgical treatment and minimally invasive extrafocal fixation, high-tech surgical interventions of considerable complexity with the use of additive and tissue-engineering technologies have been coming to the forefront. It is necessary to determine their place in the current algorithm of limb bone defect management, which was the substantiation of our study.

The **purpose** of the study was to improve the algorithm for selecting a treatment method for patients with associated gunshot defects of the forearm based on the literature and clinical observations.

Materials and Methods We analyzed scientific articles in PubMed and Scientific Electronic Library (eLIBRARY.ru) platforms, published from 2004 to 2024, on the basis of which we could refine the algorithm of treatment method selection for patients with associated gunshot defects of the forearm. The developed algorithm was used to treat 178 patients with gunshot fractures of the forearm.

Results The review of the literature established the main provisions and principles that are applied in the reconstruction of the forearm with an associated defect. When choosing the method of bone defect management, a great number of authors tend to build a "reconstructive ladder", moving from less severe (one bone) and extended defects (small defect up to 2 cm) to more complex (both bones) and massive defect (more than 10 cm). Upon having considered the revealed regularities, we improved the algorithm of surgical treatment of the latter, which is based on two classification principles: defect extention and location. Reconstruction of the forearm as a dynamic system after diaphyseal fractures requires consider the state of the radioulnar joint. The function of the latter depends on the length ratio of the radius and ulna bones. Therefore, we substantiated small (up to 2 cm) forearm bone defects that can be managed by simple surgical methods. Another fundamental addition to the algorithm was the allocation of a patients' group with a defect of one forearm bone and a fracture of the other bone (defect-fracture); this combination allows avoiding complex surgical methods for reconstruction and use segment shortening.

Discussion The treatment of associated forearm defects is challenging, the choice of reconstruction technique remains uncertain, and the required consensus is lacking. Several forearm reconstruction techniques are available, yet there is no reliable evidence of their effectiveness in terms of treatment time, complications, reoperations, and functional recovery.

Conclusion The algorithm proposed for the treatment of extensive gunshot-associated defects of the forearm allows us to consider the change in the anatomy, make a surgical plan based on the reconstruction vector, and select optimal surgical techniques.

Keywords: gunshot wound, diaphyseal defect, forearm bones, treatment algorithm

For citation: Davydov DV, Brizhan LK, Kerimov AA, Maksimov AA, Khominets IV, Lychagin AV, Gritsyuk AA, Arsomakov AZ. Algorithm of surgical treatment for diaphyseal defects of the forearm bones due to gunshot injuries. *Genij Ortopedii*. 2024;30(4):487-501. doi: 10.18019/1028-4427-2024-30-4-487-501

© Davydov D.V., Brizhan L.K., Kerimov A.A., Maksimov A.A., Khominets I.V., Lychagin A.V., Gritsyuk A.A., Arsomakov A.Z., 2024
© Translator Tatyana A. Malkova, 2024

INTRODUCTION

Gunshot injuries to the extremities remain one of the most challenging problems of military medicine. The relevance of this problem is associated with the constant development of firearms and the emergence of new wounding projectiles that cause significant destruction of bone and soft tissue. The problem requires revision of some of the tactical approaches to the treatment of this pathology that have been established over the past decades [1–3].

Diaphyseal fractures of the forearm bones account for 10–15% of all fractures [4]. The average duration of management is 6–8 months [5], and in 6–17% of cases, patients remain disabled [6]. In the treatment of closed fractures, extramedullary and, less commonly, intramedullary osteosynthesis are used, as well as extrafocal fixation [6, 7]. Gunshot injuries of the forearm are characterized by their severity, difficulties in treatment, and a significant rate of complications [8].

Treatment of gunshot-associated forearm defects is a serious reconstructive problem due to high rates of purulent complications, difficulties with soft tissue healing and bone consolidation, and restoration of upper limb function [9]. Particular difficulties arise in defects of one bone that measure more than 5 cm, defects in both bones of the forearm, and bone defects associated with soft tissue deficiencies [10].

In gunshot or blast injuries, primary loss of bone fragments occurs at the moment of impact of the wounding projectile. Modern classifications of open fractures require considering the loss of bone mass. Bone loss is usually described by its anatomical location: diaphyseal, metaphyseal or articular defect. The diaphyseal defect is usually characterized by its length and circumferential loss of the affected bone. From the point of view of reparative bone regeneration, segmental (circular) defects larger than 2 cm are considered not able to be spontaneously restored, even under the condition of stable fixation; partial defects (less than 50% of the circumference) also do not spontaneously restore without additional treatment [11–14]. In recent works, the methodology for determining the size of a bone defect remains the same [15, 16].

Current clinical methods of limb bone defect management include simple (non-vascularized) bone grafting with cancellous or cortical auto- or allografts, membrane-induced osteogenesis (the Masquellet technique), microsurgical vascularized grafting of iliac or fibular bone grafts with blood vessels, and non-free bone grafting under external fixation using the Ilizarov technique [17–19]. Each of these methods has its own advantages and, when used according to appropriate indications, provides good results. In bone defects smaller than 5 cm, non-vascularized auto- or allogenic bone grafting has been usually used. In bone defects larger than 5 cm, microsurgical bone grafts with blood vessels or the Ilizarov technique are used, but the latter is applicable if the soft tissues are in a satisfactory condition [20–22]. Acute segment shortening as a method of bone defect management without subsequent restoration of limb length is possible without functional impairment in the lower limbs with up to 2 cm and in the upper limbs up to 4 cm of discrepancy [23, 24]. One-stage plate fixation and autologous bone grafting can be effective in treating forearm bone defects up to 5 cm [25, 26], however, in defects exceeding 5 cm, the probability of graft resorption is very high [27]. Non-vascularized fibula autograft with plate osteosynthesis was successfully used in 20 patients with medium 2-cm diaphyseal bone defects of the forearm bones [28].

Vascularized fibular autograft or structural allograft with intramedullary fixation, acute limb shortening and Ilizarov bone transport technique is difficult to use in the forearm due to the complexity of the anatomical and functional structure of this segment [29–31]. Free vascularized fibular graft (FVFP) is recommended for extensive defects, although widespread use of this technique is limited by the need for specialized microvascular resources [32, 33]. The use of distraction osteogenesis of bone transport is limited by frequent complications associated with the fixator, impaired bone union at the site of contact of fragments and contractures of the adjacent joints [34, 35]. Additive

technologies open new opportunities in the treatment of bone defects, which allow for the maximum implementation of an individual approach in the selection of implants or fixators with the possibility of osseointegration [36–38]. This direction has been considered promising in surgery of injuries of the musculoskeletal system [39].

Due to the significant relevance of the problem of treating bone defects, the variety of causes, severity and high incidence caused by modern weapons, especially for military medical institutions and hospitals located in close proximity to combat zones, the creation of a unified algorithm for providing surgical care is an urgent need. Algorithms for determining the viability of a limb segment and primary surgical treatment have been developed [1–3], but the algorithm for long bone defect management in contemporary conditions requires modification.

In the current system of providing care to wounded military personnel, the following have been established: primary surgical debridement (PSD) of a gunshot wound, minimally invasive extrafocal fixation of a fracture, approaching to the elements of specialized medical care (SMC) or rapid evacuation to the SMC stage. The possibilities of effective active wound treatment are expanding: general (infusion, systemic antibacterial, anti-inflammatory and immunostimulating therapy) and local (plasma, laser, ultraviolet, VAC therapy, local antibacterial and bacteriophage therapy). High-tech surgical interventions using additive and tissue engineering technologies are coming to the forefront, which place must be determined in the current algorithm for treating limb bone defects based on the principle of anatomical location, which was the rationale for our study.

Purpose To improve the algorithm for choosing a treatment method for patients with associated gunshot defects of the forearm based on literature data and clinical observations

MATERIAL AND METHODS

To analyze the current state of specialized surgical care for patients with associated gunshot defects of the forearm and to subsequently form an algorithm for reconstructive treatment, a search was conducted for scientific articles in the PubMed abstract and bibliographic database and the eLIBRARY.ru Scientific Electronic Library, published from 2004 to 2024. The analysis also includes articles by the most prominent scientists published earlier. The results of studies of the mechanism and structure of combat injuries to the extremities, the effectiveness of the methods used to manage bone defects and soft tissues of the forearm were summarized.

The developed algorithm was used to treat 178 patients with gunshot fractures of the forearm. All injuries were defined as associated, since in all cases the presence of bone and soft tissue destruction (muscles, tendons, vessels and nerves) was diagnosed. Isolated fractures of one bone with the other intact one were less common, they accounted for about 32.6 % (58 cases). Most gunshot wounds of the forearm (mainly shrapnel, which account for about 90 %) are characterized by significant destruction of one of the bones with a "relatively simple" fracture of the other bone (53.9 %, 96 cases); significant destruction of both forearm bones was observed in 24 patients (13.5 %). The true size of the bone defect increases since non-viable bone fragments are removed during staged surgical treatments. The assessment of the defects at the stage of reconstruction/osteosynthesis found that the largest number of patients had a defect in one of the forearm bones ranging from 0 to 2 cm (73 patients, 41.0 %) and from 2.1 to 5 cm (48 patients, 27.0%), 42 (23.6 %) patients had a defect from 5.1 to 10 cm; a defect of more than 10 cm was observed in 15 (8.4 %) patients.

Forearm bone grafting using a free fibular flap was performed in 18 (10.1%) cases, while an individual 3D design was required in 2/3 of observations (12 patients). In the remaining cases, non-vascularized bone auto- and allografts were used in combination with various osteosynthesis options.

RESULTS

The available literature contains a large number of methods for treating mechanical injuries of the musculoskeletal system, and in particular the forearm, as well as their complications. One of the earliest relevant algorithms for treating bone defects of the extremities was presented by Keating et al. [40] (Fig. 1).

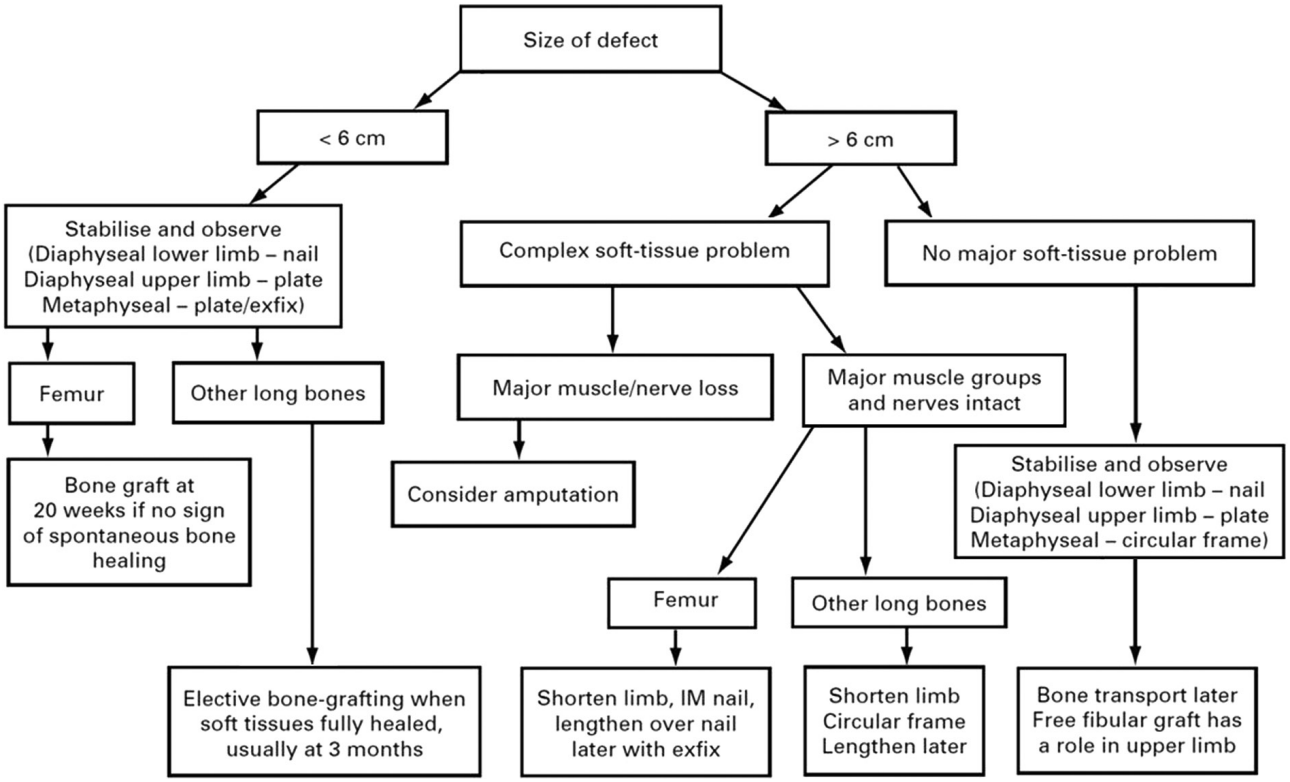

Fig. 1 Algorithm of limb defect management according to Keating et al. (2005) [40]

In this algorithm, defects are divided by length (up to 6 cm and more than 6 cm) and soft tissue problems. In the case of small and extensive (without soft tissue problems) defects, it is proposed to stabilize, observe and then, once the wound heals, use plates in the upper limbs, nails in the lower limbs in the diaphysis, and plates in the metaepiphyseal bone. Ten-year results of using this strategy confirmed the severity and diversity of injuries, on the basis of which Molina et al. [41] proposed to form narrower groups for comparison. Mauffrey et al. [21] proposed changing the algorithm with division into defects up to 1–3 cm (acute shortening is possible), 3–5 cm (non-vascularized bone grafting and internal osteosynthesis), 5–10 cm (shortening in combination with vascularized and non-vascularized grafting), and more than 10 cm (Ilizarov bone transport or vascularized bone autografts).

Unfortunately, there are very few scientific papers in the literature on the treatment of gunshot defects of the forearm bones that would discuss methodological approaches to choosing the optimal reconstruction method and timing of the operation. They mainly consider various issues of the compartment syndrome, antibacterial therapy, the need to remove wounding projectiles, and treatment tactics for individuals with bone defects of gunshot etiology [42, 43].

A comprehensive review of the literature on the treatment strategy for extensive bone defects in the extremities after trauma, infection, or tumor excision is provided by Migliorini et al., who emphasize that the problem remains complex and unresolved, the choice of method is still being discussed, and there is no consensus. Several equivalent methods of bone defect management

are used. However, the number of cases, which is insufficient for reliable statistics, does not allow obtaining convincing evidence of their effectiveness. Therefore, the issues of treatment duration, number and severity of complications, frequency and complexity of repeated surgeries remain open and require further study [44].

The algorithm we propose for treating patients with forearm defects is based on two principles of their classification: location and extent. According to the provisions of the Osteosynthesis Association (AO), the treatment of diaphyseal fractures of the forearm bones requires complete elimination of all types of displacement and provision of conditions for the restoration of the function of the radioulnar joints. Therefore, in the event of defects in the forearm bones, it is necessary to ensure their reconstruction in a way that would eliminate the disruption of the anatomical and physiological relationships in the radioulnar joints, which is the basis for subsequent rehabilitation [45].

Defects of one or both bones of the forearm are identified. We consider it necessary to supplement the existing classification by identifying small (up to 2 cm) defects of the bones of the forearm, which can be reconstructed with the simplest methods. Special surgical tactics are required for patients with a defect of one bone and a fracture of the other bone of the forearm (defect-fracture). This type of damage, despite its severity, in some sense makes the surgeon's task easier: to shorten the bone with a simple fracture and avoid bone plasty in the defect zone of the other bone (Fig. 2).

For choosing methods for bone defect reconstruction, most surgeons use the "reconstructive ladder" rule, using simple methods for less severe (one bone) and less extended defects (small defect up to 2 cm) and complex ones for more severe (both bones) and massive (more than 10 cm) defects. In our opinion, modern ideas about ranking methods are becoming broader, from osteosynthesis, possibly with acceptable shortening or non-vascularized bone grafting, through a combination of partial shortening with non-vascularized bone grafting to microsurgical free vascularized bone autoplasty and tissue-engineered complex grafts. The osteosynthesis system has evolved from traditional plates through plates with limited contact and angular stability of screws to custom-made 3D structures. The latter can only perform osteosynthesis of fragments or additionally fix various grafts. 3D bioengineered structures such as a biologically active bone prosthesis that unites with the fragments have been used.

We propose to optimize the choice of the method for forearm bone defect management by using the reconstruction vector rule, which consists in the need to use more complex methods if the size of the defect and the complexity of its structure increases. Thus, the surgeon's efforts are directed from simple to complex, and the possibility of combining various surgical methods in one operation is ensured. This approach allows, by combining the effectiveness of individual methods, to obtain the maximum effect in terms of anatomical and subsequent functional restoration.

Currently, the general trend in reconstructive surgery is the use of a one-stage and comprehensive method. This allows the maximum effect with minimal costs for a more complete recovery with reduced hospitalization and rehabilitation periods. The Ilizarov methods, which have been used in our country for many years, fully comply with the above requirements and allow us to solve almost all issues of treating such patients. However, for the forearm, the Ilizarov apparatus assemblies are quite complex and cumbersome and require constant medical supervision throughout the entire recovery period.

Many of the current one-stage comprehensive surgical treatment methods, in addition to technical complexity, require the use of complex and expensive technological solutions. However, reducing the duration of inpatient treatment and the number of staged hospitalizations and operations, the use of such methods will allow the medical service to compensate for costs and obtain the most complete anatomical and functional restoration in the wounded and injured persons.

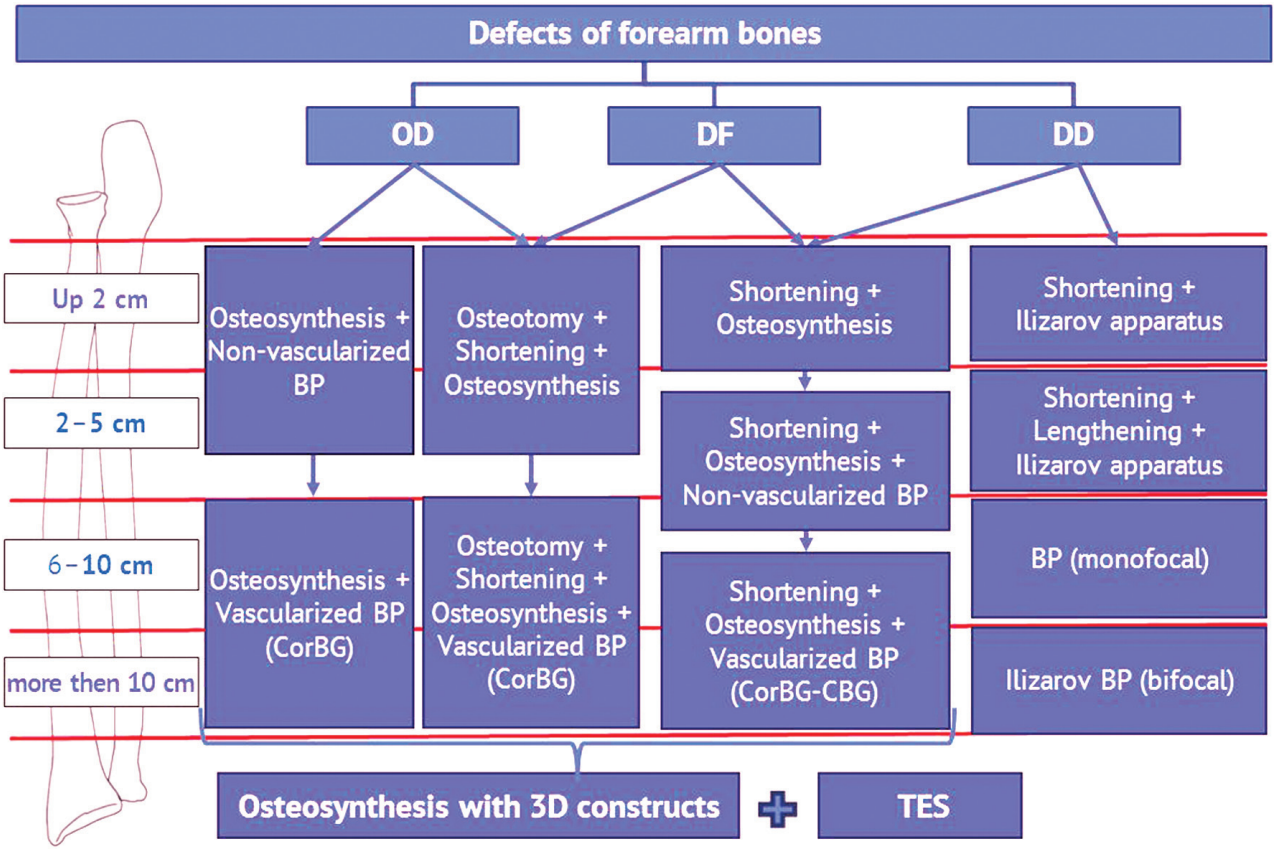

Fig. 2 Algorithm for treating forearm bone defects. OD — one-bone defect of the forearm bones; DD — double-bone defect of the forearm bones; DF — defect of one bone and fracture of the other (defect-fracture); CBG— cancellous bone graft; CorBG — cortical bone graft; TES — tissue-engineered structure

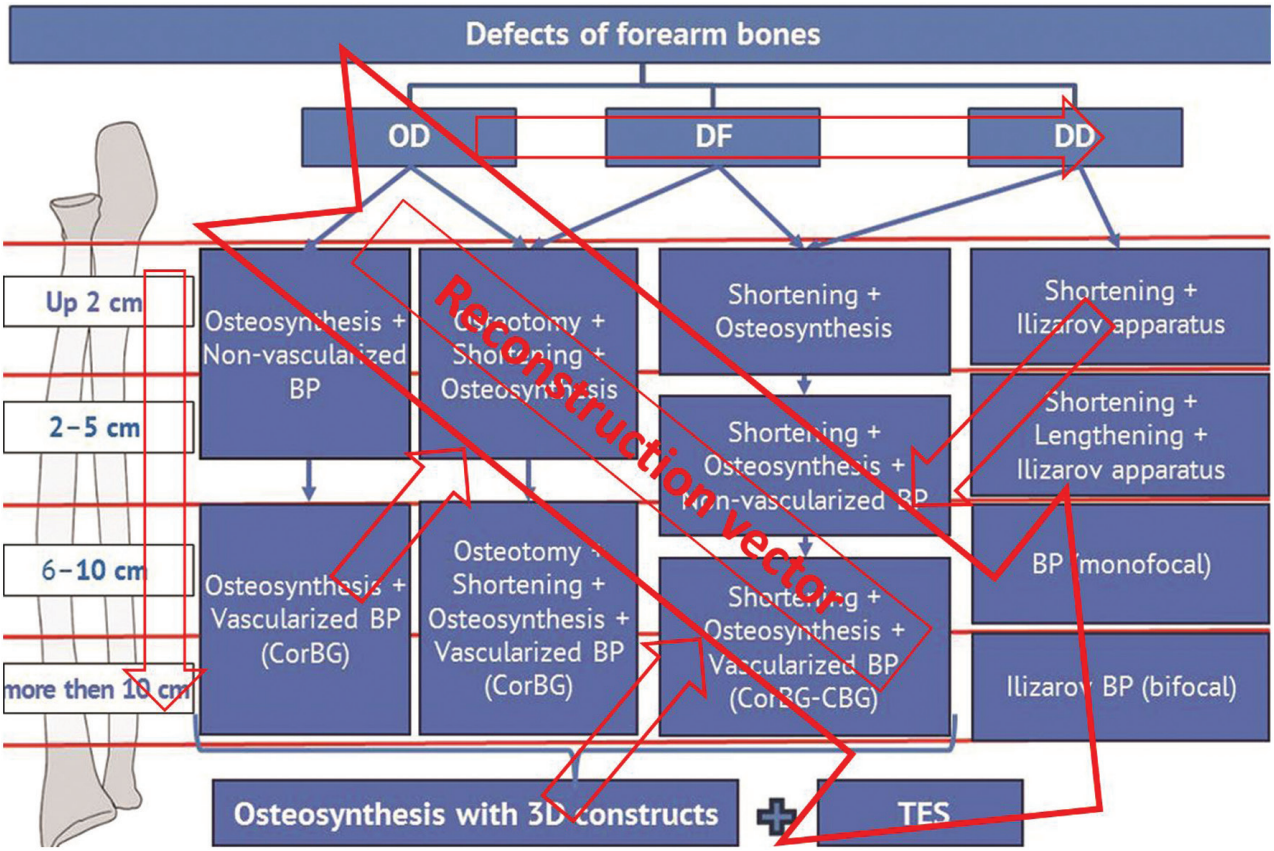

Fig. 3 Diagram of reconstruction vector

Case reports

The simplest method of treatment (osteosynthesis and bone plasty with a non-vascularized cancellous graft) is illustrated by a case of a wounded male G., 36 years old, who received a gunshot wound resulting in a 3.5 cm defect of the ulna in the middle third (Fig. 4 a). After the wound healed, osteosynthesis was performed with a plate with angular stability of screws in a bridge version and the ulna defect was bridged with a cancellous graft from the iliac crest (Fig. 4 b, c). Six months after the operation, signs of graft remodeling are visualized on the radiograph (Fig. 4 d).

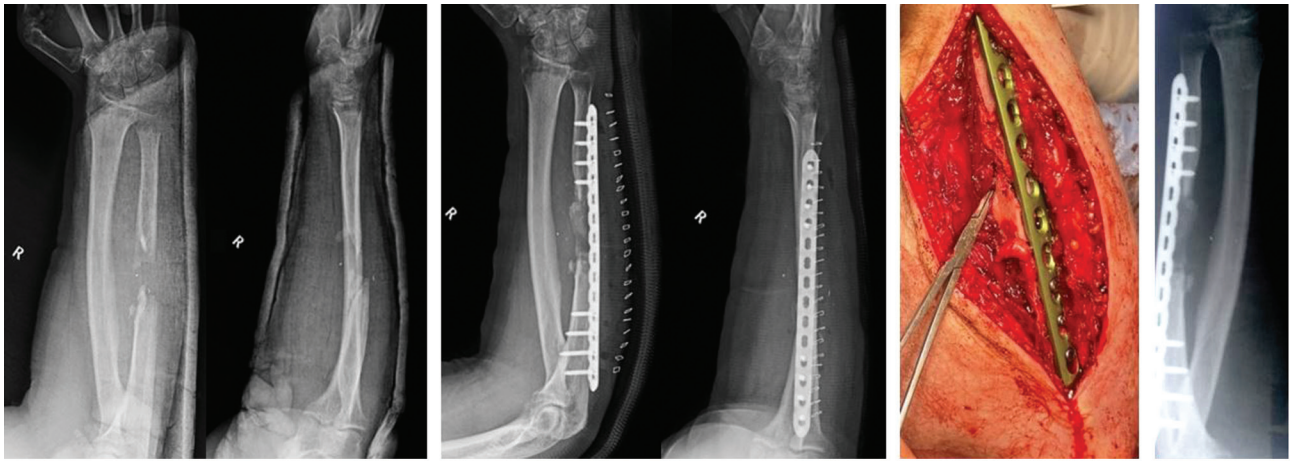

Fig. 4 Injured male G., radiographs of forearm bones: *a* before surgery; *b* after the surgery; *c* an intra-operative view of the wound, osteosynthesis and cancellous graft from the iliac crest; *d* at 6 months after the surgery

The combination of acute shortening of the forearm due to osteotomy of the intact radius, which allowed reduction of the ulnar defect and perform non-vascularized bone grafting with a cortical bone graft, is illustrated by the case of patient K., 23 years old, who sustained a gunshot wound to the left forearm from a smoothbore gun (shots) on 02.03.2023. The X-ray of the left forearm showed the following: a gunshot wound to the middle third of the left forearm, a gunshot comminuted fracture of the middle third of the ulna with a 6 cm bone tissue defect, multiple foreign bodies in the soft tissues of the left forearm (Fig. 5 a).

The wounded man was taken to a military hospital, where primary surgical treatment and drainage of the left forearm wound were performed, followed by local wound treatment and healing by secondary intention.

On April 26, 2023, at the Burdenko Main Military Clinical Hospital, acute shortening osteotomy of the intact radius (2 cm) was performed, the ulna defect (3 cm) was replaced with a non-vascularized cortical bone autograft and osteosynthesis of both forearm bones was performed (Fig. 5 b).

The postoperative period was uneventful, the wounds healed by primary intention, the radius fracture consolidated (osteotomy site) 4 months after the operation (Fig. 5 c), signs of cortical fibular bone graft fusion were noted 6 months after the operation (Fig. 5 d).

After rehabilitation treatment, the patient was declared fit for service and continued military service (Fig. 5 d).

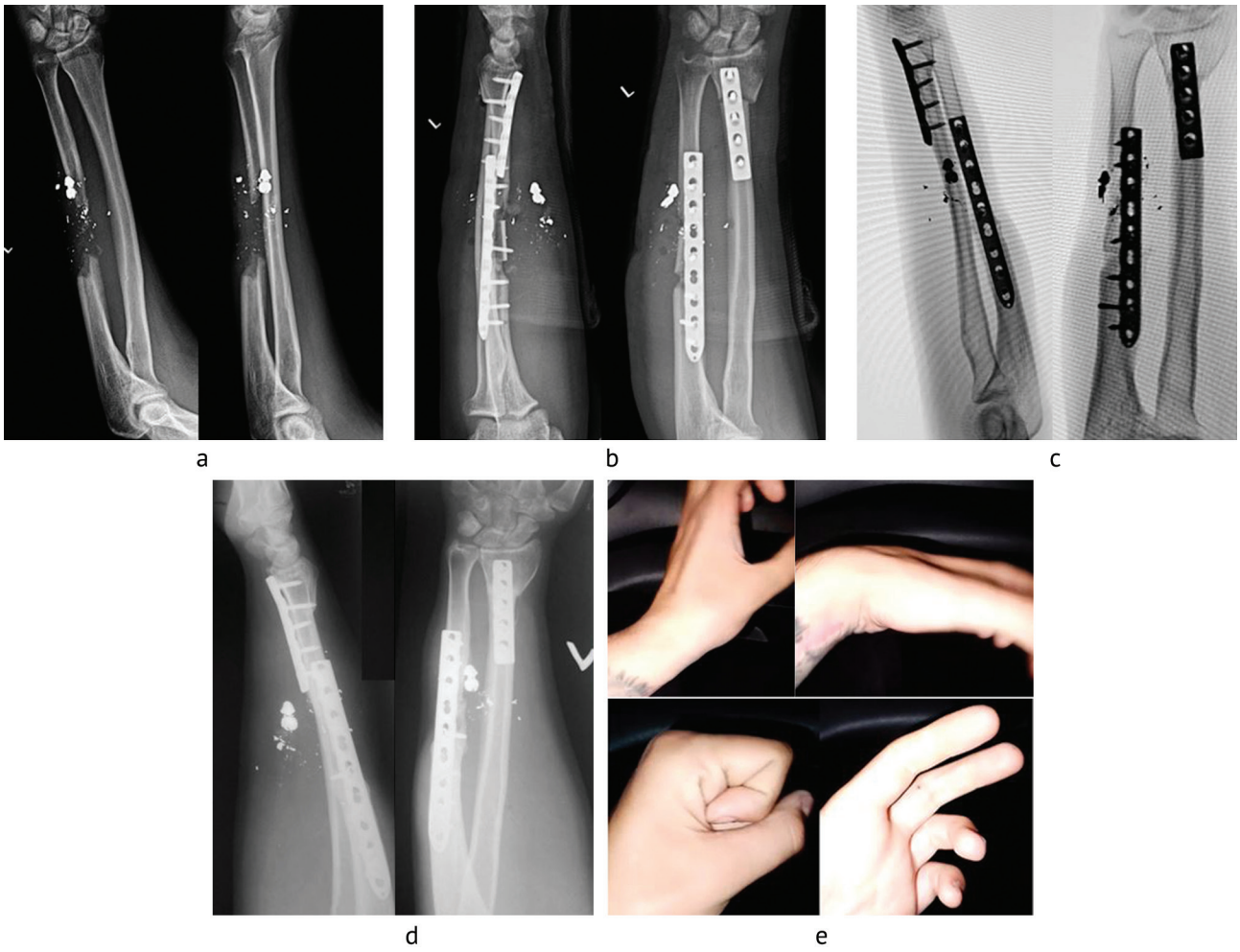

Fig. 5 Patient K.: *a* radiographs of the forearm bones before surgery; *b* radiographs of the forearm bones after surgery; *c* digital radiographs of the forearm bones 4 months after surgery; *d* radiographs of the forearm bones 6 months after surgery; *e* hand function 8 months after surgery (photo taken with a mobile phone camera by the patient himself in the area of a special military operation)

Patient A., 27 years old, sustained a gunshot wound to the right upper limb during combat operations on 20.03.2022. First aid was provided on the site. Then he was evacuated to the N.N. Burdenko Main Military Clinical Hospital, where on 24.03.2022, primary surgical treatment of the wounds of the right forearm, fixation of the right ulna with an external fixation device (EFD) of the military field rod kit (MFRC) and VAC therapy of wounds were performed (Fig. 6 a-d).

On 28.03.2022, repeated surgical treatment of the wounds of the right forearm, skin grafting of the wound defect with local tissues were performed. The wounds healed (Fig. 6 e).

On 27.05.2022, the external fixation device was removed and free vascularized plastic surgery of the ulnar bone defect of the right forearm with fibular graft (8 cm long) was performed and fixed with a 3D construct (Fig. 7 a).

The postoperative period was uneventful; the graft healed after 6 months, the metal implant was removed 12 months after surgery (Fig. 7 b, c). The functional result after rehabilitation treatment is shown in Figure 7 d.

Fig. 6 Patient A.: *a* appearance of soft tissue wound; *b* radiographs of the forearm; *c* view of soft tissue wound during VAC therapy; *d* radiographs of the forearm after fixation of the EFD MFRK; *e* soft tissue wounds after plastic surgery with local tissues

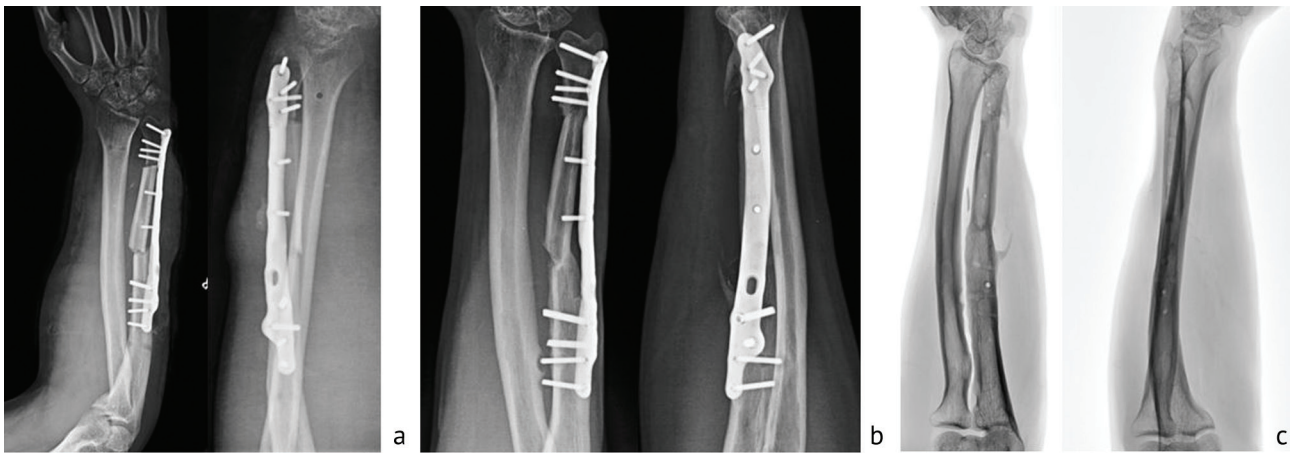

Fig. 7 Injured patient A.: *a* radiographs of the forearm after plastic surgery and fixation with a 3D-implant; *b* radiographs of the forearm 6 months after surgery; *c* digital radiographs of the forearm after removal of the metal implant (12 months after reconstructive surgery); *d* function of the upper limbs after rehabilitation

Fig. 7 (continued) Injured patient A.: *d* function of the upper limbs after rehabilitation

Male patient M., 35 years old, sustained a shrapnel penetrating wound of the left forearm and an open multi-fragmentary fracture in the middle and upper thirds of both bones of the left forearm, with displacement of bone fragments, defect of bones and soft tissues. Primary surgical treatment and immobilization with EFD were performed at the stage of qualified surgical care, after which he was referred to the N.N. Burdenko Main Military Clinical Hospital (Fig. 8 a, b). The wounds healed partially by secondary intention using local tissue grafting. After wound healing and CT scanning of the limb, 3D planning was performed, a resection template and a metal implant were designed (Fig. 8 c–e).

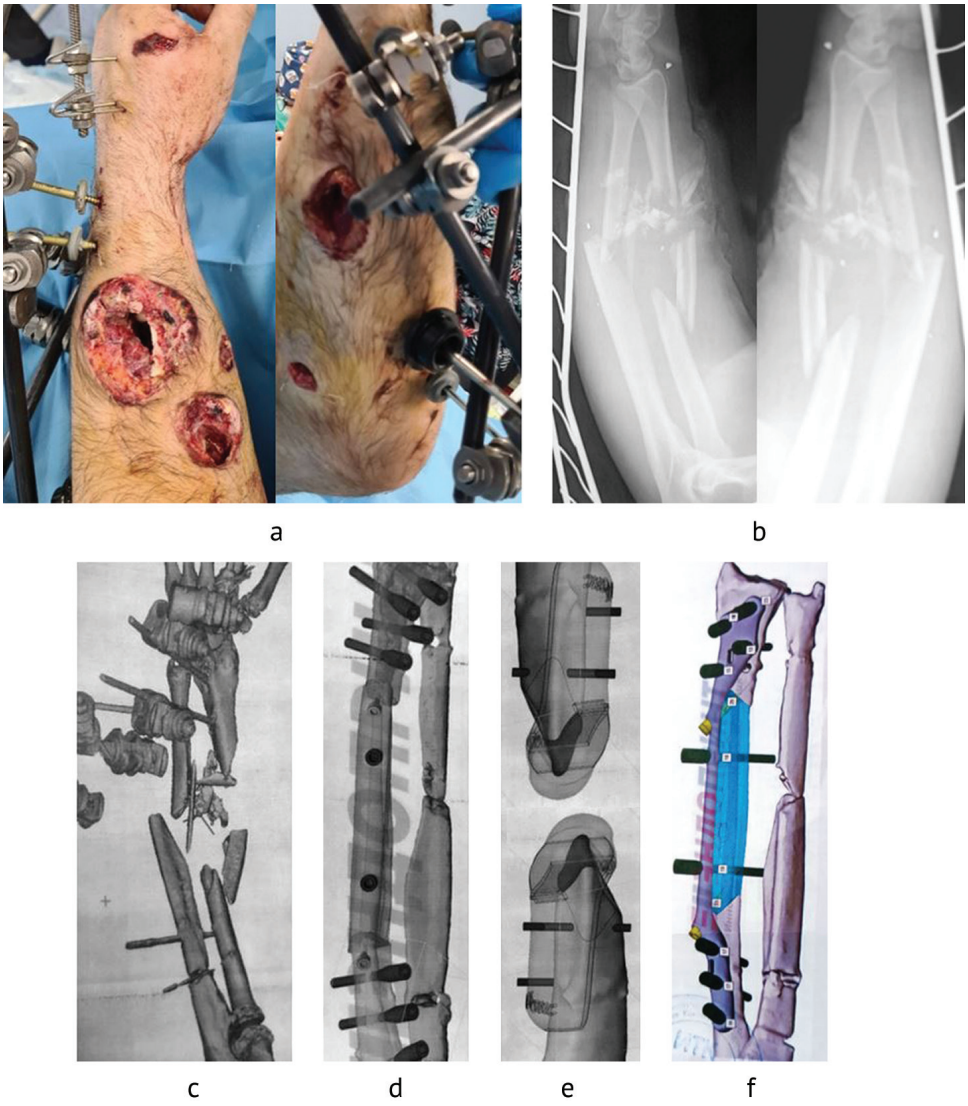

Fig. 8 Patient M.: *a* soft tissue wounds; *b* radiographs of the forearm. Planning the operation: c CT of the forearm bones; *d* planning grafting; *e* resection templates; *f* 3D reconstruction plan

The radial bone defect was repaired using a free vascularized fibular bone graft with a fasciocutaneous flap and 3D metal implant fixation (Fig. 9). The use of a customized implant in this case was determined by the size of the defect and the need to bypass the vascular "pedicle" of the fibular graft. Osteosynthesis of the ulna was performed using a standard plate with angular stability of screws (Fig. 10 a). The wounds healed; the fractures united 6 months after the operation (Fig. 10 b, c).

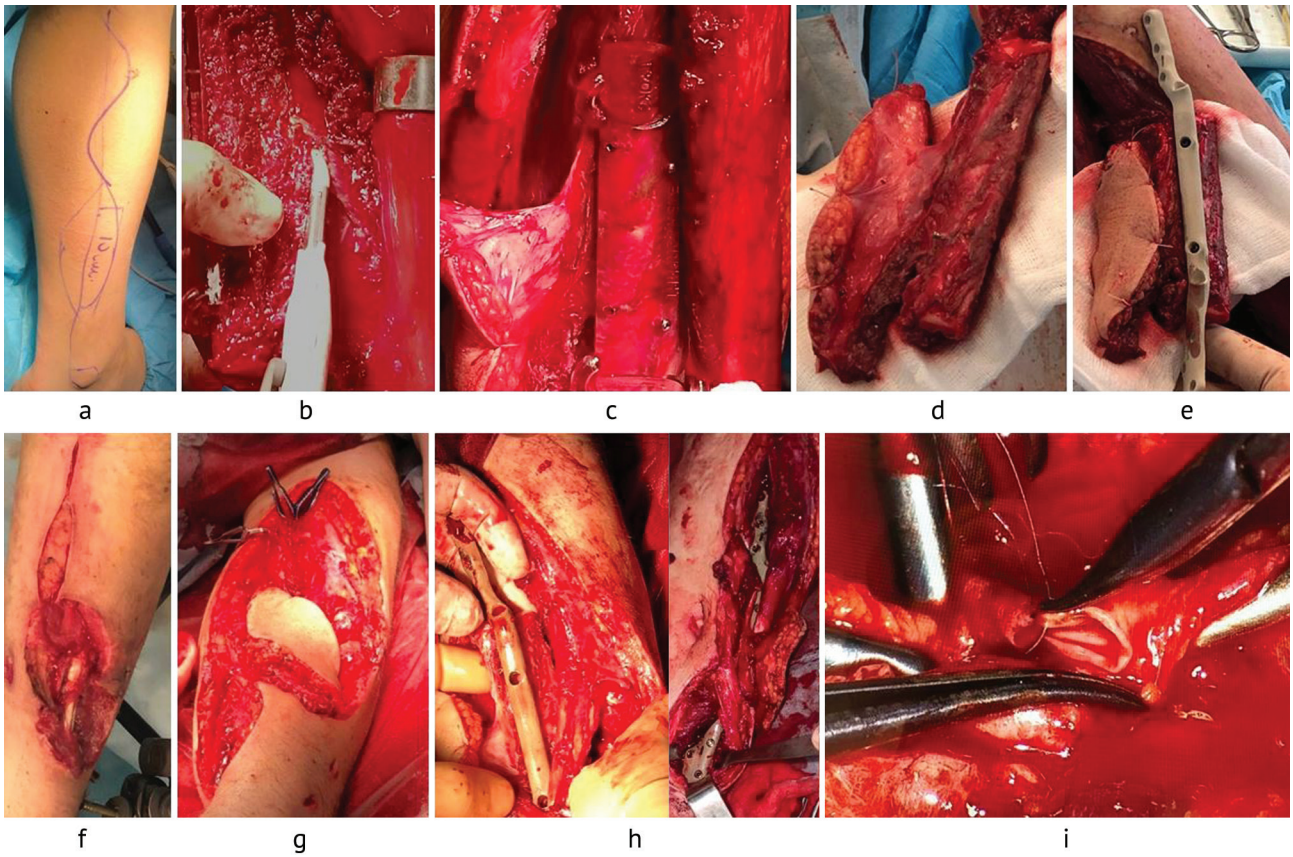

Fig. 9 Patient M.; stages of the operation: *a* graft planning; *b* isolating the fibular graft; *c* use of resection template; *d* appearance of the fibular graft; *e* view of the 3D-construction; *f* excision of the wound edges and mobilization of the vascular bundle; *g* view of the fibular graft; *h* fixation with a 3D-construct; *i* microvascular stage of the operation (suture of the artery of the fibular graft)

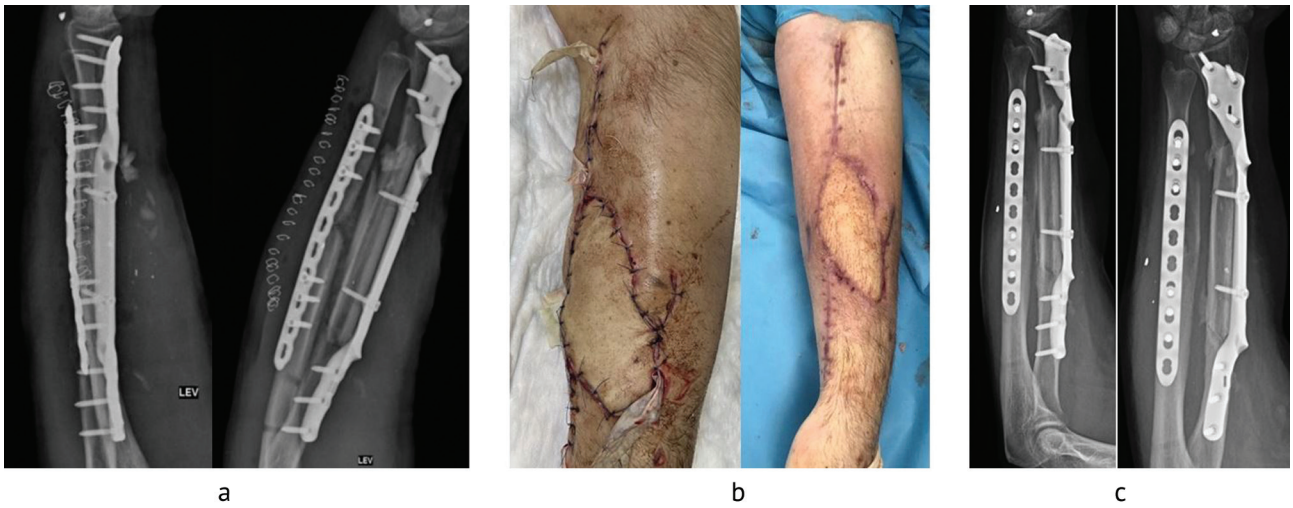

Fig. 10 Patient M.: *a* radiographs after the intervention; *b* views after the operation and after suture removal; *c* radiographs 6 months after the operation

DISCUSSION

The study of specialized literature and the analysis of the hospital's experience in treating wounded patients with severe gunshot injuries to the forearm have shown the difficulties of choosing the optimal surgical tactics. Gunshot wounds differ from other injuries by a primary defect. The size and structure of the latter depend on the magnitude of the energy of the wounding projectile. The characteristics of the secondary defect are largely determined by subsequent treatment. The use of time-tested treatment methods does not always allow for an optimal result in a short time. The experience of treating peacetime trauma to solving the problem of combat trauma requires verification and comprehension in order to be utilized. Nevertheless, the principle of the "reconstruction vector" we propose provides the surgeon with a methodological tool based on the logic and experience of many generations of surgeons.

The algorithm proposed by us is based on the principle of dividing bone defects by their anatomical features (single-, double-bone and fracture defects) and size (these indicators serve as a kind of coordinate axes, based on which the direction of the reconstruction vector should be determined). The end point of the algorithm is a point on the coordinate plane located opposite the corresponding points on the anatomy and size axes. Studying previous experience allowed us to arrange the known proven and proposed new treatment methods from simple to complex on the plane of choosing treatment tactics. Thus, optimal treatment methods are located in the direction of the reconstruction vector, which can be used with a combination of the corresponding structure and size of the defect.

The treatment of bone integrity disorders is based on bone reduction and osteosynthesis. Stable fixation is required after correcting the length, rotational and angular displacements, and can be provided in mild severity cases with standard metal fixators, and in severe cases requires the use of customized 3D constructs. All methods must meet the principle of minimal invasiveness, maintaining and restoring blood supply. Compliance with these principles ensures the possibility of early rehabilitation and working ability, which can serve as confirmation of the correctness of the chosen concept.

The shift of the reconstruction vector to one of the coordinate axes or its reduction indicates a simplification of the surgical task. Thus, in the case of a fracture defect, a relatively simple technique of acute shortening helps to solve the problem of a large defect by reducing the latter, which allows the use of less traumatic non-vascularized bone grafting instead of a complex multi-hour microsurgical intervention.

Bone grafting with iliac crest fragment is one of the frequently used and simple solutions for bone defect reconstruction [46, 47]. Iliac crest graft has all the advantages of autografts: osteogenesis, osteoinduction, osteoconduction and histocompatibility [48, 49]. Bone graft can be obtained from the anterior or posterior part of the iliac crest, vascularized or not, and cortical, cancellous or combined. However, its size and especially mechanical strength are limited [50, 51].

Vascularized fibula grafts are commonly used to reconstruct bone defects larger than 6 cm [52], often associated with soft tissue defects [53]. Three different options of vascularized fibular grafting have been developed: a single vascularized fibula (up to 25 cm in an adult patient), a double technique, and a combined reconstruction with vascularized fibula and allograft [54–56]. However, the bone defect for which this method can be used should not exceed 13 cm in length [57].

Fibular graft healed without further surgical interventions in 70% of patients after an average of 10 months. There were serious complications, such as deep soft tissue infection, pedicle thrombosis, stress fracture not associated with fixation failure, compartment syndrome, but the union rate was 82 % within 2 years of follow-up and 97% after 5 years [58–61]. Our results on the rates and duration of healing are consistent with the work of Liu et al. (2018) [62], who reported on long-term

follow-ups of FG: the healing rate was 100% and the average time was 21.3 weeks. The combined reconstruction with vascularized fibula and allograft has the advantages of both previously described techniques [63].

For reconstruction of segmental defects, metal prostheses are an alternative to massive bone grafts; they provide immediate stability, rapid rehabilitation and early weight bearing [64]. However, frequent infectious complications, mechanical loosening and mechanical wear, high risk of prosthetic and periprosthetic fractures have made this technique applicable only to cancer patients with limited life expectancy [65–67]. However, the proposed tissue-engineered structures based on metal scaffolds with a set of biological components are capable of being integrated into living tissues and may soon replace auto- and allografting in separate cases.

The Ilizarov method has long served as a reliable and effective means of solving many problems associated with injuries to the musculoskeletal system. It can be used for any type of defect, which does not contradict the rule of the reconstruction vector. However, its place in the treatment system for associated gunshot defects of the forearm requires clarification.

CONCLUSION

Management of large bone defects is a complex task, the choice of reconstruction method remains labor-intensive and uncertain; the necessary consensus is lacking. Several methods of treating bone defects are available, but there is insufficient quantitative and qualitative evidence to draw convincing conclusions, especially about the timing of treatment, complications and reoperations.

The algorithm proposed for surgical treatment of wounded persons with gunshot defects of the forearm bones allows for a detailed consideration of the anatomical features of pathological changes, drawing the reconstruction vector in specific cases and assists in the optimal choice of surgical treatment method.

Conflict of interest *Not declared.*

Funding *Not declared.*

REFERENCES

1. Trishkin DV, Kryukov EV, Alekseev DE, et al. *Military field surgery. National leadership. Ser. National leadership*. Moscow: GEOTAR-Media Publ.; 2024:180-208. (In Russ.) doi: 10.33029/9704-8023-6-vpt-2023-1-736
2. Trishkin DV, Kryukov EV, Chuprina AP. et al. *Methodological recommendations for the treatment of combat surgical trauma*. St. Petersburg: Military Medical Academy named after S.M. Kirov; 2022:373. (In Russ.) Available at: http://xn----9sbdbejx7bdduahou3a5d.xn--p1ai/upload/metod_rek_VPH_ver-1.pdf. Accessed Jun 26, 2024.
3. Kerimov A, Nelin N, Perekhodov S, et al. Current approaches to surgical treatment of extremity gunshot injuries. *MIA Medical Bulletin*. 2023;124(3):2-6. (In Russ.) doi: 10.52341/20738080_2023_124_3_2
4. Chelnokov AN, Lazarev AYu, Solomin LN, et al. Functional recovery after minimally invasive osteosynthesis in fractures of the shaft of the radius and ulna. *Traumatology and Orthopedics of Russia*. 2016;22(1):74–84. (In Russ.) doi: 10.21823/2311-2905-2016-0-1-74-84
5. Miziev IA, Baksanov KhD, Zhigunov AK, et al. Treatment of Forearm Fractures in Multiple and Associated Injuries. *Disaster Medicine*. 2018;(4):24-27. (In Russ.).
6. Stavytsky OB, Pasternak DV, Karpushkin OV, et al. Our experience of using of locking intramedullary nailing in the treatment of patients with forearm fractures at the premises of Regional Intensive Care Hospital in Mariupol. *Trauma*. 2019;20(4):61-65. (In Ukr.) doi: 10.22141/1608-1706.4.20.2019.178747
7. Kupkenov DE. The use of rod devices with reposition units for treatment of forearm bone shaft fractures. *Genij Ortopedii*. 2011;(1):13-16. (In Russ.).
8. Korol' SA, Matveiichuk BV, Domansky AN. Extent of the surgical care to the wounded with gunshot forearm fractures at the stages of medical evacuation during anti-terrorist operation. *Trauma*. 2016;17(6):76-80. (In Ukr.) doi: 10.22141/1608-1706.6.17.2016.88621
9. Walker M, Sharareh B, Mitchell SA. Masquelet Reconstruction for Posttraumatic Segmental Bone Defects in the Forearm. *J Hand Surg Am*. 2019;44(4):342.e1-342.e8. doi: 10.1016/j.jhsa.2018.07.003
10. Wang P, Wu Y, Rui Y, et al. Masquelet technique for reconstructing bone defects in open lower limb fracture: Analysis of the relationship between bone defect and bone graft. *Injury*. 2021;52(4):988-995. doi: 10.1016/j.injury.2020.12.009
11. Gustilo RB, Anderson JT. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. *J Bone Joint Surg Am*. 1976;58(4):453-458.
12. Gustilo RB, Mendoza RM, Williams DN. Problems in the management of type III (severe) open fractures: a new classification of type III open fractures. *J Trauma*. 1984;24(8):742-746. doi: 10.1097/00005373-198408000-00009

13. Gustilo RB, Merkow RL, Templeman D. The management of open fractures. *J Bone Joint Surg Am*. 1990;72(2):299-304.
14. Keating JF, Simpson AH, Robinson CM. The management of fractures with bone loss. *J Bone Joint Surg Br*. 2005;87(2):142-150. doi: 10.1302/0301-620x.87b2.158744
15. Baldwin P, Li DJ, Auston DA, et al. Autograft, allograft, Autograft, Allograft, and Bone Graft Substitutes: Clinical Evidence and Indications for Use in the Setting of Orthopaedic Trauma Surgery. *J Orthop Trauma*. 2019;33(4):203-213. doi: 10.1097/BOT.0000000000001420
16. Nashi N, Kagda FH. Current concepts of bone grafting in trauma surgery. *J Clin Orthop Trauma*. 2023;43:102231. doi: 10.1016/j.jcot.2023.102231
17. Robinson CM, McLauchlan G, Christie J, et al. Tibial fractures with bone loss treated by primary reamed intramedullary nailing. *J Bone Joint Surg Br*. 1995;77(6):906-913.
18. Harris AM, Althausen PL, Kellam J, et al. Complications following limb-threatening lower extremity trauma. *J Orthop Trauma*. 2009;23(1):1-6. doi: 10.1097/BOT.0b013e31818e43dd
19. Ilizarov GA. Clinical application of the tension-stress effect for limb lengthening. *Clin Orthop Relat Res*. 1990;(250):8-26.
20. Lasanianos NG, Kanakaris NK, Giannoudis PV. Current management of long bone large segmental defects. *Orthop Trauma*. 2010;24(2):149-163. doi: 10.1016/j.mporth.2009.10.003
21. Mauffrey C, Barlow BT, Smith W. Management of segmental bone defects. *J Am Acad Orthop Surg*. 2015;23(3):143-153. doi: 10.5435/JAAOS-D-14-00018
22. Pipitone PS, Rehman S. Management of traumatic bone loss in the lower extremity. *Orthop Clin North Am*. 2014;45(4):469-482. doi: 10.1016/j.ocl.2014.06.008
23. El-Rosasy MA. Acute shortening and re-lengthening in the management of bone and soft-tissue loss in complicated fractures of the tibia. *J Bone Joint Surg Br*. 2007;89(1):80-88. doi: 10.1302/0301-620X.89B1.17595
24. Eralp L, Balci HI, Kocaoglu M, et al. Is acute compression and distraction superior to segmental bone transport techniques in chronic tibial osteomyelitis ? Comparison of Distraction Osteogenesis Techniques. *Acta Orthop Belg*. 2016;82(3):599-609.
25. Regan DK, Crespo AM, Konda SR, et al. Functional Outcomes of Compression Plating and Bone Grafting for Operative Treatment of Nonunions About the Forearm. *J Hand Surg Am*. 2018;43(6):564.e1-564.e9. doi: 10.1016/j.jhsa.2017.10.039
26. Ring D, Allende C, Jafarnia K, et al. Ununited diaphyseal forearm fractures with segmental defects: plate fixation and autogenous cancellous bone-grafting. *J Bone Joint Surg Am*. 2004;86(11):2440-2445.
27. Weiland AJ, Phillips TW, Randolph MA. Bone grafts: a radiologic, histologic, and biomechanical model comparing autografts, allografts, and free vascularized bone grafts. *Plast Reconstr Surg*. 1984;74(3):368-379.
28. Faldini C, Pagkrati S, Nanni M, et al. Aseptic forearm nonunions treated by plate and opposite fibular autograft strut. *Clin Orthop Relat Res*. 2009;467(8):2125-2134. doi: 10.1007/s11999-009-0827-5
29. Giannoudis PV, Harwood PJ, Tosounidis T, Kanakaris NK. Restoration of long bone defects treated with the induced membrane technique: protocol and outcomes. *Injury*. 2016;47 Suppl 6:S53-S61. doi: 10.1016/S0020-1383(16)30840-3
30. Wong TM, Lau TW, Li X, et al. Masquelet technique for treatment of posttraumatic bone defects. *ScientificWorldJournal*. 2014;2014:710302. doi: 10.1155/2014/710302
31. Davis JA, Choo A, O'Connor DP, et al. Treatment of Infected Forearm Nonunions With Large Complete Segmental Defects Using Bulk Allograft and Intramedullary Fixation. *J Hand Surg Am*. 2016;41(9):881-887. doi: 10.1016/j.jhsa.2016.05.021
32. Wood MB, Bishop AT. Massive bone defects of the upper limb: reconstruction by vascularized bone transfer. *Hand Clin*. 2007;23(1):49-56. doi: 10.1016/j.hcl.2007.01.002
33. Safoury Y. Free vascularized fibula for the treatment of traumatic bone defects and nonunion of the forearm bones. *J Hand Surg Br*. 2005;30(1):67-72. doi: 10.1016/j.jhsb.2004.09.007
34. Zhang Q, Yin P, Hao M, et al. Bone transport for the treatment of infected forearm nonunion. *Injury*. 2014;45(12):1880-1884. doi: 10.1016/j.injury.2014.07.029
35. Green SA. Skeletal defects. A comparison of bone grafting and bone transport for segmental skeletal defects. *Clin Orthop Relat Res*. 1994;(301):111-117.
36. Kovalenko AN, Shubnyakov II, Bilyk SS, Tikhilov RM. The modern technologies of treatment of severe bone defects in the acetabulum region: which problems are solved with individual implants? *Polytrauma*. 2017;(1):72-81. (In Russ.).
37. Tikhilov RM, Shubnyakov II, Kovalenko AN, et al. Indications for revision hip arthroplasty, planning and technique of revision surgery. In: Tikhilov RM, Shubnyakov II. (eds.) *Guide to hip surgery*. SPb.: RSRI of TO na RR Vreden; 2015;2:258-355. (In Russ.)
38. Efetov SK, Lychagin AV, Zubayraeva AA, et al. 3D-printed pubic bone for pelvic ring reconstruction after exenteration for anal cancer recurrence. *Br J Surg*. 2020;107(11):e512-e514. doi: 10.1002/bjs.11982
39. Peleshok SA, Golovko KP. 3D printing and medicine. *Russian Military Medical Academy Reports*. 2022;41(3):325-333. (In Russ.) doi: 10.17816/rmmar88645
40. Keating JF, Simpson AH, Robinson CM. The management of fractures with bone loss. *J Bone Joint Surg Br*. 2005;87(2):142-150. doi: 10.1302/0301-620x.87b2.15874
41. Molina CS, Stinner DJ, Obremskey WT. Treatment of Traumatic Segmental Long-Bone Defects: A Critical Analysis Review. *JBJS Rev*. 2014;2(4):e1. doi: 10.2106/JBJS.RVW.M.00062
42. Omid R, Stone MA, Zalavras CG, Marecek GS. Gunshot Wounds to the Upper Extremity. *J Am Acad Orthop Surg*. 2019;27(7):e301-e310. doi: 10.5435/JAAOS-D-17-00676
43. Ebrahimi A, Nejadsarvari N, Ebrahimi A, Rasouli HR. Early Reconstructions of Complex Lower Extremity Battlefield Soft Tissue Wounds. *World J Plast Surg*. 2017;6(3):332-342.
44. Migliorini F, La Padula G, Torsiello E, et al. Strategies for large bone defect reconstruction after trauma, infections or tumour excision: a comprehensive review of the literature. *Eur J Med Res*. 2021;26(1):118. doi: 10.1186/s40001-021-00593-9
45. Jebson PJL, Hayden RJ. AO Principles of Fracture Management. *JAMA*. 2008;300(20):2432-2433. doi:10.1001/jama.2008.703
46. Ebraheim NA, Elgafy H, Xu R. Bone-graft harvesting from iliac and fibular donor sites: techniques and complications. *J Am Acad Orthop Surg*. 2001;9(3):210-218. doi: 10.5435/00124635-200105000-00007
47. Tonoli C, Bechara AH, Rossanez R, et al. Use of the vascularized iliac-crest flap in musculoskeletal lesions. *Biomed Res Int*. 2013;2013:237146. doi: 10.1155/2013/237146

48. Roberts TT, Rosenbaum AJ. Bone grafts, bone substitutes and orthobiologics: the bridge between basic science and clinical advancements in fracture healing. *Organogenesis*. 2012;8(4):114-124. doi: 10.4161/org.23306
49. Lei P, Du W, Liu H, et al. Free vascularized iliac bone flap based on deep circumflex iliac vessels graft for the treatment of osteonecrosis of femoral head. *J Orthop Surg Res*. 2019;14(1):397. doi: 10.1186/s13018-019-1440-2
50. Kessler P, Thorwarth M, Bloch-Birkholz A, et al. Harvesting of bone from the iliac crest--comparison of the anterior and posterior sites. *Br J Oral Maxillofac Surg*. 2005;43(1):51-56. doi: 10.1016/j.bjoms.2004.08.026
51. Myeroff C, Archdeacon M. Autogenous bone graft: donor sites and techniques. *J Bone Joint Surg Am*. 2011;93(23):2227-2236. doi: 10.2106/JBJS.J.01513
52. Beris AE, Lykissas MG, Korompilias AV, et al. Vascularized fibula transfer for lower limb reconstruction. *Microsurgery*. 2011;31(3):205-211. doi: 10.1002/micr.20841
53. Kalra GS, Goel P, Singh PK. Reconstruction of post-traumatic long bone defect with vascularised free fibula: A series of 28 cases. *Indian J Plast Surg*. 2013;46(3):543-548. doi: 10.4103/0970-0358.122013
54. Zekry KM, Yamamoto N, Hayashi K, et al. Reconstruction of intercalary bone defect after resection of malignant bone tumor. *J Orthop Surg (Hong Kong)*. 2019;27(1):2309499019832970. doi: 10.1177/2309499019832970
55. Bumbasirevic M, Stevanovic M, Bumbasirevic V, et al. Free vascularised fibular grafts in orthopaedics. *Int Orthop*. 2014;38(6):1277-82. doi: 10.1007/s00264-014-2281-6
56. Muramatsu K, Ihara K, Shigetomi M, Kawai S. Femoral reconstruction by single, folded or double free vascularised fibular grafts. *Br J Plast Surg*. 2004;57(6):550-555. doi: 10.1016/j.bjps.2003.08.021
57. Wieser K, Modaressi K, Seeli F, Fuchs B. Autologous double-barrel vascularized fibula bone graft for arthrodesis of the shoulder after tumor resection. *Arch Orthop Trauma Surg*. 2013;133(9):1219-1224. doi: 10.1007/s00402-013-1795-5
58. Roddy E, DeBaun MR, Daoud-Gray A, et al. Treatment of critical-sized bone defects: clinical and tissue engineering perspectives. *Eur J Orthop Surg Traumatol*. 2018;28(3):351-362. doi: 10.1007/s00590-017-2063-0
59. Estrella EP, Wang EH. A Comparison of Vascularized Free Fibular Flaps and Nonvascularized Fibular Grafts for Reconstruction of Long Bone Defects after Tumor Resection. *J Reconstr Microsurg*. 2017;33(3):194-205. doi: 10.1055/s-0036-1594299
60. McCullough MC, Arkader A, Ariani R, et al. Surgical Outcomes, Complications, and Long-Term Functionality for Free Vascularized Fibula Grafts in the Pediatric Population: A 17-Year Experience and Systematic Review of the Literature. *J Reconstr Microsurg*. 2020;36(5):386-396. doi: 10.1055/s-0040-1702147
61. Houdek MT, Bayne CO, Bishop AT, Shin AY. The outcome and complications of vascularised fibular grafts. *Bone Joint J*. 2017;99-B(1):134-138. doi: 10.1302/0301-620X.99B1.BJJ-2016-0160.R1
62. Liu S, Tao S, Tan J, et al. Long-term follow-up of fibular graft for the reconstruction of bone defects. *Medicine* (Baltimore). 2018;97(40):e12605. doi: 10.1097/MD.0000000000012605
63. Bakri K, Stans AA, Mardini S, Moran SL. Combined massive allograft and intramedullary vascularized fibula transfer: the capanna technique for lower-limb reconstruction. *Semin Plast Surg*. 2008;22(3):234-241. doi: 10.1055/s-2008-1081406
64. Zekry KM, Yamamoto N, Hayashi K, et al. Reconstruction of intercalary bone defect after resection of malignant bone tumor. *J Orthop Surg* (Hong Kong). 2019;27(1):2309499019832970. doi: 10.1177/2309499019832970
65. Panagopoulos GN, Mavrogenis AF, Mauffrey C, et al. Intercalary reconstructions after bone tumor resections: a review of treatments. *Eur J Orthop Surg Traumatol*. 2017;27(6):737-746. doi: 10.1007/s00590-017-1985-x
66. Zheng K, Yu XC, Hu YC, et al. Outcome of segmental prosthesis reconstruction for diaphyseal bone tumors: a multi-center retrospective study. *BMC Cancer*. 2019;19(1):638. doi: 10.1186/s12885-019-5865-0
67. Palumbo BT, Henderson ER, Groundland JS, et al. Advances in segmental endoprosthetic reconstruction for extremity tumors: a review of contemporary designs and techniques. *Cancer Control*. 2011;18(3):160-170. doi: 10.1177/107327481101800303

The article was submitted 04.04.2023; approved after reviewing 11.09.2023; accepted for publication 21.02.2024.

Information about the authors:

Denis V. Davydov — Doctor of Medical Sciences, Professor, Chief of the Hospital;

Leonid K. Brizan — Doctor of Medical Sciences, Professor, Deputy Head, brizhan.leonid@mail.ru;

Artur A. Kerimov — Candidate of Medical Sciences, Head of the Traumatology Center, kerartur@yandex.ru;

Andrey A. Maksimov — Candidate of Medical Sciences, Head of the Department, aam.moscow.hand.72@gmail.com, https://orcid.org/0000-0002-0891-4937;

Igor V. Khominets — Candidate of Medical Sciences, Head of the Department;

Alexey V. Lychagin — Doctor of Medical Sciences, Professor, Head of the Department, dr.lychagin@mail.ru, https://orcid.org/0000-0002-2202-8149;

Andrey A. Gritsyuk — Doctor of Medical Sciences, Professor, Professor of the Department, drgaamma@gmail.com, https://orcid.org/0000-0003-4202-4468;

Adam Z. Arsomakov — Candidate of Sciences in Medicine, Head of the Department, arsamakov-a@ mail.ru.

Original article

https://doi.org/10.18019/1028-4427-2024-30-4-502-510

CC BY

Modification of proximal row carpectomy (PRC) technique for adaptive wrist collapse (pilot study)

Sh.K. Kuttygul✉, D.E. Tyagunov, N.A. Shchudlo

Ilizarov National Medical Research Centre for Traumatology and Orthopedics, Kurgan, Russian Federation

Corresponding author: Shyngys K. Kuttygul, artana.kaz@gmail.com

Abstract

Introduction Proximal carpal row resection has been used for many decades as a "salvage procedure" for progressive wrist collapse. Improving the technique of its implementation, as well as introducing various modifications of the technique into practice are an important area for achieving better results of surgical treatment.

The **purpose** of this work was to demonstrate aspects of the modified proximal row carpectomy (PRC) technique and the immediate results of its use.

Materials and methods Eight patients aged from 24 to 57 years (seven men and one woman) were treated with the modified PRC technique. Treatment results were assessed using an adapted QuickDASH questionnaire, a visual analogue scale (VAS), based on patient satisfaction and radiographic results.

Results The average duration of surgical intervention was (149.0 ± 35.5) minutes. In the postoperative period, six patients (75 %) underwent fixation with an Ilizarov apparatus, the rest with a plaster splint. The average range of motion of flexion and extension was (67.5 ± 18.3)°, range: 40–95°. The patients had an average of (35.6 ± 16.13)° extension, range: 10–65° and (31.87 ± 10.9)° flexion, range: 10–45°. Patients reported decreased grip strength after surgery. Pain syndrome according to VAS at rest was equal to 0–1 points and 3–4 points when the affected limb was loaded. Six patients completed the QuickDASH survey, with a mean score of (14.83 ± 4.25) points. All patients are satisfied with the result of treatment and the absence of pain at rest. Patients returned to their usual work.

Discussion Unlike the conventional dorsal approach through the III–IV tendon canals, the use of two mini-approaches provides a better cosmetic effect and makes it easier to restore the integrity of the tendon canals, which are important for the prevention of desmogenic contractures. The use of the Ilizarov apparatus has proven to be the method of choice, providing absolute stability and reduction of pain in the postoperative period. For patients under 45 years of age with increased functional demands, a balanced approach is required when choosing PRC or intercarpal arthrodesis, depending on which functional parameters are more important to the patient.

Conclusion The analysis of short-term results of using the modified PRC technique shows that it reduces the invasiveness of the operation, improves its esthetic result, provides pain relief and a satisfactory range of motion and grip strength.

Keywords: adaptive carpal collapse (ACC), Ilizarov apparatus, resection, proximal row of carpal bones

For citation: Kuttygul ShK, Tyagunov DE, Shchudlo NA. Modification of proximal row carpectomy (PRC) technique for adaptive wrist collapse (pilot study). *Genij Ortopedii*. 2024;30(4):502-510. doi: 10.18019/1028-4427-2024-30-4-502-510

© Kuttygul Sh.K., Tyagunov D.E., Shchudlo N.A., 2024
© Translator Tatyana A. Malkova, 2024

INTRODUCTION

A pain-free and stable wrist joint is essential for full hand function. In clinical practice, patients frequently refer with pain at the wrist level, the causes of which are conventionally divided into mechanical, neurological and systemic [1]. The most common cause of chronic pain is osteoarthritis of the wrist, which is classified into inflammatory, degenerative, infectious and hemorrhagic [2]. Primary idiopathic osteoarthritis of the wrist (osteoarthritis) is a rare condition [3], while secondary osteoarthritis occurs after simple trauma, instability, dislocations, or inflammatory arthritis resulting from cerebral palsy, penetrating gunshot wounds [4], and infections [5].

Secondary degenerative arthritis of the wrist frequently results from injuries to the scapholunate ligament or fractures of the scaphoid followed by nonunion or malunion. Subsequently, adaptive collapse of the wrist may develop, a pathological condition consisting of a progressive disruption of the anatomically correct relative position of the bones and their fragments or rows of bones of the wrist, leading to a decrease in height, changes in biomechanics and a high rate of degenerative process. Wrist collapse should be considered as a unique outcome of instability, which has a long-standing nature that will aggravate the course of post-traumatic osteoarthritis [6].

One of the main tasks of a hand surgeon is to restore the anatomical and functional integrity of the damaged segment and relieve pain, and the surgeon has various types of surgical interventions for this purpose. The choice of treatment method depends on the cause and nature of the consequences of the causing pathology and the needs of the patient. Available procedures can be grouped into two main treatment options, namely partial or complete wrist arthrodesis [7–11] and wrist arthroplasty [12–16], as well as palliative and salvage treatments.

To relieve chronic carpal pain syndrome, decompression of the bone marrow cavity of the distal end of the radius is used [17], aimed at improving its blood supply, as well as partial or complete denervation of the wrist [18], which can be independent operations or complement others [19].

A common surgical technique for various degenerative conditions is resection of the proximal row of carpal bones. It refers to operations that preserve the range of motion (as opposed to total arthrodesis, when movement in the joint is sacrificed) [20]. Resection of the proximal row of carpal bones has several advantages: relative ease of execution, shorter duration of postoperative immobilization, and no risk of bone nonunion, unlike arthrodesis [21, 22]. It can be used in patients who do not require greater handgrip strength [23]. The consequence of the technique may be the process of osteoarthritis in the formed radiocapitate joint, which develops over time in most patients and is associated with heavy physical labor [24]. It may subsequently require additional surgical interventions. Despite that resection of the proximal row of carpal bones is time-tested, the problem of improving the technique of its implementation remains relevant [25]. It determined the purpose of our study.

The purpose of the work was to demonstrate aspects of the modified proximal row carpectomy (PRC) technique and short-term results of its use.

MATERIALS AND METHODS

Eight patients aged from 24 to 57 years were treated with the use of a modified technique for resection of the proximal row of carpal bones (Table 1), the average age was (37.75 ± 10.42) years.

Preoperative assessment was aimed at understanding the patient's degree of disability and is based on the patient's subjective assessment of pain and loss of function, as well as objective assessment of range of motion (goniometry) [26] and imaging data (radiography and CT).

Table 1

Preoperative clinical and demographic data

Patient	Age	Sex	Dominant hand	Affected hand	Indications	Range of motion (extension/axial alignment/flexion)	DASH	Pain at rest	Pain under loading
1	24	M	right	right	Aseptic necrosis of the lunate bone	30° / 0° / 10°	30	yes	yes
2	30	M	right	left	Transscaphoid perilunate dislocation	4° / 0° / 28°	–	yes	yes
3	40	F	right	right	SNAC stage 2	20° / 0° / 30°	71.6	yes	yes
4	37	M	right	left	Neglected perilunate dislocation	10° / 0° / 10°	–	yes	yes
5	57	M	right	right	SLAC stage 2	10° / 0° / 20°	47.5	yes	yes
6	47	M	left	left	Aseptic necrosis of the lunate bone	90° / 0° / 90°	–	yes	yes
7	36	M	right	left	Neglected perilunate dislocation	15° / 0° / 35°	–	yes	yes
8	31	M	right	left	SNAC stage 2	5° / 0° / 30°	–	yes	yes

All patients were admitted for planned treatment. Six patients (75 %) had a history of trauma. Indications for surgery were:

— chronic perilunate dislocation (*n* = 2; 25 %);

— transscaphoid perilunate dislocation (*n* = 1; 12.5 %);

— advanced collapse due to nonunion of the scaphoid fracture [SNAC stage 2] (*n* = 2; 25 %);

— scapholunate advanced collapse (SLAC stage 2) (*n* = 1; 12.5 %);

— signs of grade 4 aseptic necrosis of the lunate bone without a positive effect from conservative treatment (*n* = 2; 25 %).

All patients complained of aching pain at rest. The pain intensified with exercise and caused limited movement and decreased handgrip strength.

Treatment results were assessed based on the QuickDASH (Quick Diasabilities of the Arm, Shoulder and Hand) questionnaire [27], pain was evaluated with the Visual Analogue Scale (VAS), goniometric assessment of range of motion in the wrist joint, and hand grip strength score (0–1, 1–2, 2–3), where a score of "3" corresponded to the strength of a healthy contralateral hand.

Surgical technique

During the operation, conduction anesthesia was used. The patient's position was supine with the arm on the bedside counter. After preparing the surgical field, a hemostatic pneumatic tourniquet was applied at the level of the middle third of the humerus. Surgical approach to the scaphoid bone was carried out from a 4–5 cm long incision along the anterior surface of the forearm, using the flexor carpi radialis (FCR) as an external landmark. After making the incision, the tendon was moved to the side for exposure of the capsule of the wrist joint and for examination of the articular surfaces of the distal radius and scaphoid bones (Fig. 1). Next, resection of the scaphoid bone was performed. To prevent impingement syndrome, resection of the styloid process of the radius was performed. Then, through an additional dorsal approach 4–5 cm long, the retinaculum extensorum was exposed and the 5th canal of extensors was opened. The extensor tendons of the fifth finger were moved to the side, the wrist capsule was incised along the dorsal radiocarpal ligament (DRC) (Fig. 2), and the distal radius and midcarpal joint were examined to ensure the integrity of the lunate fossa of the radius and capitate bones.

If they are damaged, an alternative to surgery must be considered. If there is any question regarding the correct identification of the carpal bones, fluoroscopy with a metal wire marker is an option. Removal of the triquetral and lunate bones is performed similarly to the removal of the scaphoid using surgical techniques.

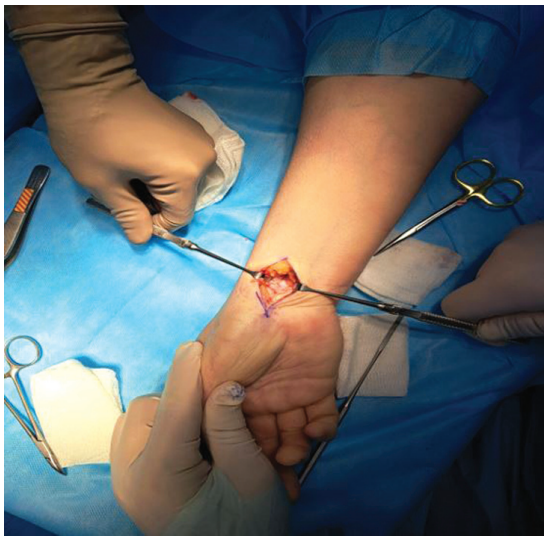

Fig. 1 Palmar approach

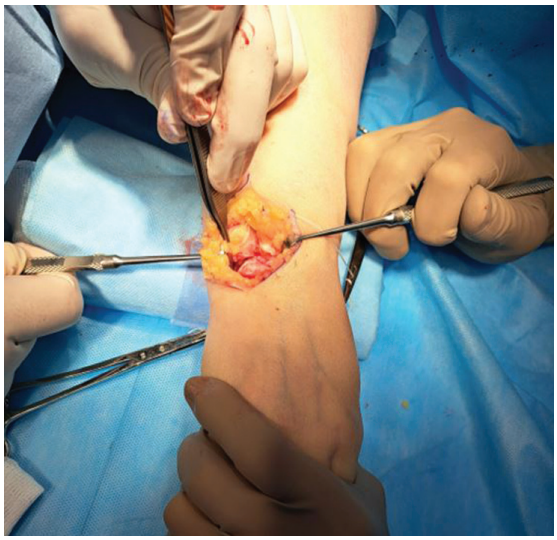

Fig. 2 Dorsal approach to the wrist

Then X-ray control was carried out. The joint capsule was sutured with non-absorbable suture material in accordance with literature recommendations [28]. After removing the tourniquet, thorough hemostasis was carried out and the wound was closed in layers with an interrupted or intradermal suture. In the case of perilunar dislocation and damage to the ligamentous apparatus, the wrist was immobilized in a functionally advantageous position using the Ilizarov apparatus. To do this, two wires were inserted crosswise in the lower third of the forearm and two wires were inserted in the middle third. The wires in the forearm were secured and tensioned in rings. The rings were connected to each other by straight rods. Two wires were drilled through the bases of the II–V metacarpal bones. The wires were fixed in a half ring. The half-ring and rings were connected by rods through hinges, providing a functionally advantageous position of the hand in relation to the forearm.

In the postoperative period, painkillers, dressings, antibiotic prophylaxis were prescribed; from the third day after the operation, exercise therapy was initiated.

RESULTS

Short-term results

The short-term results up to 1 year after removal of the device were monitored on an outpatient basis. At follow-ups, complaints were assessed, goniometry (Table 2), and radiography of the hand in two projections (direct and lateral) were performed to assess the condition of the radiocapitate joint.

A particular feature of the studied group of patients was their young age, mean 37.75 ± 10.42 years.

The average duration of surgery was (149.0 ± 35.51) minutes. In the postoperative period, six patients (75 %) underwent fixation with the Ilizarov apparatus, in the rest fixation with a plaster splint was used.

In the period from 3 months up to 1 year from the moment of surgery, the average volume of flexion and extension was (67.5 ± 18.3)°, range: 40–95°, of which (35.6 ± 16.13)° extension, range: 10–65°, and 31.8 ± 10.9° of flexion, range: 10–45°.

Table 2

Short-term results (up to 1 year)

Patient	Age	Sex	Dominant hand	Affected hand	Indications	Range of motion (extension/axial alignment/flexion)	Quick DASH	Pain at rest	Pain under loading
1	24	M	right	right	Aseptic necrosis of the lunate bone	10° / 0° / 30°	17.5	no	yes
2	30	M	right	left	Transscaphoid perilunate dislocation	30° / 0° / 45°	–	–	–
3	40	F	right	right	SNAC stage 2	45° / 0° / 45°	17.6	no	yes
4	37	M	right	left	Neglected perilunate dislocation	65° / 0° / 30°	13	no	no
5	57	M	right	right	SLAC stage 2	30° / 0° / 30°	7	no	no
6	47	M	left	left	Aseptic necrosis of the lunate bone	30° / 0° /3 0°	18	no	no
7	36	M	right	left	Neglected perilunate dislocation	30° / 0° / 35°	–	–	–
8	31	M	right	left	SNAC stage 2	45° / 0° / 10°	15.9	no	no

Pain according to VAS at rest was 0–1 points, and 3–4 points under loading of the affected limb. Six patients underwent a QuickDASH survey, the average score was (14.83 ± 4.25) points. The strength of the hand grip was 1–2 points.

All patients are satisfied with the result of treatment and the absence of pain at rest. The patients returned to their normal activities.

Case report

A 36-year old patient aged complained of pain at rest and during exercise, limited movement in the left hand. An. morbi: domestic injury on 23.10.2021, bruise from falling on the hand. Perilunar dislocation of the hand was diagnosed at his residence hospital. Under local anesthesia, the dislocation was reduced and the hand and wrist joint were immobilized with a plaster splint. The follow-up radiographs detected that the dislocation had not been eliminated. The patient fixed his hand with an orthosis for two months and underwent physiotherapy courses. Due to persisting complaints, he was hospitalized at the National Ilizarov Medical Research Center for Traumatology and Orthopaedics on 09.03.2022.

The examination revealed chronic transscaphoid perilunate dislocation of the left hand, arthrosis, synovitis of the left wrist joint, and a nonunion of a comminuted fracture of the styloid process of the left ulna (Fig. 3–4).

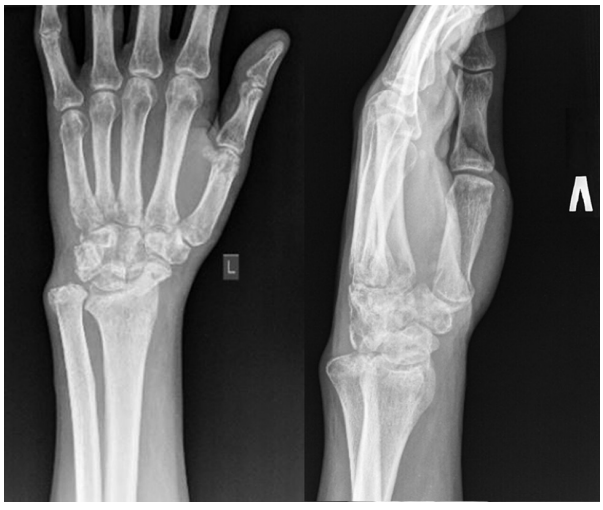

Fig. 3 Radiographs at admission

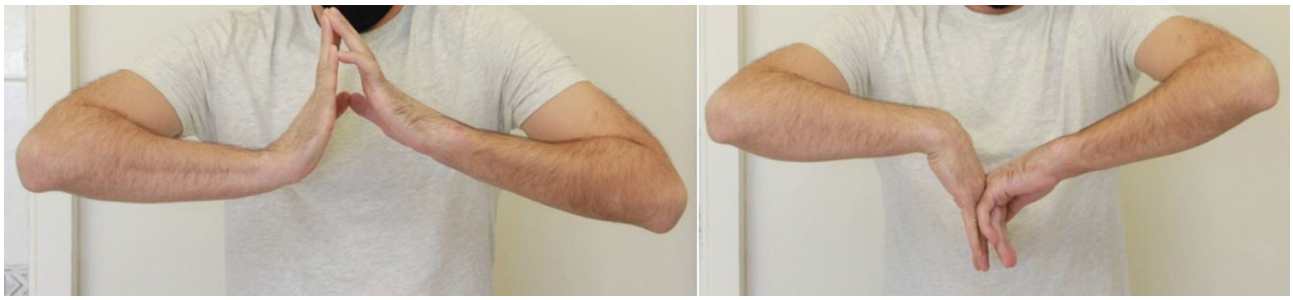

Fig. 4 Function before surgery

Soft tissue contracture prevented reduction of the dislocation. On March 18, 2022, resection of the proximal row of carpal bones was performed, as well as resection of a fragment of the styloid process of the left radius with fixation of the hand and forearm in the Ilizarov frame (Fig. 5).

In the postoperative period, the pain severity decreased compared to the preoperative period and, due to fixation with the Ilizarov apparatus, no repeated subluxations or dislocations were noted. On April 12, 2022 (27 days after the operation), the device was removed. Subsequently, fixation with an orthosis was indicated for one month.

1 year after the operation, the volume of flexion and extension was 95°, of which 65° extension and 30° flexion (Fig. 6, 7).

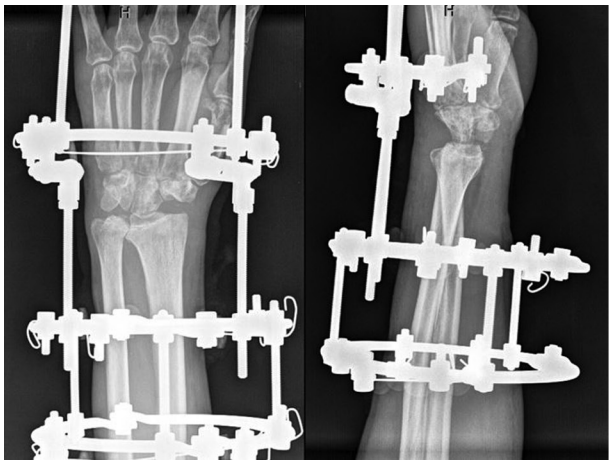

Fig. 5 AP and lateral radiographs taken on day 1 post-surgery

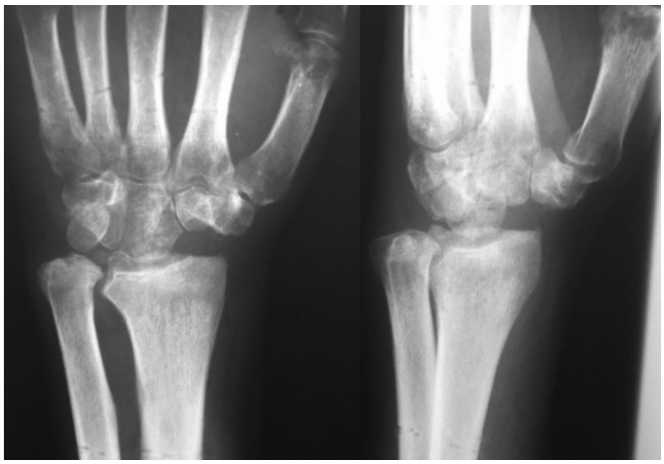

Fig. 6 Treatment result. AP and lateral radiographs at 1-year follow-up

Fig. 7 Photos of patient's hand function at 1-year follow-up

Pain score according to VAS at rest and under loading was zero. The QuickDASH score was 13 points. Hand grip strength was 2 points relative to a healthy hand.

DISCUSSION

According to literature sources, PRC has a wide range of indications [20]:

— scapholunate advanced collapse of the wrist [SLAC];

— advanced collapse due to scaphoid fracture nonunion [SNAC];

— Kienböck's disease with collapse of the wrist;

— chronic perilunate dislocation;

— osteonecrosis of the scaphoid bone (Preiser's disease or post-traumatic osteonecrosis);

— severe flexion contractures associated with systemic diseases (cerebral palsy or arthrogryposis).

Relative contraindications:

— lack of patient compliance;

— chronic compensated diseases of internal organs;

— skin diseases in the area of surgical intervention (in the acute stage): pyoderma, erysipelas;

— mental illnesses;

— young age, heavy physical work.

Absolute contraindications:

— chronic decompensated diseases of internal organs;

— mental illness of the patient;

— degenerative changes in the lunate fossa of the radius and capitate bone;

— inflammatory arthropathy (rheumatoid arthritis).

Progressive narrowing of the joint space and arthrosis of the radiocapitate joint inevitably occur after PRC due to replacement of the complex carpal joint with a hinge joint [24].

In patients under forty-five years of age with increased functional demands, a balanced approach is required when choosing PRC or quadrilateral arthrodesis, depending on which functional parameters (grip strength or range of motion) are more important to the patient [29].

Chim et Moran in a 2012-study analyzed long-term results of PRC in 147 patients and reported an average result of postoperative range of motion (flexion and extension: 73.5°) [24], which does not contradict our average results of range of motion, flexion and extension (67. 5 ± 18.3)°.

A special feature of our PRC technique is the presence of two mini-approaches. Unlike the conventional dorsal approach through the III–IV tendon canals, the use of two mini-approaches makes it easier to restore the integrity of the tendon canals and provides a better cosmetic effect, including by maintaining incisions along the Langer tension lines, which correspond to the natural orientation of the collagen fibers of the dermis. Such incisions usually heal better and cause less scarring [30], which is a significant factor in the prevention of desmogenic contractures. The use of the Ilizarov apparatus for chronic perilunar dislocations is also a new aspect of PRC modification, which has proven to be the technique of choice, providing high-quality immobilization of the wrist and reduction of pain in the postoperative period.

CONCLUSION

The analysis of the short-term results of the modified PRC technique shows that it reduces the invasiveness of the operation, improves the esthetic result, provides relief of pain at rest, a satisfactory range of motion and grip strength. The data obtained from eight patients treated are preliminary; further studies of short-term and long-term results will justify the introduction of the modified PRC technique into clinical practice.

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

Source of funding *The authors received no funding for this work.*

Ethical statement *The studies were conducted in accordance with the ethical standards of the World Medical Association Declaration of Helsinki, Ethical Principles for Medical Research Involving Human Subjects, as amended 2000.*

Informed consent *All patients or their legal representatives signed informed consent for the publication of data obtained as a result of the studies, without personal identification.*

REFERENCES

1. Forman TA, Forman SK, Rose NE. A clinical approach to diagnosing wrist pain. Am Fam Physician. 2005;72(9):1753-8.
2. Maklad M. Wrist arthritis and carpal advanced collapse- systematic review. *Int J Orthop*. 2020;7(6):1374-1378. doi: 10.17554/j.issn.2311-5106.2020.07.400
3. Laulan J, Marteau E, Bacle G. Wrist osteoarthritis. *Orthop Traumatol Surg Res*. 2015;101(1 Suppl):S1-S9. doi: 10.1016/j.otsr.2014.06.025
4. Nissen KL. Symposium on cerebral palsy (orthopaedic section). *Proc R Soc Med*. 1951;(44):87-90.
5. Ely LW. An operation for tuberculosis of the wrist. JAMA. 1920;75(25):1707-1709. doi: 10.1001/jama.1920.02620510021009
6. Voltovsky AI. Adaptive collapse of the wrist: notion, classification, modern methods of diagnostics. *Medical journal*. 2012;(3):26-31. (In Russ.)
7. Borisch N, Haussmann P. Radiolunate arthrodesis in the rheumatoid wrist: a retrospective clinical and radiological longterm follow-up. *J Hand Surg Br*. 2002;27(1):61-72. doi: 10.1054/jhsb.2001.0681
8. Chamay A, Della Santa D, Vilaseca A. Radiolunate arthrodesis. Factor of stability for the rheumatoid wrist. *Ann Chir Main*. 1983;2(1):5-17. doi: 10.1016/s0753-9053(83)80073-8
9. Tubiana R, Thomine J-M, Mackin E. *Examination of the hand and wrist*. London: Martin Dunitz; 1996:185-197.
10. Viegas SF, Patterson RM, Peterson PD, et al. Ulnar-sided perilunate instability: an anatomic and biomechanic study. *J Hand Surg Am*. 1990;15(2):268-278. doi: 10.1016/0363-5023(90)90107-3
11. Watson HK, Ashmead D. Triscaphe fusion for chronic scapholunate instability. In: Gelberman RH. (ed). *The wrist*. New York: Raven Press; 1994:183-194.
12. Alnot JY. Guepar's total arthroplasty of the wrist in rheumatoid polyarthritis. *Acta Orthop Belg*. 1988;54(2):178-184.
13. Clayton ML. Surgical treatment at the wrist in rheumatoid arthritis: a review of thirty-seven patients. *J Bone Joint Surg Am*. 1965 Jun;47:741-750.
14. Cobb TK, Beckenbaugh RD. Biaxial total-wrist arthroplasty. *J Hand Surg Am*. 1996;21(6):1011-1021. doi: 10.1016/S0363-5023(96)80309-1
15. Divelbiss BJ, Sollerman C, Adams BD. Early results of the Universal total wrist arthroplasty in rheumatoid arthritis. *J Hand Surg Am*. 2002;27(2):195-204. doi: 10.1053/jhsu.2002.31728
16. Gupta A. Total wrist arthroplasty. *Am J Orthop* (Belle Mead NJ). 2008;37(8 Suppl 1):12-16.
17. Wu J, Sun J, Liu X, et al. Clinical analysis of distal radius core decompression for chronic wrist pain. *Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi*. 2023;37(7):815-820. (In Chin.) doi: 10.7507/1002-1892.202303131
18. Smeraglia F, Basso MA, Famiglietti G, et al. Partial wrist denervation versus total wrist denervation: A systematic review of the literature. *Hand Surg Rehabil*. 2020;39(6):487-491. doi: 10.1016/j.hansur.2020.05.010
19. Kadiyala RK, Lombardi JM. Denervation of the Wrist Joint for the Management of Chronic Pain. *J Am Acad Orthop Surg*. 2017;25(6):439-447. doi: 10.5435/JAAOS-D-14-00243
20. Stern PJ, Agabegi SS, Kiefhaber TR, Didonna ML. Proximal row carpectomy. *J Bone Joint Surg Am*. 2005;87 Suppl 1(Pt 2):166-174. doi: 10.2106/JBJS.E.00261
21. Tomaino MM, Miller RJ, Cole I, Burton RI. Scapholunate advanced collapse wrist: proximal row carpectomy or limited wrist arthrodesis with scaphoid excision? *J Hand Surg Am*. 1994;19(1):134-142. doi: 10.1016/0363-5023(94)90237-2
22. Trumble TE, Salas P, Barthel T, Robert KQ 3rd. Management of scaphoid nonunions. *J Am Acad Orthop Surg*. 2003;11(6):380-391. doi: 10.5435/00124635-200311000-00002. Erratum in: J Am Acad Orthop Surg. 2004;12(1):33A.
23. Dacho AK, Baumeister S, Germann G, Sauerbier M. Comparison of proximal row carpectomy and midcarpal arthrodesis for the treatment of scaphoid nonunion advanced collapse (SNAC-wrist) and scapholunate advanced collapse (SLAC-wrist) in stage II. *J Plast Reconstr Aesthet Surg*. 2008;61(10):1210-1218. doi: 10.1016/j.bjps.2007.08.007
24. Chim H, Moran SL. Long-term outcomes of proximal row carpectomy: a systematic review of the literature. *J Wrist Surg*. 2012;1(2):141-148. doi: 10.1055/s-0032-1329547

25. Altaf W, Bhardwaj P, Sabapathy SR, Haseeb BA. A simple trick to excise the carpal bones during proximal row carpectomy. *Indian J Plast Surg*. 2018;51(1):101-102. doi: 10.4103/ijps.IJPS_213_17
26. Carter TI, Pansy B, Wolff AL, et al. Accuracy and reliability of three different techniques for manual goniometry for wrist motion: a cadaveric study. *J Hand Surg Am*. 2009;34(8):1422-1428. doi: 10.1016/j.jhsa.2009.06.002
27. Su Y. QuickDASH. *J Physiother*. 2014;60(3):167. doi: 10.1016/j.jphys.2014.06.003
28. El-Mowafi H, El-Hadidi M, Boghdady GW, Hasanein EY. Functional outcome of four-corner arthrodesis for treatment of grade IV scaphoid non-union. *Acta Orthop Belg*. 2007;73(5):604-611.
29. Wagner ER, Barras LA, Harstad C, et al. Proximal Row Carpectomy in Young Patients. *JBJS Essent Surg Tech*. 2021;11(1):e19.00054-e19.00054. doi: 10.2106/JBJS.ST.19.00054
30. Volgas DA, Harder I. *Manual of Soft-Tissue Management in Orthopaedic Trauma*. New York: AOTrauma Publ.; 2011:4-5.

The article was submitted 25.10.2023; approved after reviewing 04.04.2024; accepted for publication 18.06.2024.

Information about the authors:

Shyngys K. Kuttygul — post-graduate student, artana.kaz@gmail.com;
Denis E. Tyagunov — orthopaedic surgeon, head of the department;
Natalya A. Shchudlo — Doctor of Medical Sciences, leading researcher, nshchudlo@mail.ru.

Original article
https://doi.org/10.18019/1028-4427-2024-30-4-511-521

Prospective comparative study of medial parapatellar and medial subvastus approaches in total knee arthroplasty

I.A. Badawi, A.S. Ismail, A.H. Waly, M.A.N. Khalkaf✉

Faculty of Medicine, Alexandria University, Egypt

Corresponding author: Moustafa Ali Nagui Khalkaf, moustafa.nagui78@gmail.com

Abstract

Introduction Total knee arthroplasty (TKA) is the treatment of end-stage osteoarthritis in patients who failed to respond to conservative treatment in providing significant pain relief and improving joint function. The medial parapatellar approach (MPP) allows adequate patellar eversion and sufficient knee flexion to expose the knee joint, but the incision through the quadriceps tendon may impair the extensor mechanism of the knee post-operatively. The subvastus approach (SV) completely spares both the quadriceps tendon and muscle and provides adequate exposure of the knee joint for the replacement procedure, SV maintains integrity of the patellar blood supply and reduces post-operative pain resulting in shorter hospital stay.

The **aim** of this prospective study was to compare the results of the medial parapatellar and subvastus approaches in primary total knee arthroplasty (TKA) regarding postoperative pain, recovery of muscle strength, range of knee motion and return to regular daily activities.

Materials and Methods Sixty patients underwent TKA at El-Hadara university hospital in Alexandria. The medial parapatellar apphroach (MPP) was performed in 30 patients while the subvastus approach (SV) was used for the other 30 patients. The choice of approach was randomly assigned.

Results The statistical analysis of the results at the end of a 6-month follow-up showed that there were no significant differences between the patients in group 1 (MPP) and group 2 (SV) with respect to age, gender, comorbidity, side operated or body mass index (BMI). Regarding the functional knee scores (IKDC, WOMAC), there were no differences at 4 weeks, 3 months and 6 months postoperatively between the two groups. However, we found better outcomes in the SV group regarding the VAS score during the first five postoperative days, earlier quadriceps recovery by assessment of Straight Leg Raising test (SLR), while the operative time was longer in the SV group with less blood collected postoperatively in hemovac drain in the same group.

Discussion In our study during the operation via the MPP approach, the index suture positioned at the superomedial border of the patella and the opposite suture on the medial retinacular flap had enabled the surgeon to avoid patellar maltracking during closure of the wound. In the SV group, the L-shaped incision of the medial capsule was considered an efficient landmark for accurate soft tissue closure avoiding the patellar maltracking.

Conclusion The subvastus approach offers the advantage of keeping the integrity of quadriceps muscle and the extensor mechanism remains intact post-surgery. It causes less pain and less blood loss postoperatively than the regular parapatellar approach. The patient could recover the knee function in a shorter time with fewer complications, which is greatly in line with the concept of ERAS (Enhanced Recovery After Surgery).

Keywords: arthroplasty, knee joint, medial parapatellar approach, subvastus approach

For citation: Badawi IA, Ismail AS, Waly AH, Khalkaf MAN. Prospective comparative study of medial parapatellar and medial subvastus approaches in total knee arthroplasty. *Genij Ortopedii*. 2024;30(4):511-521. doi: 10.18019/1028-4427-2024-30-4-511-521

© Badawi I.A., Ismail A.S., Waly A.H, Khalkaf M.A.N., 2024

INTRODUCTION

Total knee arthroplasty (TKA) is the treatment of end-stage osteoarthritis in patients who failed to respond to conservative treatment in providing significant pain relief and improving joint function [1]. The medial parapatellar approach (MPP) is the most common approach performed by orthopaedic surgeons [2]. This approach allows adequate patellar eversion and sufficient knee flexion to expose the knee joint [3], but unfortunately the incision through the quadriceps tendon may impair the extensor mechanism of the knee post-operatively [4]. The subvastus approach (SV) completely spares both the quadriceps tendon and muscle and provides adequate exposure of the knee joint for the replacement procedure [5]. This procedure theoretically maintains integrity of the patellar blood supply and reduces post-operative pain resulting in shorter hospital stay [6].

Other approaches have been documented in the literature, with the majority, if not all, aiming to maintain the quadriceps mechanism in order to have fast postoperative recovery and quadriceps function. The midvastus technique, which differs from the subvastus technique in that the vastus medialis muscle is split in line with its fibres rather than being subluxated laterally in its whole, is another strategy to access the joint. The quadriceps tendon and the superior genicular artery to the patella are preserved with this technique [7].

While the lateral parapatellar approach is performed mainly in valgus knees, other techniques as tibial tubercle osteotomy (TTO), rectus snip and quadriceps turndown are preserved for stiff knee and revision total knee arthroplasty [2].

The goal of this prospective study is to compare the results of the medial parapatellar and subvastus approaches in primary total knee arthroplasty regarding postoperative pain, recovery of muscle strength, range of knee motion and return to regular daily activities.

MATERIALS AND METHODS

Sixty patients scheduled for primary total knee arthroplasty were included in this study.

All patients underwent TKA at El-Hadara university hospital in Alexandria during the period from October 2021 till May 2022.

The study was conducted after approval from the ethical committee and patients' consent.

Characteristics of the study patients:

- The MPP approach was performed in 30 patients (group 1) while the SV approach was performed in the other 30 patients (group 2).
- The choice of approach was randomly assigned.
- The diagnosis leading to total knee replacement was primary degenerative osteoarthritis in all patients.
- All patients had the same preoperative preparation as well as the postoperative protocol of treatment.
- We have unified the preoperative quadriceps muscle power fin all patients included in this study to be grade 3.
- The implant used in all patients was PCS (posterior cruciate scarifying) Total Knee Arthroplasty. All patients were operated under inflated tourniquet.
- Time of operative interference was monitored starting from skin incision till skin stapler application.
- In all patients, hemovac drain was used to monitor blood loss postoperatively.
- Patients suffering from pre-existing muscular or neurologic disease, previous operations on the knee or history of previous injury involving any portion of the quadriceps mechanism were excluded from our study.

Preoperative evaluation

Each patient had his/her affected knee assessed regarding pain, swelling , giving way, stiffness, difficulty with and catching / pseudolocking.

Our clinical examination included BMI calculation (Body Mass Index), gait, medial joint line tenderness and range of motion.

Radiological evaluation included standing AP and lateral plain radiographs as well as stitch long lower limb films of the affected side.

Visual analogue scale (VAS), International Knee Documentation Committee Subjective Knee Score (IKDCS) and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) were the scores recorded preoperatively.

Operative procedure

Surgery was performed either under general or spinal anaesthesia.

Prophylactic antibiotics were given one hour pre-operatively.

— In group 1, patients were operated via MPP approach. A standard anterior midline skin incision proximally around 5–7 cm proximal to upper patella pole and distally to the tibial tubercle. Subcutaneous tissue was dissected to develop a full thickness flap. The capsule was incised through a medial parapatellar approach approximately 1 cm from the medial border of the patella. Incision of the quadriceps mechanism longitudinally allowed adequate patellar eversion and sufficient knee flexion. An index suture was taken on the superomedial border of the patella and another corresponding suture on the superomedial portion of the tendon considering a landmark for later closure after prosthesis implantation to avoid patellar maltracking. The patella was everted laterally, the knee flexed to expose the knee joint.

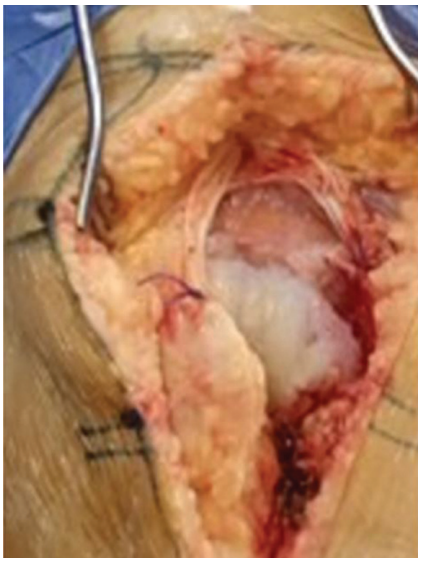

Fig. 1 Index suture marking the superomedial patella and the superomedial capsule

— In group 2, patients were operated via the SV approach. A straight anterior midline skin incision extended proximally around 5-7 cm proximal to upper patella pole and distally to the tibial tubercle. Subcutaneous tissue was dissected to develop a full thickness flap. Both the quadriceps tendon and muscle was spared. An L-shaped capsulotomy was performed; first, the vertical line of the incision was made along the medial edge of the patellar tendon from the tibial tubercle until crossing the inferior margin of the vastus medialis obliquus, and second, the horizontal line of the incision was made along the inferior margin of the vastus medialis obliquus. After insertion of the implant, the capsule was closed and the muscle remained completely intact.

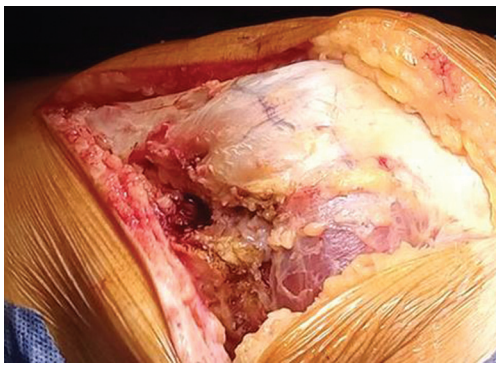

Fig. 2 L-shaped incision capsulotomy

Post-operative period

— Postoperatively, Teicoplanin 400 mg (Targocid) intravenous injection was given once daily and Amikacin 500 mg intravenous injection every 12 hours for 3 days.

— Upon home discharge, oral Levofloxacin 500 mg once daily (Tavanic) for 5 days and Oxazolidinone 600 mg (lenozolid) twice daily for 7 days were prescribed for every patient.

— Ketorolac Tromethamine (Ketolac) infusion was given every 12 hours and Paracetamol intravenous infusion (Perfalgan) was given every 8 hours as analgesic for 3 days.

— At home, Paracetamol 100 mg orally was prescribed for all patients.
— Deep vein thrombosis (DVT) prophylaxis started by Enoxaparin Sodium (Clexane) 40 mg subcutaneous injection prescribed for both groups for 14 days then oral Rivaroxaban once daily for 4 weeks.
— Postoperatively, knee range of motion was started on the first postoperative day as well as weight bearing as tolerated with aids.
— Clinical integrity of the extensor mechanism by the ability of each patient to perform Straight leg raising test (SLR)as soon as possible after the operation.

Method of assessment of results

- Visual analogue scale (for the first 5 days daily postoperatively).
- The International Knee Documentation Committee Subjective Knee score (IKDCS) and The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) at 4 weeks, 3 months and 6 months post operatively.

Statistical analysis of the data

The data were uploaded in the computer and analyzed using IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp). Qualitative data were described using number and percent. The Shapiro – Wilk test was used to verify the normality of distribution. Quantitative data were described using range (minimum and maximum), mean, standard deviation, median and interquartile range (IQR). Significance of the obtained results was judged at the 5 % level. The used tests were: 1) Chi-square test; 2) Fisher's Exact test or Monte – Carlo correction; 3) Student t-test; 4) Mann – Whitney test.

RESULTS

All 60 patients included in the study had completed the follow-up period till the end of 6 month.

Demographic data of study patients

Gender There were no statistical differences between the groups regarding gender.

Table 1

Comparison between the two studied groups according to sex

Sex	Group 1 (n = 30)		Group 2 (n = 30)		χ^2 test	p
	No.	%	No.	%		
Male	5	16.7	10	33.3	2.222	0.136
Female	25	83.3	20	66.7		

p — p value for comparing between the two studied groups.

Age The age difference was statistically insignificant.

Table 2

Comparison between the two studied groups according to age

Age (years)	Group 1 (n = 30)	Group 2 (n = 30)	Student t-test	p
Min – Max	55.0 – 73.0	55.0 – 67.0	0.936	0.354
Mean ± SD	63.30 ± 4.96	62.30 ± 3.10		
Median (IQR)	62.0 (60.0 – 67.0)	62.0 (60.0 – 65.0)		

SD — Standard deviation; IQR — Interquartile range; p — p value for comparing between the two studied groups.

Side Operated The difference between both groups regarding the affected side was not statistically significant.

Table 3

Comparison between the two studied groups according to affected side

Side	Group 1 (n = 30)		Group 2 (n = 30)		χ^2 test	p
	No.	%	No.	%		
Right	19	63.3	22	73.3	0.693	0.405
Left	11	36.7	8	26.7		

p — p value for comparing between the two studied groups.

Co-morbidity In group 1, 31 patients had mainly hypertension (53.3 %) and diabetes m ellitus (30 %).In group 2, 26 patients were suffering from only hypertension (76.7 %) and diabetes mellitus (43.3 %).The difference between two groups in terms of co-morbidity was statistically insignificant.

Table 4

Comparison between the two studied groups according to co- morbidity

Comorbidity	Group 1 (n = 30)		Group 2 (n = 30)		χ^2 test	p
	No.	%	No.	%		
HTN	16	53.3	23	76.7	3.590	0.058
DM	9	30.0	13	43.3	1.148	0.284
History Hep C	1	3.3	0	0.0	1.017	^{FE}p = 1.000
Bronchitis	1	3.3	0	0.0	1.017	^{FE}p = 1.000
Right knee TKA 1 year ago	1	3.3	0	0.0	1.017	^{FE}p = 1.000
Rx Hepatitis C	1	3.3	0	0.0	1.017	^{FE}p = 1.000
CVA	1	3.3	0	0.0	1.017	^{FE}p = 1.000
Cardiac	1	3.3	0	0.0	1.017	^{FE}p = 1.000
Right THA 2 years ago	0	0.0	1	3.3	1.017	^{FE}p = 1.000

p — p value for comparing between the two studied groups; ^{FE} — Fisher Exact.

Body Mass Index (BMI) Average BMI in group 1 ranged from 29.04 ± 2.91 while in group 2 ranged from 28.66 ± 2.76.

Table 5

Comparison between the two studied groups according to BMI

BMI (kg/m^2)	Group 1 (n = 30)		Group 2 (n = 30)		Test of sig.	p
	No.	%	No.	%		
Normal	3	10.0	5	16.7	χ^2 = 0.921	^{MC}p = 0.600
Overweight	13	43.3	14	46.7		
Obese class I	14	46.7	11	36.7		
Min – Max	23.30 – 34.30		24.00 – 33.10		t = 0.519	0.606
Mean ± SD	29.04 ± 2.91		28.66 ± 2.76			
Median (IQR)	30.15 (26.70 – 31.0)		28.6 (26.50 – 30.70)			

χ^2 — Chi square test; ^{MC} — Monte – Carlo; t — Student t-test; SD — Standard deviation; IQR — Interquartile range; p — p value for comparing between the two studied groups.

Operative time Patients in group 2 (SV) had more operative time than those in group 1 (MPP) and this was statistically significant (p < 0.001).

Table 6

Comparison between the two studied groups according to operative time

Time	Group 1 (n = 30)	Group 2 (n = 30)	Mann – Whitney test	p
Min – Max	1.75 – 2.0	1.83 – 2.25	196.0*	< 0.001*
Mean ± SD	1.93 ± 0.08	2.07 ± 0.13		
Median (IQR)	1.92 (1.83 – 2.0)	2.08 (1.92 – 2.17)		

SD — Standard deviation; IQR — Interquartile range; p — p value for comparing between the two studied groups; * — Statistically significant at $p \leqslant 0.05$.

Hemovac Drain In group 1, the median blood loss calculated in redevac suction was 500 cc while for group 2 it was 350 cc; this difference was statistically significant (p < 0.001).

Table 7

Comparison between the two studied groups according to drain

Drain	Group 1 (n = 30)	Group 2 (n = 30)	Mann – Whitney test	p
Min – Max	450.0 – 600.0	300.0 – 450.0	12.0*	< 0.001*
Mean ± SD	513.3 ± 49.01	366.7 ± 40.11		
Median (IQR)	500.0 (450.0 – 550.0)	350.0 (350.0 – 400.0)		

SD — Standard deviation; IQR — Inter quartile range; p — p value for comparing between the two studied groups; * — Statistically significant at $p \leqslant 0.05$.

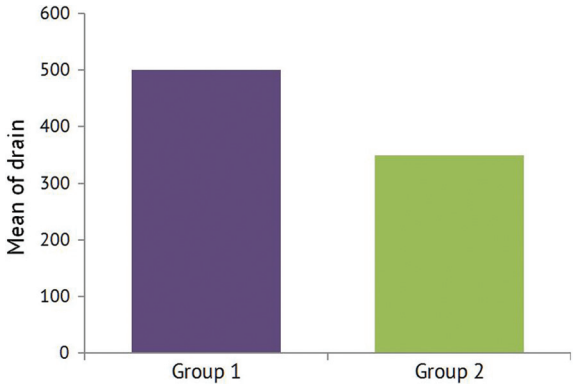

Fig. 3 Comparison between the two studied groups according to drain

Visual Analogue Scale (VAS) On postoperative day 1 and 2, the average in group 1 was 7.80 ± 0.96, while in group 2 it was 4.87 ± 1.01. Starting from postoperative day 3, the difference was more obvious as the average in group 1 was 6.27 ± 1.26 while in group 2 was 2.80 ± 1.35. There were obvious decline in pain sensation and increase in the degree of patient satisfaction, especially in group 2, and this was statistically significant ($p \leqslant 0.001$) for daily assessment of Visual Analogue Scale.

Table 8

Comparison between the two studied groups according to VAS

Day	VAS	Group 1 (n = 30)	Group 2 (n = 30)	Mann – Whitney test	p
Preoperative	Min – Max	8.0 – 10.0	8.0 – 10.0	405.0	0.351
	Mean ± SD	9.67 ± 0.76	9.47 ± 0.90		
	Median (IQR)	10.0 (10.0 – 10.0)	10.0 (8.0 – 10.0)		
1st	Min – Max	6.0 – 10.0	4.0 – 6.0	32.50*	< 0.001*
	Mean ± SD	7.80 ± 0.96	4.87 ± 1.01		
	Median (IQR)	8.0 (8.0 – 8.0)	4.0 (4.0 – 6.0)		
2nd	Min – Max	6.0 – 10.0	4.0 – 6.0	36.0*	< 0.001*
	Mean ± SD	7.80 ± 0.96	4.87 ± 1.01		
	Median (IQR)	8.0 (6.0 – 8.0)	4.0 (2.0 – 6.0)		
3rd	Min – Max	4.0 – 8.0	0.0 – 6.0	37.0*	< 0.001*
	Mean ± SD	6.27 ± 1.26	2.80 ± 1.35		
	Median (IQR)	6.0 (6.0 – 8.0)	2.0 (2.0 – 4.0)		
4th	Min – Max	2.0 – 6.0	0.0 – 4.0	48.0*	< 0.001*
	Mean ± SD	5.40 ± 1.07	2.20 ± 1.42		
	Median (IQR)	6.0 (4.0 – 6.0)	2.0 (2.0 – 4.0)		
5th	Min – Max	2.0 – 6.0	0.0 – 4.0	45.0*	< 0.001*
	Mean ± SD	4.53 ± 1.38	1.27 ± 1.11		
	Median (IQR)	4.0 (4.0 – 6.0)	2.0 (0.0 – 2.0)		

SD — Standard deviation; IQR — Inter quartile range; p — p value for comparing between the two studied groups; * — Statistically significant at $p \leqslant 0.05$.

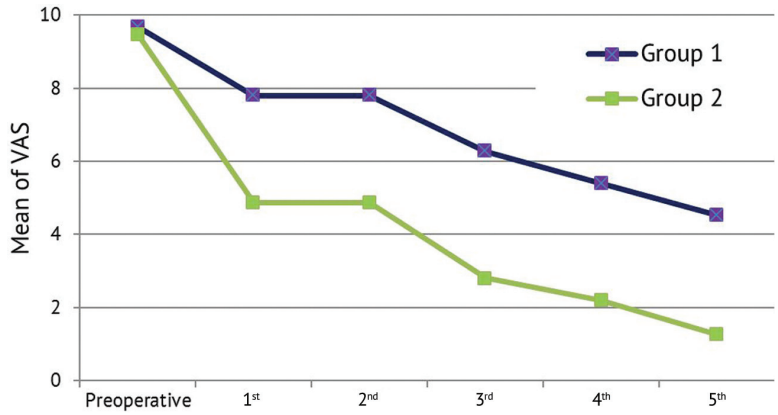

Fig. 4 Comparison between the two studied groups according to VAS

IKDC AND WOMAC scores There were no statistical differences between both groups regarding the IKDC and WOMAC indices.

Table 9

Comparison between the two studied groups according to IKDC

	VAS	Group 1 (*n* = 30)	Group 2 (*n* = 30)	Student t-test	*p*
Preoperative	Min – Max	20.0 – 30.0	22.0 – 29.0	0.805	0.424
	Mean ± SD	25.67 ± 2.44	26.13 ± 2.03		
	Median (IQR)	26.0 (24.0 – 28.0)	26.0 (25.0 – 28.0)		
4 weeks	Min – Max	30.0 – 43.0	30.0 – 43.0	0.696	0.489
	Mean ± SD	36.80 ± 3.42	37.43 ± 3.63		
	Median (IQR)	36.50 (35.0 – 39.0)	37.50 (35.0 – 40.0)		
3 months	Min – Max	38.0 – 57.0	40.0 – 56.0	1.914	0.061
	Mean ± SD	45.87 ± 4.58	48.03 ± 4.18		
	Median (IQR)	46.0 (43.0 – 47.0)	48.0 (45.0 – 51.0)		
6 months	Min – Max	35.0 – 64.0	39.0 – 66.0	1.648	0.105
	Mean ± SD	53.70 ± 5.95	56.13 ± 5.48		
	Median (IQR)	54.0 (52.0 – 56.0)	56.0 (53.0 – 59.0)		

SD — Standard deviation; IQR — Inter quartile range; *p* — *p* value for comparing between the two studied groups.

Table 10

Comparison between the two studied groups according to WOMAC

	VAS	Group 1 (*n* = 30)	Group 2 (*n* = 30)	Mann – Whitney test	*p*
Preoperative	Min – Max	69.0 – 81.0	67.0 – 80.0	377.0	0.277
	Mean ± SD	74.97 ± 3.18	73.90 ± 2.77		
	Median (IQR)	75.0 (73.0 – 77.0)	74.0 (72.0 – 76.0)		
4 weeks	Min – Max	40.0 – 75.0	42.0 – 70.0	385.0	0.335
	Mean ± SD	52.83 ± 7.57	51.13 ± 5.76		
	Median (IQR)	53.0 (50.0 – 56.0)	52.0 (46.0 – 55.0)		
3 months	Min – Max	27.0 – 70.0	23.0 – 66.0	361.0	0.187
	Mean ± SD	40.67 ± 9.56	37.53 ± 7.68		
	Median (IQR)	40.0 (35.0 – 43.0)	37.0 (32.0 – 41.0)		
6 months	Min – Max	20.0 – 68.0	22.0 – 60.0	336.0	0.091
	Mean ± SD	32.77 ± 10.84	28.83 ± 6.52		
	Median (IQR)	30.0 (26.0 – 35.0)	28.0 (26.0 – 30.0)		

SD — Standard deviation; IQR — Inter quartile range; *p* — *p* value for comparing between the two studied groups.

Straight Leg Raising test (SLR) The time lapsed after operation to restore the quadriceps function to perform SLR test was statistically significant between the groups. Patients in group 2 needed shorter time to perform SLR postoperatively than patients in group 1.

Table 11

Comparison between the two studied groups according to postoperative SLR

VAS	Group 1 (*n* = 30)	Group 2 (*n* = 30)	Mann – Whitney test	*p*
Min – Max	7.0 – 45.0	7.0 – 21.0	184.50*	< 0.001*
Mean ± SD	18.83 ± 7.18	11.43 ± 5.35		
Median (IQR)	21.0 (14.0 – 21.0)	7.0 (7.0 – 14.0)		

SD — Standard deviation; IQR — Inter quartile range; *p* — *p* value for comparing between the two studied groups; * — Statistically significant at $p \leqslant 0.05$.

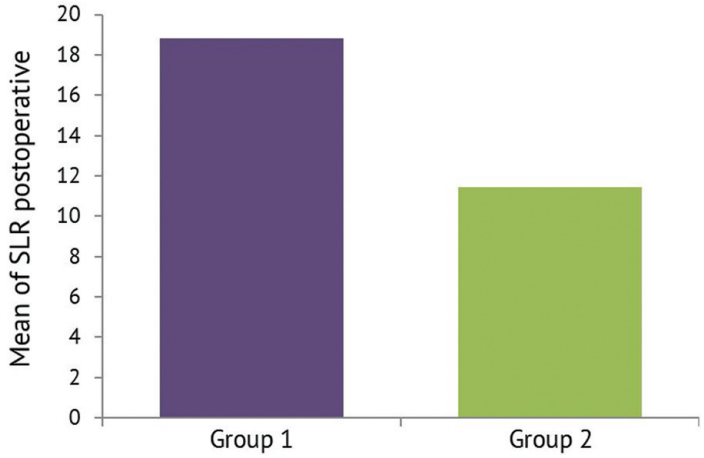

Fig. 5 Comparison between the two studied groups according to postoperative SLR

Complications One female in group 1 (MPP) had paralytic ileus on the 2nd postoperative day and was treated intensively by parentral nutrition and prokinetics. That complication did not affect our results. Two infected cases in group 1 (MPP) at 7 month and 6 month respectively. One infected case in group 2 (SV) 6 month after the end of the follow-up. Those cases underwent two-stage revision using mobile-bearing antibiotic impregnated cemented spacer in the first stage followed by more constrained knee arthroplasty (CCK) 6 weeks later. Two patients suffered femoral component malrotation, one patient in each group which was not related to the approach selected. Those two cases did not need or did not accept revision at the end of the follow-up.

Table 12

Comparison between the two studied groups according to complications

Complications	Group 1 (n = 30)		Group 2 (n = 30)		χ^2 test	^{FE}p
	No.	%	No.	%		
No	25	83.3	26	86.7	0.131	1.000
Yes	5	16.7	4	13.3		
Paralytic Ileus	1	3.3	0	0.0		
Femoral component malrotation	1	3.3	1	3.3		
Infected, 7 months	1	3.3	0	0.0		
Infected, 6 months	1	3.3	0	0.0		
Patient did not apply Physiotherapy settings	1	3.3	0	0.0		
Wound dehiscence	0	0.0	2	6.7		
Infected case	0	0.0	1	3.3		

^{FE} — Fisher exact test; p — p value for comparing between the two studied groups.

DISCUSSION

Although the subvastus (SV) approach was described in 1929 [5], it is still a debate regarding the efficacy of performing such approach when compared to the popular medial parapatellar (MPP) approach.

In our study, we found better pain tolerance and pain subsidence in the SV group which was evident during the first 5 days post-surgery by recording the Visual Analogue Scale (VAS) scale.

Dileep et al., in their study of 54 patients during the postoperative period found that pain scores accessed using VAS showed significant lower values in SV group from postoperative day 1 onward [8].

Hafez concluded in his study that subvastus patients recovered early considering knee pain and motion, which was verified in his series by lower use of painkillers within the first 48 hours and the ability to SLR in a significantly lesser time [9].

According to Seon et al., the scores on postoperative day 3 were significantly higher on a 10-point visual analogue pain scale for patients who had been randomly assigned to SV approach than in the patients who underwent the standard MPP approach [10].

In our cases, the straight leg raising (SLR) test was performed earlier in the subvastus group as the quadriceps had been left intact; this was evident in the short term period of time at 4 weeks postoperatively. There was no difference in the range of mtotion (ROM).

Berstock et al's comparative study showed that the SV approach resulted in earlier recovery of SLR and improved ROM at one week. However, there was no statistical difference between the SV and MPP approaches in KSS (Knee Severity Score) at 6-weeks and 1-year postoperatively [3].

A meta-analysis by Bouché et al. concluded that no differences were found between various approaches of TKA regarding the functional outcomes, but the SV approach showed higher mean ROM at 6-month post-surgery as compared to all the other surgical approaches of TKA [11].

According to Wu et al's meta-analysis, the SV approach offered higher total KSS and fewer days of SLR ability during primary TKA. The SV approach provided early ROM improvement and a mean decrease in SRL days of 2.35 days compared to patients in the MPP group [12].

Khan and his colleagues concluded that individuals who had surgery using the SV method recovered their quadriceps strength more quickly. This supported their claim that the SV approach is more anatomically sound and speeds up the healing process after surgery [13].

Matehuala et al's results of the total of 64 patients included in their study showed better evolution in the first four weeks with the subvastus approach, but after six-month follow-up the results were very similar [14].

The SV technique maintains vascular flow to the patella and protects the quadriceps tendon's integrity during surgery, that's why in our series, there was statistical difference regarding blood loss collected in hemovac drain postoperatively.

In our study, we have faced difficulty in surgical exposure in some cases of the SV group. Therefore, there was longer operative time which was statistically significant during collecting our results.

This prolonged time enabled the surgeon to adequately expose the articular surfaces, inserting homan retractors, directly visualizing the placement of our jigs without compromising the inserted implants nor the final result.

According to Wu et al's meta-analysis, patients in the SV group had a mean increase in operation time of 8.88 minutes over those in the MPP technique. On the other hand, compared to the patients receiving the MPP approach, the SV group could dramatically minimize blood loss by a mean of 56.92 mL [12].

Other authors found no appreciable variations in either the length of the procedure nor in the amount of blood loss, as well as no modifications in the end ROM result by operating via the subvastus technique at any time point [15, 16].

Although the subvastus method has numerous advantages, some authors have theorized that because of the small surgical field, it might have a negative impact on the prosthesis positioning and limb alignment [17–20].

Butala and his collegues in the original study did not recommend the SV approach as they stated that TKA by conventional MPP approach demonstrated better functional outcomes, reduced operative time, reduced tissue trauma (lesser pressure by retractors), shorter learning curve, easier availability of implant and instrument sets and precise implant placement due to a good visualization of the surgical field in comparison to minimal invasive SV approach [21].

In another study by Bourke et al., it was clear that surgeons viewed the SV technique to be a more technically challenging surgical approach and that the AKSS Functional ratings by 12 months postoperatively favored the MPP group [22].

It is important to consider the Sukeik et al's opinion about the limitations of the SV approach. The current meta-analysis found that using an SV technique makes surgery more challenging and demanding since total visibility is decreased, especially in obese patients [23].

In their study, Geng et al. found that SV group had an advantage over the conventional MPP group in terms of ROM, VAS, satisfaction rate and the recovery time to SLR within 7 days after operation. However, the above outcomes showed no statistical difference on postoperative day 30 between the two groups. The alignment of the component did not differ significantly between the two groups [24].

In our study, one patient in each group suffered patellar maltracking due to component malrotation which had no relation statistically with the approach used.

The proper component orientation was essentially related to proper visualization of the articular surfaces and proper placement of the retractors.

During the operation via the MPP approach, the index suture positioned at the superomedial border of the patella and the opposite suture on the medial retinacular flap had enabled the surgeon to avoid patellar maltracking during closure of the wound.

In the SV group, the L-shaped incision of the medial capsule was considered an efficient landmark for accurate soft tissue closure avoiding the patellar maltracking.

CONCLUSION

The subvastus approach offers the advantage of keeping the integrity of quadriceps muscle thus the extensor mechanism remains intact post-surgery. It causes less pain and less blood loss postoperatively than the regular parapatellar approach. It can restore the function of the knee joint earlier after the operation with few complications, which is greatly in line with the concept of ERAS (Enhanced Recovery After Surgery). We recommend in cases of BMI obese class I, an expert arthroplasty surgeon perform the subvastus approach in total knee replacement surgery.

REFERENCES

1. Mahomed NN, Barrett J, Katz JN, et al. Epidemiology of total knee replacement in the United States Medicare population. *J Bone Joint Surg Am*. 2005;87(6):1222-1228. doi: 10.2106/JBJS.D.02546
2. Barrack RL, Smith P, Munn B, et al. The Ranawat Award. Comparison of surgical approaches in total knee arthroplasty. *Clin Orthop Relat Res*. 1998;(356):16-21. doi: 10.1097/00003086-199811000-00004
3. Berstock JR, Murray JR, Whitehouse MR, et al. Medial subvastus versus the medial parapatellar approach for total knee replacement: A systematic review and meta-analysis of randomized controlled trials. *EFORT Open Rev*. 2018;3(3):78-84. doi: 10.1302/2058-5241.3.170030
4. Fehring TK, Odum S, Griffin WL, Mason JB. Patella inversion method for exposure in revision total knee arthroplasty. *J Arthroplasty*. 2002;17(1):101-104. doi: 10.1054/arth.2002.29326
5. Hofmann AA, Plaster RL, Murdock LE. Subvastus (Southern) approach for primary total knee arthroplasty. *Clin Orthop Relat Res*. 1991;(269):70-77.
6. Lin TC, Wang HK, Chen JW, et al. Minimally invasive knee arthroplasty with the subvastus approach allows rapid rehabilitation: a prospective, biomechanical and observational study. *J Phys Ther Sci*. 2013;25(5):557-562. doi: 10.1589/jpts.25.557
7. Engh GA, Holt BT, Parks NL. A midvastus muscle-splitting approach for total knee arthroplasty. *J Arthroplasty*. 1997;12(3):322-331. doi: 10.1016/s0883-5403(97)90030-9
8. Dileep P, Padmanabhan V, Krishnaraj CP. Subvastus approach versus medial parapatellar approach in total knee arthroplasty – A prospective comparative study of functional outcome. *Journal of Orthopaedic Association of South Indian States*. 2022;19(1):2-6. doi: 10.4103/joasis.joasis_5_22
9. Hafez MA. The subvastus approach for primary total knee replacement: Does it affect the early results? *Pan Arab J Orth Trauma*. 2002;6:181-187.
10. Seon JK, Song EK. Navigation-assisted less invasive total knee arthroplasty compared with conventional total knee arthroplasty: a randomized prospective trial. *J Arthroplasty*. 2006;21(6):777-782. doi: 10.1016/j.arth.2005.08.024
11. Bouché PA, Corsia S, Nizard R, Resche-Rigon M. Comparative Efficacy of the Different Surgical Approaches in Total Knee Arthroplasty: A Systematic-Review and Network Meta-Analysis. *J Arthroplasty*. 2021;36(3):1187-1194.e1. doi: 10.1016/j.arth.2020.09.052
12. Wu Y, Zeng Y, Bao X, Xiong H, Hu Q, Li M, Shen B. Comparison of mini-subvastus approach versus medial parapatellar approach in primary total knee arthroplasty. *Int J Surg*. 2018;57:15-21. doi: 10.1016/j.ijsu.2018.07.007
13. Khan MNH, Abbas K, Faraz A, et al. Total knee replacement: A comparison of the subvastus and medial parapatellar approaches. *Ann Med Surg* (Lond). 2021;68:102670. doi: 10.1016/j.amsu.2021.102670
14. Matehuala GJ, Pérez AJM, Villarreal BFJ, Ramos GMQ. Subvastus versus medial parapatellar approach in total knee arthroplasty, functional results. *Orthotips*. 2021;17(4):206-210. (In Span.) doi: 10.35366/102218

15. Matsueda M, Gustilo RB. Subvastus and medial parapatellar approaches in total knee arthroplasty. *Clin Orthop Relat Res*. 2000;(371):161-168. doi: 10.1097/00003086-200002000-00020
16. Cila E, Güzel V, Ozalay M, et al. Subvastus versus medial parapatellar approach in total knee arthroplasty. *Arch Orthop Trauma Surg*. 2002;122(2):65-68. doi: 10.1007/s004020100319
17. Barrack RL, Barnes CL, Burnett RS, et al. Minimal incision surgery as a risk factor for early failure of total knee arthroplasty. *J Arthroplasty*. 2009;24(4):489-98. doi: 10.1016/j.arth.2009.02.004
18. Lin WP, Lin J, Horng LC, et al. Quadriceps-sparing, minimal-incision total knee arthroplasty: a comparative study. *J Arthroplasty*. 2009;24(7):1024-1032. doi: 10.1016/j.arth.2008.07.005
19. Thiengwittayaporn S, Fusakul Y, Kangkano N, Jarupongprapa C, Charoenphandhu N. Hand-held navigation may improve accuracy in minimally invasive total knee arthroplasty: a prospective randomized controlled trial. *Int Orthop*. 2016;40(1):51-57. doi: 10.1007/s00264-015-2848-x
20. Jung YB, Lee YS, Lee EY, et al. Comparison of the modified subvastus and medial parapatellar approaches in total knee arthroplasty. *Int Orthop*. 2009;33(2):419-423. doi: 10.1007/s00264-007-0510-y
21. Butala R, Parelkar K, Pandey A. Comparative Analysis of Functional Outcome of Conventional Midline Parapatellar to Minimally Invasive Subvastus Approach in Total Knee Replacement. *Orthop J MPC*. 2021;27(2):70-74.
22. Bourke MG, Buttrum PJ, Fitzpatrick PL, et al. Systematic review of medial parapatellar and subvastus approaches in total knee arthroplasty. *J Arthroplasty*. 2010;25(5):728-734. doi: 10.1016/j.arth.2009.06.008
23. Sukeik M, Sohail MZ, Hossain FS, et al. Comparing the Sub-Vastus and Medial Parapatellar Approaches in Total Knee Arthroplasty: A Meta-Analysis of Short-Term Outcomes. *Dr. Sulaiman Al Habib Med J*. 2021;3(2):66-73. doi: 10.2991/dsahmj.k.210203.001
24. Geng L, Fu J, Xu C, et al. The Comparison between Mini-Subvastus Approach and Medial Parapatellar Approach in TKA: A Prospective Double-Blinded Randomized Controlled Trial. *Orthop Surg*. 2022;14(11):2878-2887. doi: 10.1111/os.13494

The article was submitted 28.11.2023; approved after reviewing 20.02.2024; accepted for publication 18.06.2024.

Information about the authors:

Ihab Abdelwahab Badawi — Prof. Dr., Professor of Orthopaedic surgery, ihabbadawj@yahoo.com;

Ayman Soliman Ismail — Prof. Dr., Professor of Orthopaedic surgery, ssssoliman@gmail.com;

Ahmed Hassan Waly — Prof. Dr., Professor of Orthopaedic surgery, Drwaly28@gmail.com;

Moustafa Ali Nagui Khalkaf — moustafa.nagui78@gmail.com.

Original article
https://doi.org/10.18019/1028-4427-2024-30-4-522-532

Effect of elastic intramedullary nailing on lower limb lengthening in acquired shortenings: a prospective study

D.V. Tropin, V.I. Tropin, A.A. Chertishchev, N.S. Gvozdev✉, D.A. Popkov

Ilizarov National Medical Research Centre for Traumatology and Orthopedics, Kurgan, Russian Federation

Corresponding author: Nikita S. Gvozdev, nikitozgvozdev@mail.ru

Abstract

Introduction Lengthening and correction of limb deformities using Ilizarov external fixation is a frequent standard operation. However, the risk of complications associated with limb lengthening, including superficial or deep infection, contractures, secondary deformity, and fractures after device removal associated with delayed bone consolidation, remains significant.

The **purpose** of the work was to identify the features of bone lengthening with an external fixator in combination with elastic intramedullary nails, titanium or titanium with a composite hydroxyapatite coating, in the conditions of shortening of the lower extremities of acquired etiology.

Materials and methods The study included 64 patients, of which 31 patients underwent monofocal lengthening of the femur, 33 patients underwent monofocal lengthening of the tibia.

Results The mean external fixation indices (EFIs) of the groups compared for similar lengthening types (femoral or tibial lengthening) did not differ significantly for the types of intramedullary nails implanted. In femoral lengthening, a significant effect on the EFI had the nail type and the ratio of "nail diameter / medullary canal diameter". The dependence of EFI on the nail type in tibial lengthening was associated with the ratio "nail diameter / internal diameter at the osteotomy site" ($p = 0.023$). Two-way ANOVA showed that the effect of the nail type on EFI depended on the nail diameter/ internal diameter at osteotomy site ratio in the tibial lengthening group ($p = 0.034$).

Discussion In acquired shortening of the lower extremities, there is no difference in EFI by using titanium elastic nails or intramedullary nails coated with composite hydroxyapatite. The use of a combined technique, in any case, has advantages: it provides good and excellent results without serious complications during lengthening in patients with shortening of acquired etiology. The strong positive correlation between the bone diameter/internal cortical distance ratio at the osteotomy site, coupled with the significant influence of the nail type and nail diameter on EFI, suggests that both factors should be considered together in future studies.

Conclusion In shortening of the lower extremities of acquired etiology, the use of a combined bone lengthening technique, comprising an external fixator in combination with elastic intramedullary nailing, provides good and excellent results without serious complications.

Keywords: limb lengthening, Ilizarov apparatus, elastic intramedullary nailing, hydroxyapatite

For citation: Tropin DV, Tropin VI, Chertishchev AA, Gvozdev NS, Popkov DA. Effect of elastic intramedullary nailing on lower limb lengthening in acquired shortenings: a prospective study. *Genij Ortopedii*. 2024;30(4):522-532. doi: 10.18019/1028-4427-2024-30-4-522-532

© Tropin D.V., Tropin V.I., Chertishchev A.A., Gvozdev N.S., Popkov D.A., 2024
© Translator Tatyana A. Malkova, 2024

INTRODUCTION

The incidence of leg length discrepancy requiring surgical intervention is approximately 1:1000 [1]. Acquired lower limb length discrepancy (ALLD) and deformities are among the most common reasons for referral to an orthopaedic surgeon [2–6]. Surgical treatment options for this pathology include the use of circular external fixators, lengthening with a fully implanted electromagnetic rod, or lengthening over intramedullary nails using external devices [2, 7–12].

Lengthening and correction of limb deformities using external fixation based on the principles of the Ilizarov method is a common standard operation [9, 13, 14]. However, the risk of complications associated with limb lengthening, including superficial or deep infection, contractures [15–17], secondary deformity and fractures after removal of the device associated with delayed bone consolidation [16, 18, 19], remains an essential problem. It is also necessary to consider the negative long-term psychological burden associated with restrictions in everyday life in these patients [20].

Limb lengthening with elastic intramedullary rods/nails has been described in the literature [21–24]. This combined method provides a number of advantages: additional stability of the bone fragment position, prevention of secondary displacements, especially translation, and fractures after removal of the device, reduction of the duration of external fixation. Considering the elastic nature of the implants, gradual correction of the limb axis is possible in case of severe deformity; the small diameter of the nails makes them suitable for narrow medullary canals; installation of the nails through the metaphysis eliminates injury of the growth zones [21–24]. Animal studies have shown that this method also spares the intramedullary blood supply [25].

Experimental studies have shown that elastic HA-coated nails have a stimulating effect on bone consolidation [7, 8, 26, 27]. But the role of such composite coatings in elongation of healthy bone tissue in the clinical conditions remains unclear [28].

The **purpose** of the work was to identify the features of bone lengthening with an external fixator combined with elastic intramedullary nails, titanium or the ones with composite hydroxyapatite coating, in shortening of the lower extremities of acquired etiology.

MATERIALS AND METHODS

A non-randomized prospective study of treatment results in patients with acquired shortenings and deformities of the lower extremities was conducted. All patients included in the study were diagnosed with acquired lower limb length discrepancy (post-traumatic, consequences of neonatal osteomyelitis, consequences of poliomyelitis or spastic hemiparesis, classified according to the GMFCS system as level I–II). All patients underwent monosegmental lengthening using a combined technique of external fixation and elastic intramedullary osteosynthesis. The follow-up period after dismantling the external fixation device was 10–12 months. The study did not include patients who underwent simultaneous correction, polysegmental lengthening, patients with congenital shortening or systemic pathology, as well as those who underwent lengthening without elastic reinforcement.

The results were analyzed in two groups: monofocal lengthening of the femur (group F, $n = 31$) and monofocal lengthening of the tibia (group T, $n = 33$). These groups were divided into subgroups: lengthening over titanium elastic nails (F-Ti and T-Ti) and over titanium nails coated with hydroxyapatite (HA) (F-HA and T-HA).

Surgical technique

Under general anesthesia, in the supine position, a wire/half-pin external fixation device was installed on the femur or tibia considering the deformity, and a percutaneous corticotomy was performed. Then elastic intramedullary nailing was performed: retrograde for the femur and antegrade for the tibia. The choice of the diameter of the elastic nails was determined arbitrarily by the surgeon, focusing on the diameter of the bone marrow canal. Titanium nails without HA coating were used

in 29 patients (intramedullary elastic pediatric nails from MEDIN, Nove Mesto na Morave, Czech Republic). Titanium nails with HA coating (Orthopediatrics, modified by Metis LLC, Tomsk, Russia) were used in 24 limb lengthening operations. Long bone canals were not drilled. The Ilizarov apparatus was used in 51 cases, and CORA and ACA were used for hinge placement (Fig. 1). Three patients were treated with the Taylor Spatial frame (TSF) (Smith & Nephew, Memphis, Tennessee, USA), in which CORA was integrated into the distraction and correction program as a reference point (Fig. 2). Before surgery, after consultation with the treating physician, patients were given the opportunity to choose between non-coated or HA-coated titanium itramedullary nails.

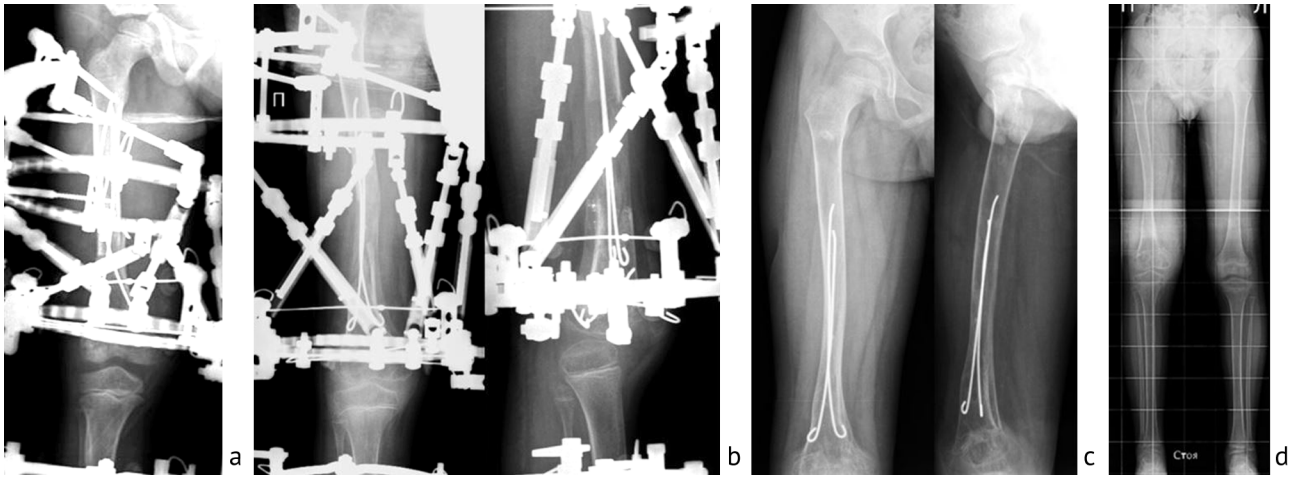

Fig. 1 Radiographs of the femur of a patient of the F-HA subgroup: *a* femoral osteotomy, initial position of intramedullary elastic nails; *b* at the end of the distraction period; *c* after removal of the external fixation device; *d* after removal of intramedullary nails, remodeling of the distraction regenerate

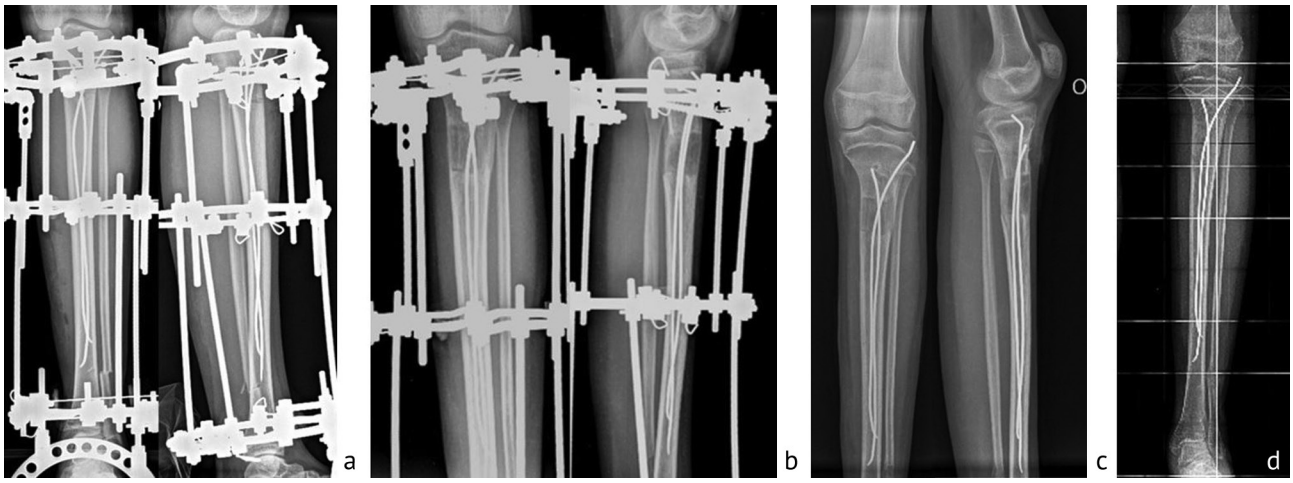

Fig. 2 Radiographs of a patient of the T-Ti subgroup: *a* proximal osteotomy of the tibia, initial position of the elastic nails; *b* at the end of the fixation period, bone fusion; *c* after removal of the external fixation device; *d* 14 months after removal of the external fixation device, bone callus remodeling

In all patients, lengthening and deformity correction were progressive and were initiated on days 5–7 after the operation. Associated deformities were corrected gradually. Upon achieving consolidation (X-ray picture and clinical test), the device was removed and a plaster cast was applied for 3–4 weeks. All complications and treatment outcomes were classified according to the Lascombes system [29]. Treatment results were classified retrospectively, 10–12 months after removal of the device, depending on the obtained lengthening magnitude and the complications that arose, the treatment performed and their impact on the final result. In each group and subgroups, we analyzed factors that could affect the EFI (the number of days of external fixation divided by the lengthening measured in cm), complications and the outcome of treatment:

— age;
— magnitude of elongation (cm and % of the original length of the segment);
— ratio of the diameter of the nail to the diameter of the narrowest part of the medullary canal;
— ratio of the diameter of the nail to the internal distance between the cortical plates at the level of osteotomy;
— type of elastic intramedullary nails used (HA-coated or not).

Subgroup data were compared for EFI, complication risks, and treatment outcomes.

Statistical analysis was performed using AtteStat 12.0.5 software. Means, standard deviations, and ranges were used to describe continuous variables. The nonparametric Mann – Whitney test was used to compare parameters of age, lengthening, nail diameter/intramedullary canal ratio, or osteotomy site diameter in subgroups. Differences in the frequency of patients' gender were assessed between subgroups using the chi-square test. The Post-hoc Conover test was used for subgroup comparisons (Ti nails vs Ti HA-coated nails) for differences in mean values of EFI as the dependent variable. Two-way analysis of variance was used to evaluate the simultaneous effect of nail types (the first determinant) and one of the quantitative parameters (the second determinant: age, amount of elongation, nail/medullary canal ratio, nail/osteotomy internal diameter ratio), classified into ordinal categories EFI. Spearman's rank correlation coefficient was used to assess the correlation between continuous measures in each subgroup. Significance was set at $p < 0.05$ for all comparative statistics.

The study was conducted in accordance with the ethical standards of the Declaration of Helsinki of the World Medical Association "Ethical Principles for Scientific Medical Research Involving Human Subjects" as amended in 2000, and the "Rules of Clinical Practice in the Russian Federation" approved by Order of the Ministry of Health of the Russian Federation dated June 19, 2003 No. 266. Patients or parents of patients, authorized employees of social institutions confirmed their consent to conduct the study and publish the results without personal identification.

RESULTS

Demographic data (age, gender), the affected segment and type of surgical intervention, the lengthening magnitude, the relationship between the diameter of the nail and the radiographic parameters of the medullary canal, as well as the EFI value are reflected in Table 1 and Table 2 (values are given as mean and standard deviation, range in parentheses). Within the groups, we did not find a statistically significant difference between lengthening using non-coated or HA-coated Ti-nails in mean age, gender, lengthening value, the ratio between the diameter of the nails and the medullary canal at the narrowest point or the osteotomy site. Moreover, the average values of EFI in the subgroups of non-coated or HA-coated Ti-nails compared with similar types of elongation (F-group or T-group) were not significantly different.

Table 1

Demographic, clinical and radiographic data of the femoral lengthening group

Parameter	Subgroup F-Ti (n = 16)	Subgroup F-HA (n = 15)	p-value
Age (years)	16.7 ± 5.8 (7.6 – 32.6)	16.1 ± 7.3 (7.3 – 24.2)	0.916^{mw}
Female to male ratio	8/8	7/8	0.928*
Lengthening (cm)	4.5 ± 1.7 (3.0 – 7.1)	4.7 ± 1.8 (2.5 – 6.5)	0.820^{mw}
Lengthening (%)	11.4 ± 4.1 (6.9 – 21.4)	12.6 ± 4.9 (6.2 – 23.6)	0.661^{mw}
Ratio of the nail diameter to the narrowest part of bone marrow canal	0.18 ± 0.08 (0.11 – 0.26)	0.18 ± 0.06 (0.07 – 0.25)	0.547^{mw}
Ratio of the nail diameter and internal distance between the cortices at the osteotomy level	0.11 ± 0.04 (0.05–0.22)	0.10 ± 0.04 (0.06–0.13)	0.822^{mw}
IEF (days/cm)	26.5 ± 9.2 (19.1 – 42.9)	28.1 ± 6.2 (20.4 – 39.3)	0.713^{mw}

Note: ^{mw} — Mann – Whitney тест; * — chi-square test.

Table 2

Demographic, clinical and radiographic data of the tibial lengthening group

Parameter	Subgroup T-Ti (n = 17)	Subgroup T-HA (n = 16)	p-value
Age (years)	15.7 ± 7.9 (6.1 – 31.8)	16.3 ± 3.4 (10.7 – 24.5)	0.34[mw]
Female to male ratio	8/9	7/9	0.67*
Lengthening (cm)	3.5 ± 0.91 (2.0 – 5.5)	4.0 ± 1.3 (2.5 – 6.0)	0.058[mw]
Lengthening (%)	12.9 ± 3.23 (6.7 – 14.6)	14.7 ± 4.45 (6.0 – 21.7)	0.188[mw]
Ratio of the nail diameter to the narrowest part of bone marrow canal	0.21 ± 0.044 (0.15 – 0.28)	0.21 ± 0.08 (0.11 – 0.30)	0.565[mw]
Ratio of the nail diameter and internal distance between the cortices at the osteotomy level	0.11 ± 0.03 (0.08 – 0.19)	0.1 ± 0.03 (0.05 – 0.13)	0.472[mw]
IEF (days/cm)	34.9 ± 9.6 (23.2 – 48.8)	32.7 ± 7.65 (23 – 44.3)	0.285[mw]

Note: [mw] — Mann – Whitney test; * — chi-square test

The Conover test did not reveal a statistically significant effect of the type of intramedullary nails on the EFI in the subgroups. The F-statistic was 0.363 with p = 0.342 for femoral lengthening and 1.063 for tibia lengthening with p = 0.157. However, two-way ANOVA revealed a significant simultaneous effect of the nail type and nail diameter/medullary canal diameter ratio on EFI in femoral lengthening (p = 0.029). The effect of nail type on EFI during tibia lengthening was associated with the ratio of nail diameter/internal diameter at the osteotomy site (p = 0.021). Moreover, this test showed that the effect of nail type (non-coated vs. HA-coated Ti-nail) on EFI depended on the nail/internal diameter ratio at the osteotomy site in the T-G group (p = 0.029).

The relationship between treatment parameters and EFI determines a significant negative correlation of the elongation value (both absolute and expressed in %) with EFI both for elastic HA-coated nailing in femur lengthening, and for elastic titanium nail in tibial lengthening (Table 3). Moreover, Spearman's rank correlation coefficient demonstrated a statistically significant positive correlation between the nail diameter/internal diameter ratio at the osteotomy level and EFI in tibial lengthening (T-HA subgroup) and a significant positive correlation between age and EFI in the F-HA subgroup.

Table 3

Significant correlations between the studied parameters and EFI (Spearman coefficient)

Parameter		EFI value	p-value
Femur lengthening (subgroup F-HA)	cm	–0.509	0.031
	%	–0.558	0.018
Tibial lengthening (subgroup T-Ti)	cm	–0.589	0.017
	%	–0.565	0.022
Relationship between the nail diameter and the internal distance between the cortical plates at the level of osteotomy (subgroup T-HA)		0.776	0.008
Age (subgroup F-HA)		0.549	0.025

The severity and incidence of complications encountered are shown in Table. 4. One patient had concomitant complication: wire breakage and subsequent secondary displacement, which frame adjustment under general anesthesia. There was a case of premature bone consolidation that required reosteotomy. In another case, external migration of an intramedullary and uncoated with HA nail occurred, which required its premature removal. In 48 patients, intramedullary nails were removed within 4 to 13 months after removing the external fixator.

Table 4

Complications

Type of complication	Femur lengthening				Tibial lengthening			
	F-Ti		F-HA		T-Ti		T-HA	
	N	%	N	%	N	%	N	%
Superficial infection	2	12.6	3	20.1	3	17.7	2	12.6
Wire-tract osteomyelitis	–		1	6.7	–		–	
Parasthesia, transitory paresis	–		–		1	5.9	1	6.3
Wire breakage	1	6.3	1	6.7	–		–	
Secondary fragment displacement	–		1	6.7	1	5.9	–	
External migration of an elastic intramedullary nail	1	6.3	–	–	–		–	
Premature bone union	–		1	6.7	–		–	
Fracture after external frame removal	1	6.3	–	–	–		–	
Persistent knee contracture	–		1	6.7	–		–	

A complication of deformity in the lengthening zone, which required unscheduled surgical intervention after removal of the device, was observed in one case in group F(subgroup F-Ti). In two cases of secondary displacement, unscheduled operations were performed for apparatus adjustment with additional wire/half-pin insertion. In one case, the complication was wire breakage (F-HA subgroup), in the second case it was instability of the proximal support on the tibia (T-Ti subgroup).

We did not observe any cases of intramedullary elastic nails blockage with wires or half-pins of the external fixator during the distraction stage. In 10 cases, peri-wire infection was successfully treated with oral antibiotics. In only one case of wire infection, the complication was associated with thermal necrosis of the bone and required curettage 2 months after removing the device. The range of motion in the knee or ankle joint was restored in 63 patients at the last follow-up examination. Temporary paralysis of the peroneal group was noted in two cases. Subsequently, the nerve function was completely restored after conservative treatment.

Evaluation of the results according to the Lascombes classification (Table 5) after a year showed that the triad of the conditions (planned lengthening value, duration of external fixation and functional recovery) was achieved in 60 patients (93.8 % of cases). In three cases, the EFI was more than 45 days/cm (46.3, 46.4 and 48.8 days/cm).

Table 5

Results of lengthening

Category	Femur lengthening		Tibial lengthening	
	F-Ti	F-HA	T-Ti	T-HA
I	14	11	14	16
IIa	–	2	1	–
IIb	2	1	–	–
III	–	1	3	–

The radiographic analysis showed that the consolidation index in these cases was lower than 45 days/cm. Since these patients did not show delayed consolidation, the increased EFI should be attributed to delayed removal of the external fixator caused by problems other than the lengthening process. However, we classified these three outcomes as grade IIIa. We also classified one case of persistent extension contracture of the knee joint after femoral lengthening as category III results, which required a quadriceps muscle release operation in combination with knee arthrotomy in the long term.

DISCUSSION

Shortening of one of the lower extremities, including due to acquired etiology, even if it seems insignificant, may cause the development of secondary pathology. Length discrepancy of more than 1 cm changes the biomechanics of movements, leading to scoliotic deformity of the spine, gait disorders and early deforming arthrosis of large joints [30–33]. The difference in leg length, which affects standing posture, gait balance, and pelvic balance, needs to be corrected [34]. The development of a new generation of motorized intramedullary extension nails enables to perform limb lengthening, providing precise control of the distraction mode, and avoiding the inconvenience of external fixation [1, 10, 12, 13]. However, open growth plates, the severity of the deformity, history of bone infection, and small diameter of the medullary canal significantly limit the use of such devices [13, 35, 36]. The literature reports recommend the external fixation method for limb lengthening and correction of severe deformities of acquired etiology [11, 13, 37–40].

Lengthening with external fixation devices is a complex procedure with a long treatment period. There is a significant risk of complications, including septic complications, an increase in the consolidation index, delayed bone healing and fractures after removal of the device [16, 19, 22, 29, 41–43]. Over the past twenty years, progress in limb lengthening with external fixators has been aimed at reducing the duration of external fixation and reducing the number of complications. Thus, stimulation of the regenerate with low-intensity pulsed ultrasound reduced the consolidation index from 45 days/cm to 33 days/cm according to the results of a study by Salem et al. [8] and from 48 days/cm to 30 days/cm according to the results of a study by El-Mowafi et al. [7]. Their small samples represent the results of limb lengthening in patients with acquired shortening.

Many authors note that the average external fixation index is lower during limb lengthening in patients with acquired pathology than in patients with congenital shortening. Ganger et al. [3] noted that the EFI is 2.1 months/cm for femoral lengthening and 2.8 months/cm for tibia lengthening. In a study by Antoci et al. [14] the average value was 32 days/cm; no significant difference was observed with the results of lengthening in congenital shortenings. Nakase et al. [44] reported an index of 1.45 months/cm in patients with an elongation of at least 2 cm, and Horn et al. [11] reported an index of 2.0 months/cm (range 0.8–6.0 months/cm) in patients with acquired limb length difference. Our study showed that the average values of EFI for combination with intramedullary reinforcement are lower than in the above studies.

In our previous study, the consolidation index was significantly lower with the use of intramedullary elastic nails, on average 7 days/cm, compared with the traditional Ilizarov method [45]. Saraph et al. [46] used two curved Ender nails to lengthen the tibia and found the advantages of stable osteosynthesis, a lower rate of infectious complications compared to the traditional technique, as well as the ability to prevent fractures and deformity of the lengthened tibia. Lampasi et al. [24] did not encounter any secondary displacements during the distraction phase, nor the development of infection and fractures after removal of the nail in femur lengthening with a monolateral fixator and elastic intramedullary reinforcement. Moreover, they reported two cases of premature consolidation due to intensive formation of distraction regenerates. Bukva et al. [22] and Launey et al. [19] also showed the effectiveness of using elastic intramedullary nailing to reduce the consolidation index during limb lengthening and reduce the risk of complications and fractures after removal of the device. Launey et al. [21] highlight the benefits of using intramedullary nails to prevent secondary displacement during lengthening of small diameter bones, particularly the forearm.

It has been proven that elastic intramedullary nails coated with hydroxyapatite promote bone formation and ensure osseointegration by stimulating osteogenic activity in the medullary canal [28, 47]. The purpose of this study was not only to demonstrate the features of a combined technique for lengthening the tibia and femur in patients with acquired limb length discrepancy,

but also to compare the effect of bioactive titanium elastic intramedullary nails on treatment results, and thereby to evaluate the influence of demographic and specific mechanical factors on bone union during distraction osteosynthesis and, accordingly, on the outcome of treatment.

Regarding the impact of age and lengthening magnitude, our results are consistent with those published by Fischgrund et al. [48] and Koczewski et al. [42]. Age has a significant impact on the timing of consolidation. In children, bone union occurs faster than in adult patients. In our study, the age-EFI correlation was statistically positive in the subgroup with femoral lengthening using HA-coated nails. In contrast to age, based on the lengthening value (cm or %) we determined a negative significant correlation with EFI (in the subgroup of femoral lengthening using HA-coated nails and in the subgroup of tibial lengthening using titanium intramedullary nails). These data suggest that the factors that have an effect on bone consolidation time during lengthening using the combined technique are similar to those with the traditional Ilizarov lengthening technique. Since these correlations are present in combined lengthening, it may be concluded that the biological conditions of the Ilizarov method for bone consolidation are preserved in the conditions of elastic intramedullary reinforcement.

As for EFI for different types of intramedullary nails (titanium vs. titanium with composite hydroxyapatite coating), we did not find any significant differences. We assume that in the patients with acquired shortening, included in the study, without abnormal bone tissue regeneration, mechanical stimulation of bone formation is sufficient to ensure consolidation of the lengthened bones over a period of similar duration. In practice, there have been no obvious advantages in using intramedullary nails with osteoinductive hydroxyapatite coating in comparison with titanium rods for regeneration of bone tissue without compromised histogenesis. On the other hand, the impact of intramedullary nail diameter on the biological properties of bone regeneration during limb lengthening has only been partially revealed. Our study revealed a positive significant correlation between the ratio "rod diameter / internal distance between cortical layers at the osteotomy site" in the T-HA subgroup. This result, in comparison with the significant impact of the type of nails and the ratio of "rod diameter / diameter of the medullary canal or internal diameter at the osteotomy site" on the EFI, revealed using two-way analysis of variance, means that both factors (diameter and type of elastic nail) should be considered together in future clinical and experimental studies.

In our study, we did not observe delayed formation and maturation of the distraction regenerate. As for complications, a fracture occurred only in one case at the site of lengthening after removal of the device. Danzinger et al. noted two cases of fractures after removal of the device in five patients with post-traumatic deformities [49]. Stanitski et al. described the development of deformity at the site of lengthening after removal of the apparatus in six cases out of 62 patients who had their tibia lengthened using the Ilizarov apparatus [50]. Ganger et al. [3] described the deformity at the site of lengthening after removal of the device in one patient (4.5 %). In contrast to these data, Horn et al. [11] found no fractures or other serious complications during leg lengthening in patients with acquired limb shortening.

It should be emphasized that there are specific complications of lengthening associated with the use of intramedullary elastic nailing: migration of intramedullary nail (1 case) and premature bone union (1 case). In this series of patients, they were treated surgically without consequences (Fig. 3).

In summary, the treatment results in our patients were achieved without deterioration in the function of the limb in 63 out of 64 cases. Treatment results were assessed as good or excellent in all cases. Limitations of this study are related to a small patients' sample, heterogeneity of the series, and patients with only a moderate difference in limb length were included in the study. However, it should be noted that in other series of lengthening in acquired pathologies of the lower extremities, the patient populations were usually heterogeneous [7, 11, 14, 22].

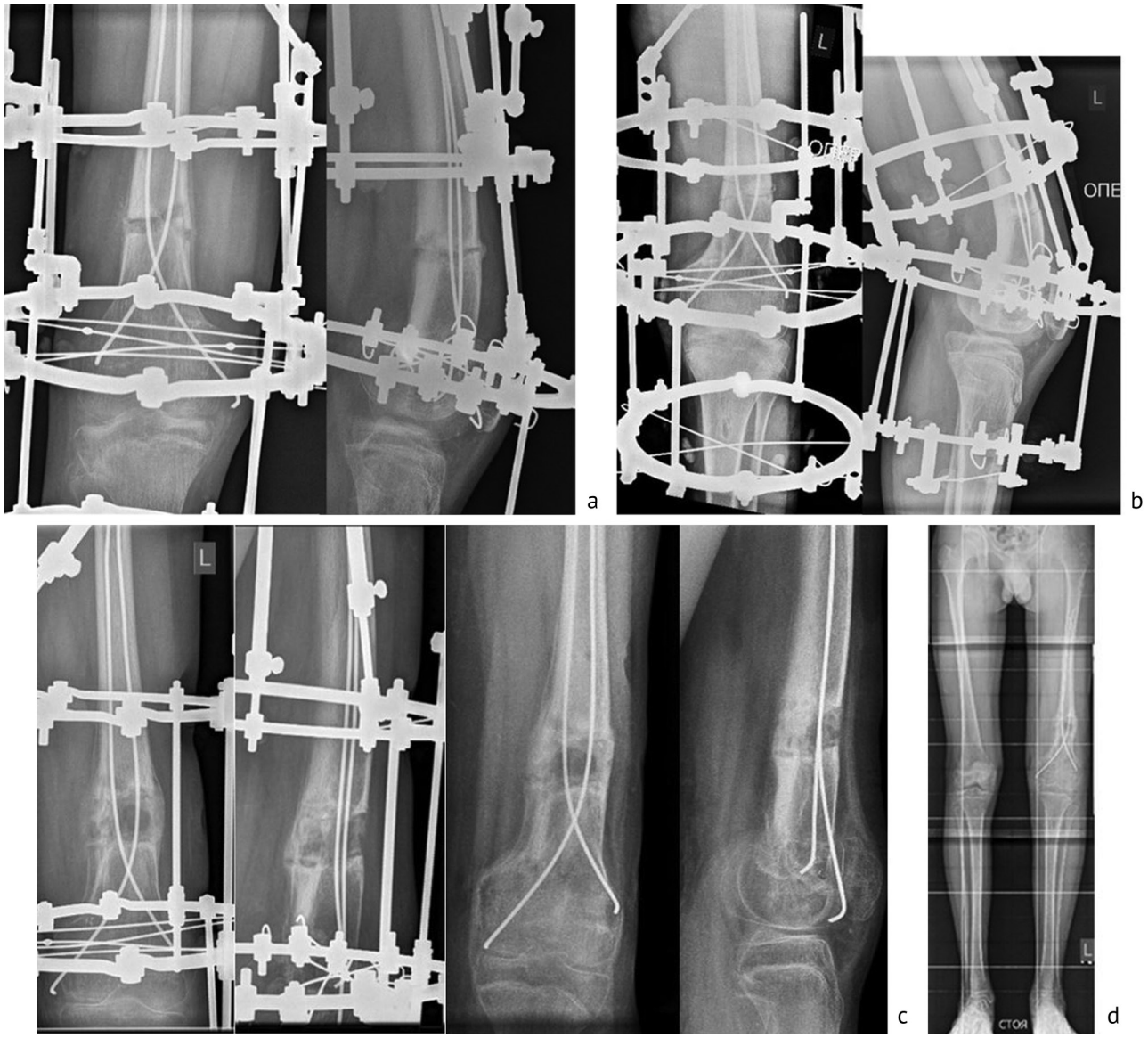

Fig. 3 Radiographs of femoral lengthening case complicated by premature consolidation, patient of the F-HA subgroup: *a* distal femoral osteotomy, retrograde nailing; *b* premature consolidation (radiography on the 21st postoperative day), requiring reosteotomy; *c* at the end of the fixation period, bone consolidation, the device is removed; *d* 40 days after removal of the external fixation device

CONCLUSION

Our prospective study showed that limb lengthening using both elastic titanium nails and composite HA-coated nails provides good to excellent results in femoral and tibia lengthening in patients with acquired lower limb length discrepancy. The use of the technique reduces EFI and the risk of complications, including severe ones, in comparison with traditional techniques without the use of intramedullary elastic nails. In acquired limb shortening and not associated with pathologically altered bone tissue, there were no differences in EFI between the use of intramedullary titanium nails and HA-coated titanium nails. The positive and significantly high correlation between nail diameter/internal distance between cortices at the osteotomy site and EFI, as well as the significant influence of nail type and nail diameter on EFI, means that both factors (diameter and type of elastic intramedullary nail used) should be considered together in future research.

Conflict of interests *None*

Funding source *None*

REFERENCES

1. Paley D. PRECICE intramedullary limb lengthening system. *Expert Rev Med Devices*. 2015;12(3):231-249. doi: 10.1586/17434440.2015.1005604
2. Friend L, Widmann RF. Advances in management of limb length discrepancy and lower limb deformity. *Curr Opin Pediatr*. 2008;20(1):46-51. doi: 10.1097/MOP.0b013e3282f35eeb
3. Ganger R, Radler C, Speigner B, Grill F. Correction of post-traumatic lower limb deformities using the Taylor spatial frame. *Int Orthop*. 2010;34(5):723-730. doi: 10.1007/s00264-009-0839-5
4. Maffulli N, Lombari C, Matarazzo L, et al. A review of 240 patients undergoing distraction osteogenesis for congenital post-traumatic or postinfective lower limb length discrepancy. *J Am Coll Surg*. 1996;182(5):394-402.
5. Massard-Combe P, Verscheure D, Jayet J, et al. Lower Limb Discrepancy Secondary to Post-traumatic Femoral Lesion: A Case Report. *Ann Vasc Surg*. 2020;68:571.e5-571.e7. doi: 10.1016/j.avsg.2020.04.048
6. Emara KM, Khames A. Functional outcome after lengthening with and without deformity correction in polio patients. *Int Orthop*. 2008;32(3):403-407. doi: 10.1007/s00264-007-0322-0
7. El-Mowafi H, Mohsen M. The effect of low-intensity pulsed ultrasound on callus maturation in tibial distraction osteogenesis. *Int Orthop*. 2005;29(2):121-124. doi: 10.1007/s00264-004-0625-3
8. Salem KH, Schmelz A. Low-intensity pulsed ultrasound shortens the treatment time in tibial distraction osteogenesis. *Int Orthop*. 2014;38(7):1477-1482. doi: 10.1007/s00264-013-2254-1
9. Kristiansen LP, Steen H, Reikerås O. No difference in tibial lengthening index by use of Taylor spatial frame or Ilizarov external fixator. *Acta Orthop*. 2006;77(5):772-777. doi: 10.1080/17453670610012971
10. Hammouda AI, Jauregui JJ, Gesheff MG, et al. Treatment of Post-Traumatic Femoral Discrepancy With PRECICE Magnetic-Powered Intramedullary Lengthening Nails. *J Orthop Trauma*. 2017;31(7):369-374. doi: 10.1097/BOT.0000000000000828
11. Horn J, Steen H, Huhnstock S, et al. Limb lengthening and deformity correction of congenital and acquired deformities in children using the Taylor Spatial Frame. *Acta Orthop*. 2017;88(3):334-340. doi: 10.1080/17453674.2017.1295706
12. Horn J, Hvid I, Huhnstock S, et al. Limb lengthening and deformity correction with externally controlled motorized intramedullary nails: evaluation of 50 consecutive lengthenings. *Acta Orthop*. 2019;90(1):81-87. doi: 10.1080/17453674.2018.1534321
13. Calder PR, Laubscher M, Goodier WD. The role of the intramedullary implant in limb lengthening. *Injury*. 2017;48 Suppl 1:S52-S58. doi: 10.1016/j.injury.2017.04.028
14. Antoci V, Ono CM, Antoci V Jr, Raney EM. Comparison of distraction osteogenesis for congenital and acquired limb-length discrepancy in children. *Orthopedics*. 2008;31(2):129. doi: 10.3928/01477447-20080201-04
15. Ceroni D, Grumetz C, Desvachez O, et al. From prevention of pin-tract infection to treatment of osteomyelitis during paediatric external fixation. *J Child Orthop*. 2016;10(6):605-612. doi: 10.1007/s11832-016-0787-8
16. Antoci V, Ono CM, Antoci V Jr, Raney EM. Bone lengthening in children: how to predict the complications rate and complexity? *J Pediatr Orthop*. 2006;26(5):634-640. doi: 10.1097/01.bpo.0000229977.31931.69
17. Aranovich A., Stogov M., Kireeva E., Menshchikova T. Prediction and control of the distraction osteogenesis course. Analytical review. *Genij Ortopedii*. 2019;25(3):400-406. doi: 10.18019/1028-4427-2019-25-3-400-406
18. Matsubara H, Tsuchiya H, Sakurakichi K, et al. Deformity correction and lengthening of lower legs with an external fixator. *Int Orthop*. 2006;30(6):550-554. doi: 10.1007/s00264-006-0133-8
19. Launay F, Younsi R, Pithioux M, et al. Fracture following lower limb lengthening in children: a series of 58 patients. *Orthop Traumatol Surg Res*. 2013;99(1):72-79. doi: 10.1016/j.otsr.2012.08.005
20. Moraal JM, Elzinga-Plomp A, Jongmans MJ, et al. Long-term psychosocial functioning after Ilizarov limb lengthening during childhood. *Acta Orthop*. 2009;80(6):704-710. doi: 10.3109/17453670903473024
21. Launay F, Jouve JL, Guillaume JM, et al. Progressive forearm lengthening in children: 14 cases. *Rev Chir Orthop Reparatrice Appar Mot*. 2001;87(8):786-795. (In French)
22. Bukva B, Vrgoč G, Rakovac I, et al. Complications in leg lengthening using an Ilizarov external fixator and intramedullary alignment in children: comparative study during a fourteen-year period. *Injury*. 2015;46 Suppl 6:S48-51. doi: 10.1016/j.injury.2015.10.058
23. Pejin Z. Femoral lengthening in children and adolescents. *Orthop Traumatol Surg Res*. 2017;103(1S):S143-S149. doi: 10.1016/j.otsr.2016.05.020
24. Lampasi M, Launay F, Jouve JL, Bollini G. Femoral lengthening over elastic stable intramedullary nailing in children using the monolateral external fixator. *Chir Organi Mov*. 2009;93(2):57-64. doi: 10.1007/s12306-009-0032-4
25. Popkov DA, Popkov AV, Kononovich NA, et al. Experimental study of progressive tibial lengthening in dogs using the Ilizarov technique. Comparison with and without associated intramedullary K-wires. *Orthop Traumatol Surg Res*. 2014;100(7):809-814. doi: 10.1016/j.otsr.2014.06.021
26. Morcos MW, Al-Jallad H, Hamdy R. Comprehensive Review of Adipose Stem Cells and Their Implication in Distraction Osteogenesis and Bone Regeneration. *Biomed Res Int*. 2015;2015:842975. doi: 10.1155/2015/842975
27. Shevtsov VI, Popkov AV, Popkov DA, et al. Elastic stable intramedullary nailing in Ilizarov bone lengthening. *Rev Chir Orthop Reparatrice Appar Mot*. 2004;90(5):399-410. (In French). doi: 10.1016/s0035-1040(04)70166-x
28. Bolbasov EN, Popkov AV, Popkov DA, et al. Osteoinductive composite coatings for flexible intramedullary nails. *Mater Sci Eng C Mater Biol Appl*. 2017;75:207-220. doi: 10.1016/j.msec.2017.02.073
29. Lascombes P, Popkov D, Huber H, et al. Classification of complications after progressive long bone lengthening: proposal for a new classification. *Orthop Traumatol Surg Res*. 2012;98(6):629-637. doi: 10.1016/j.otsr.2012.05.010
30. Shailam R, Jaramillo D, Kan JH. Growth arrest and leg-length discrepancy. *Pediatr Radiol*. 2013;43(Suppl 1):S155-S65. doi: 10.1007/s00247-012-2598-5
31. Ceroni D, Valaikaite R, Grumetz C, et al. Corrective surgery for lower limb length discrepancy and malalignment in paediatric orthopaedics. *Rev Med Suisse*. 2017;13(550):427-432. (In French)
32. McClure PK, Herzenberg JE. The Natural History of Lower Extremity Malalignment. *J Pediatr Orthop*. 2019;39(Issue 6, Supplement 1 Suppl 1):S14-S19. doi: 10.1097/BPO.0000000000001361

33. Grivas TB, Angouris K, Chandrinos M, Kechagias V. Truncal changes in children with mild limb length inequality: a surface topography study. *Scoliosis Spinal Disord*. 2018;13:27. doi: 10.1186/s13013-018-0173-z
34. Popkov AV, Aranovich AM, Novikov KI, et al. Combined high-division distraction osteosynthesis of the femur in children. *Genij Ortopedii*. 2016;(2):57-63. doi: 10.18019/1028-4427-2016-2-57-63
35. Black SR, Kwon MS, Cherkashin AM, et al. Lengthening in Congenital Femoral Deficiency: A Comparison of Circular External Fixation and a Motorized Intramedullary Nail. *J Bone Joint Surg Am*. 2015;97(17):1432-1440. doi: 10.2106/JBJS.N.00932
36. Iobst C. Limb lengthening combined with deformity correction in children with the Taylor Spatial Frame. *J Pediatr Orthop B*. 2010;19(6):529-534. doi: 10.1097/BPB.0b013e32833dec43
37. Küçükkaya M, Karakoyun Ö, Sökücü S, Soydan R. Femoral lengthening and deformity correction using the Fitbone motorized lengthening nail. *J Orthop Sci*. 2015;20(1):149-154. doi: 10.1007/s00776-014-0659-3
38. Hosny GA. Limb lengthening history, evolution, complications and current concepts. *J Orthop Traumatol*. 2020;21(1):3. doi: 10.1186/s10195-019-0541-3
39. Popkov AV, Aranovich AM, Novikov KI et al. Leg lengthening in children by the combined technique using high-divisional round-the-clock distraction. *Genij Ortopedii*. 2016;(2):51-56. doi: 10.18019/1028-4427-2016-2-51-56
40. Qin S, Zang J, Guo B. Ilizarov technology and chinese philosophy (To commemorate the 100th anniversary of the birth of Professor Ilizarov). *Genij Ortopedii*. 2021;27(3):291-295. doi: 10.18019/1028-4427-2021-27-3-291-295
41. Oostenbroek HJ, Brand R, van Roermund PM, Castelein RM. Paediatric lower limb deformity correction using the Ilizarov technique: a statistical analysis of factors affecting the complication rate. *J Pediatr Orthop B*. 2014;23(1):26-31. doi: 10.1097/BPB.0b013e32836422ba
42. Koczewski P, Shadi M. Factors influencing bone regenerate healing in distraction osteogenesis. *Ortop Traumatol Rehabil*. 2013;15(6):591-599. doi: 10.5604/15093492.1091515
43. Gordon JE, Manske MC, Lewis TR, et al. Femoral lengthening over a pediatric femoral nail: results and complications. *J Pediatr Orthop*. 2013;33(7):730-736. doi: 10.1097/BPO.0b013e3182a122a1
44. Nakase T, Kitano M, Kawai H, et al. Distraction osteogenesis for correction of three-dimensional deformities with shortening of lower limbs by Taylor Spatial Frame. *Arch Orthop Trauma Surg*. 2009;129(9):1197-1201. doi: 10.1007/s00402-008-0702-y
45. Popkov D, Popkov A, Haumont T, et al. Flexible intramedullary nail use in limb lengthening. *J Pediatr Orthop*. 2010;30(8):910-918. doi: 10.1097/BPO.0b013e3181f0eaf9
46. Saraph V, Roposch A, Zwick EB, Linhart WE. Tibial lengthening over nails in children using modified Ender nails: preliminary results of a new treatment. *J Pediatr Orthop B*. 2004;13(6):383-388. doi: 10.1097/01202412-200411000-00007
47. Popkov AV, Gorbach EN, Kononovich NA, et al. Bioactivity and osteointegration of hydroxyapatite-coated stainless steel and titanium wires used for intramedullary osteosynthesis. *Strategies Trauma Limb Reconstr*. 2017;12(2):107-113. doi: 10.1007/s11751-017-0282-x
48. Fischgrund J, Paley D, Suter C. Variables affecting time to bone healing during limb lengthening. *Clin Orthop Relat Res*. 1994;(301):31-37.
49. Danziger MB, Kumar A, DeWeese J. Fractures after femoral lengthening using the Ilizarov method. *J Pediatr Orthop*. 1995;15(2):220-223.
50. Stanitski DF, Shahcheraghi H, Nicker DA, Armstrong PF. Results of tibial lengthening with the Ilizarov technique. *J Pediatr Orthop*. 1996;16(2):168-172. doi: 10.1097/00004694-199603000-00006

The article was submitted 29.02.2024; approved after reviewing 17.05.2024; accepted for publication 18.06.2024.

Information about the authors:

Denis V. Tropin — orthopaedic surgeon, I@tropin-1.ru, https://orcid.org/0009-0001-6719-0959;

Vasily I. Tropin — Candidate of Medical Sciences, orthopaedic surgeon, Head of Departmen, vasilytropin@yahoo.com, https://orcid.org/0009-0006-2082-8341;

Aleksandr A. Chertishehev — orthopaedic surgeon;

Nikita S. Gvozdev — orthopaedic surgeon, gvozdev_n.s@mail.ru, https://orcid.org/0000-0003-3428-3742;

Dmitry A. Popkov — Doctor of Medical Sciences, Head of the Clinic, Professor of the Russian Academy of Sciences, Corresponding Member of the French Academy of Medical Sciences, orthopaedic surgeon, dpopkov@mail.ru, https://orcid.org/0000-0002-8996-867X.

Original article
https://doi.org/10.18019/1028-4427-2024-30-4-533-541

Risk factors associated with congenital clubfoot in children

M.V. Vlasov, I.V. Musikhina✉

Privolzhsky Medical Research University, Nizhny Novgorod, Russian Federation

Corresponding author: Irina V. Musikhina, i_musihina@mail.ru

Abstract

Introduction Congenital clubfoot is a frequent malformation of the lower extremities. However, the causes of this pathology in children are still unclear. The identification of the factors associated with congenital clubfoot is a relevant problem, the solution of which will allow a prenatal prevention of clubfoot in newborns thus reducing the number of patients with this pathology.

Purpose The search for possible risk factors leading to a violation of foot development in the fetus and their significance in the occurrence of congenital clubfoot in children.

Materials and methods The study was of retrospective nature and was carried out in pairs "Mother-Newborn". It included examination of 149 children. The first group (n = 97) was compiled by the "Mother Newborn" pairs, in which the child had a typical form of congenital clubfoot; the second group (n = 52) were pairs in which the baby was healthy. The data obtained were processed using tables 2×2 and logistics regression.

Results According to the results of the study, it was found that the greatest sensitivity and specificity of congenital clubfoot was associated with the external factor of nicotine dependence in pregnant women (SE = 0.32; SP = 0.90) and the factor of hereditarily burdened congenital foot pathology in close relatives (SE = 0.16; SP = 0.98). An acute respiratory viral infection in the anamnesis, anemia in a pregnant woman or toxicosis did not show statistically significant causal connection with the occurrence of congenital clubfoot according to the analysis using the method of logistics regression ($p > 0.05$) and they should not be used as prognostic ones.

Discussion The data obtained by us on the paramount significance of the two "risk" factors of the congenital clubfoot development (nicotine dependence in a pregnant woman and hereditarily burdened disorder of congenital foot pathology among close relatives) were reflected only in a few scientific sources.

Conclusion The risk factors of the greatest sensitivity, specificity and causal relationship with the congenital clubfoot development were associated with the adverse effects of the external factor of nicotine dependence during pregnancy and burdened heredity associated with congenital foot pathology in close relatives ($p < 0.05$).

Keywords: pregnancy, children, congenital clubfoot, risk factors, nicotine dependence, heredity

For citation: Vlasov MV, Musikhina IV. Risk factors associated with congenital clubfoot in children. *Genij Ortopedii*. 2024;30(4):533-541. doi: 10.18019/1028-4427-2024-30-4-533-541

© Vlasov M.V., Musikhina I.V., 2024
© Translator Tatyana A. Malkova, 2024

INTRODUCTION

The World Health Organization estimates that more than 100 thousand children worldwide are born with congenital clubfoot every year. Congenital clubfoot is a common malformation of the lower extremities and ranks second among deformities of the musculoskeletal system. The first place in terms of incidence is taken by the pathology of fingers and toes (38.16 %), foot deformities are in the second place (21.95 %), and the third place is taken by congenital deformities of the femur (13.73 %) [1–3]. The incidence of congenital clubfoot among the population of the Russian Federation is average and amounts to 1–3 cases per one thousand newborns [4–6]. There is a tendency of a growing number of children born with congenital clubfoot [7–8].

It should be noted that bilateral congenital clubfoot is more frequent than the unilateral one [9–11]; among males, congenital clubfoot occurs several times more frequently and the ratio to females is from 2.5:1 to 1.1: 1 [12–13]. In 15–30 % of cases, congenital clubfoot is closely related to other developmental anomalies of the musculoskeletal system, such as congenital dislocation of the hip, fusion of fingers and toes, muscular torticollis, amniotic bands of various locations, spina bifida [14–18].

To date, it has been proven that congenital anomalies in fetal development occur much more frequently in pregnant women living in environmentally poor conditions, exposed to dangerous carcinogenic effects at work, experiencing nicotine and alcohol intoxication, and also having sexually transmitted infections such as chlamydia, mycoplasmosis, herpesvirus [19–24]. However, there are very few studies devoted to the role of risk factors in the occurrence of congenital foot deformities [25]. Despite the fact that congenital clubfoot is a disease that has been known for a long time, and significant progress has been made in the treatment of this pathology, the causes of congenital clubfoot in children are still not clear. There is no complete unanimity among researchers on any of the existing theories. At the present stage of the development of medicine, scientists have been discussing various theories of congenital clubfoot occurrence, giving priority to certain factors that, having a negative impact on the body of the expectant mother in the first trimester of pregnancy, can disrupt the proper maturation of the fetus and, in particular, cause abnormal foot development. Data vary on the significance of such external risk factors affecting the fetus and influencing the development of clubfoot, such as smoking, alcohol, diabetes mellitus, acute respiratory infections and others.

Given the frequency of congenital clubfoot among the total number of newborns, severe consequences of the pathological process associated with a high rate of relapses of foot deformities (35–64 %), patients' disability, the detrimental effect of the anatomical defect in the feet on the physical and mental development of the child [26, 27], the search for risk factors causing clubfoot in the fetus is extremely relevant. Identification of risk factors that have the most damaging effect during the formation of organs and systems of the unborn child and lead to congenital clubfoot would enable to carry out prenatal prevention of clubfoot in newborn children thus reducing the number of patients with this pathology.

Purpose To identify possible risk factors leading to foot mal-development in the fetus, and determine their significance in the incidence of congenital clubfoot in children

MATERIALS AND METHODS

During 2017–2022, we examined 97 patients with congenital clubfoot who were admitted for surgical treatment to the children's department of traumatology and orthopaedics of the Privolzhsky Medical Research University (PMRU), and 52 practically healthy children who visited an orthopaedist at the PMRU outpatient clinic. The age of the patients was from 1 to 12 months. The study was retrospective, conducted in pairs "mother-newborn" based on observation (examination) data of 149 children. The method of interviewing mothers was used and the form 113/y (information from the maternity hospital, maternity ward of the hospital about the newborn) was studied. Inclusion criteria were a typical congenital clubfoot diagnosed in the child of the first group of patients; and the second group there was practically healthy children. In both groups, the mother's informed voluntary consent to participate in the study was obtained. Risk factors that were associated with malformations were identified using the "case-control" method based on a comparative analysis of obstetric and gynecological history and data from the form 113/y in two groups. The

first group (n = 97) consisted of "mother-newborn" pairs, in which the child had a typical congenital clubfoot; the second (n = 52) were pairs in which the baby was practically healthy.

The clubfoot grade was determined with the Dimeglio scoring system [28].

In the first group, which included 97 children (150 feet) with congenital clubfoot, all types of congenital clubfoot were represented, depending on the severity of the foot deformity (Table 1).

Table 1

Distribution of clubfoot depending on the severity of the deformity in children with congenital clubfoot

Severity grade	Number			
	детей		стоп	
	N	%	N	%
Grade I–II	15	15.5	23	15.3
Grade III	33	34.0	47	31.3
Grade IV	49	50.5	80	53.3
Total	97	100	150	100

Statistical processing of the study results was carried out using the Statistika 12.0 application package. In statistical analysis, the objective quantitative characteristics of risk factors were absolute risk (Absolute risk, R), reduction in absolute risk (Atributable risk, AR), relative risk (RR). Specificity (Sp) of the risk factor and sensitivity (Se) were calculated using 2 × 2 tables in the exposed (with the presence of the risk factor) and control (without the risk factor) groups. We determined the odds ratio (OR) and probability (P_+) of developing congenital clubfoot in a newborn according to analysis using the logistic regression method. To test the statistical significance of differences in the compared groups, the Pearson test (χ^2) was used. Differences were considered significant at $p < 0.05$.

RESULTS

The average weight at birth of children with congenital clubfoot was comparable to this indicator in healthy children (p = 0.37). After comparing the average body length in children of the two groups, no statistically significant differences were found (p = 0.31), and no significant differences were found in the average number of Apgar scores (p = 0.13) (Table 2).

The age of mothers at the time of delivery was practically the same in the groups (p = 0.47), and there were also no statistically significant differences in the height of mothers (p = 0.13). There was no significant difference after comparing mothers' weight in the groups (p = 0.08). The difference in the number of pregnancies among the mothers was statistically insignificant (p = 0.16), the number of deliveries was also statistically insignificant (p = 0.17) (Table 3).

Table 2

Average indicators in newborns with congenital clubfoot and practically healthy children (Mann – Whitney test)

Parameter	Group 1 (n = 97)	Group 2 (n = 52)	p-level
Weight at birth, g	3271.75 ± 593.6	3401.27 ± 509.7	0.37
Height at birth, cm	51.04 ± 3.31	51.50 ± 3.06	0.31
Apgar score	7.78 ± 0.74	7.65 ± 0.65	0.13

Table 3

Characteristics and obstetric history of the examined women (Mann – Whitney test)

Parameter	Mothers of children with clubfoot (group 1)	Mothers of healthy children (group 2)	p
Age, years	29.62 ± 5.12	30.23 ± 4.92	0.47
Height, cm	164.73 ± 6.62	166.25 ± 5.13	0.13
Weight, kg	67.16 ± 17.71	63.17 ± 12.93	0.08
Number of pregnancies	2.43 ± 1.54	1.98 ± 1.07	0.16
Number of deliveries	1.80 ± 0.78	1.62 ± 0.74	0.17

Thus, the compared groups did not differ from each other in terms of main indicators and could be used to identify risk factors for congenital clubfoot. Only those factors that could have a direct impact on the intrauterine formation of the fetus were analyzed, with the establishment of cause-and-effect relationships leading to the development of congenital clubfoot (Fig. 1).

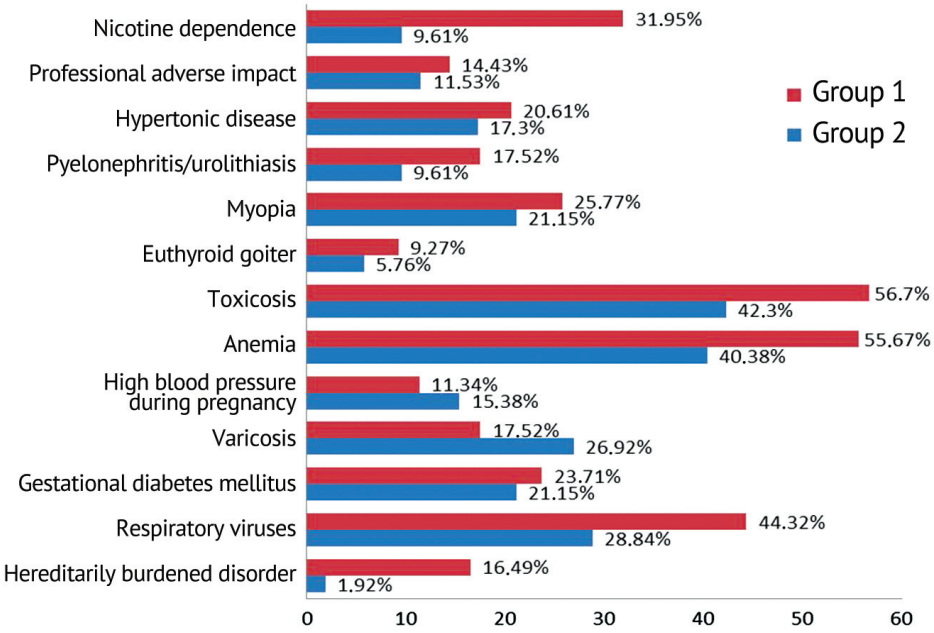

Fig. 1 Incidence of certain identified conditions/diseases and/or complications of pregnancy in mothers of children with congenital clubfoot and in mothers of healthy children

Most of the women of the first and second groups had chronic pathology before the onset of the studied pregnancy. A retrospective analysis of the obstetric anamnesis revealed that the mothers of the examined children in both groups had some pathology during pregnancy. Thus, in the first group, toxicosis was most common in 55 (56.7 %) women, hypertension in 20 (20.6 %) pregnant women. In women of the second group, toxicosis was diagnosed in 22 (42.3 %) cases, pregnancy hypertension in 9 (17.3 %). When studying the genealogical history data, congenital foot pathology in close relatives was revealed in 16 (16.49 %) children of the first group. In the second group, a family history of congenital foot defects was detected in only 1 child (1.92 %).

Using the method of correlation analysis, it was determined that the birth of a child with congenital clubfoot is associated with a number of factors that could serve as risk factors for the occurrence of this disease (Table 4).

Table 4

Determination of factors associated with congenital clubfoot (results of correlation analysis, γ)

Factor	γ	*p*
Professional adverse effects	0.13	0.46
Nicotine dependence in a pregnant woman	0.63	0.001*
Acute respiratory viral infections (ARVI)	0.32	0.006*
Anemia in pregnancy	0.30	0.008*
Toxicosis in pregnancy	0.31	0.005*
Gestational diabetes mellitus	0.07	0.60
Hereditarily burdened disorder	0.81	0.001*
Varicose disease	– 0.26	0.051
High blood pressure in pregnancy	0.14	0.32
Euthyroid goiter	0.24	0.29
Myopia	0.20	0.13
Pyelonephritis/ urolithiasis	0.33	0.054

Note: * — statistically significant ($p \leqslant 0.05$)

There was a correlation between the occurrence of congenital clubfoot and certain risk factors associated with physical health and a number of conditions in pregnant women. Thus, there is a moderate positive correlation of high significance ($\gamma = 0.630666$ at $p = 0.001$) between the occurrence of congenital clubfoot in a child and nicotine addiction in the mother. A moderate positive correlation was determined between the occurrence of congenital clubfoot in a child and anemia in pregnant women ($\gamma = 0.30$ at $p = 0.008$), ARVI ($\gamma = 0.32$ at $p = 0.006$) and toxicosis in pregnant women ($\gamma = 0.31$ at $p = 0.005$).

In the process of correlation analysis, a strong positive relationship of a high degree of significance was revealed between the risk of congenital clubfoot and a family history of congenital foot malformations ($\gamma = 0.81$ at $p = 0.001$). Thus, the identified risk factors may have an adverse effect during the period of intrauterine development of the fetus and be the cause of congenital clubfoot in the newborn.

Risk factors for congenital clubfoot were those associated with a family history of congenital foot deformity in close relatives (RR = 1.53 ± 0.09 [1.28–1.83], $p = 0.007$). Risk factors associated with the adverse effects of external factors during pregnancy: nicotine dependence in women (RR = 1.47 ± 0.10 [1.20–1.80], $p = 0.002$), a history of acute respiratory viral infection (RR = 1.25 ± 0.11 [0.99–1.56], $p = 0.06$). Risk factors associated with the somatic health of pregnant women leading to congenital clubfoot: toxicosis during pregnancy (RR = 1.22 ± 0.12 [0.96–1.55], $p = 0.09$), anemia in pregnant women (RR = 1.23 ± 0.12 [0.97–1.57], $p = 0.07$).

Despite the significant risk indicators, the sensitivity of the occurrence of congenital clubfoot to the action of the identified factors was not high and even low; and noticeably (1.61 times or more) inferior to their specificity. The greatest sensitivity and specificity for the occurrence of congenital clubfoot was for factors associated with the adverse effect of the external factor, namely, nicotine addiction in pregnant women (SE = 0.32; SP = 0.90) during pregnancy, and the factor associated with a family history of congenital foot pathology in close relatives (SE = 0.16; SP = 0.98) (Table 5).

Table 5

Risk factors associated with congenital clubfoot

Risk factor	Group 1 (n = 97)		Group 2 (n = 52)		R_1	R_2	AR	RR ± S [95 % CI]	χ^2	p	Se	Sp
	abs	%	abs	%								
Nicotine dependence	31	31.95	5	9.61	86.1	58.4	27.7	1.47 ± 0.10 [1.20–1.80]	9.22	0.002	0.32	0.90
Acute respiratory virus infections (ARVI)	43	44.32	15	28.84	74.1	59.3	14.8	1.25 ± 0.11 [0.99–1.56]	3.41	0.06	0.44	0.71
Anemia in pregnancy	54	55.67	21	40.38	72.0	58.1	13.9	1.23 ± 0.12 [0.97–1.57]	3.16	0.07	0.55	0.59
Toxicosis	55	56.7	22	42.38	71.4	58.3	13.1	1.22 ± 0.12 [0.96–1.55]	2.81	0.09	0.56	0.57
Hereditarily burdened disorder	16	16.49	1	1.92	94.1	61.4	32.8	1.53 ± 0.09 [1.28–1.83]	7.11	0.007	0.16	0.98

Note: R_1 — absolute risk in the exposed (with the presence of a risk factor) group, R_2 — absolute risk in the control (absence of a risk factor) group, AR — attributable risk, RR — relative risk, S — standard error of the relative risk, [95 % CI] — 95 % confidence interval of the relative risk, χ^2 — Pearson test, p — level of statistical significance of the relative risk, Se — sensitivity to the risk factor, Sp — specificity of the risk factor.

Certain (single) factors among those identified revealed a cause-and-effect relationship in the occurrence of congenital clubfoot in a newborn according to analysis using the logistic regression method: factors associated with the adverse effects of external factors during pregnancy: nicotine addiction in women (OR = 4.41 ± 0 .51 [1.59–12.19], $p = 0.001$). The probability of congenital clubfoot under the influence of this factor was quite high ($P_+ = 0.81$). Factor associated with a family history of congenital foot pathology among close

relatives: (OR = 10.07 ± 1.04 [1.29–78.29], $p = 0.003$), and the likelihood of congenital clubfoot under the influence of this factor was also quite high ($P_+ = 0.90$). A history of acute respiratory viral infection, anemia in pregnant women, and toxicosis in pregnant women did not show a statistically significant cause-and-effect relationship with the occurrence of congenital clubfoot according to analysis using the logistic regression method ($p > 0.05$) (Table 6).

Table 6

Odds ratio and probability of congenital clubfoot in the presence of certain factors (based on logistic regression)

Risk factor	OR ± S [95 % CI]	P_+	B_1	B_0	χ^2	p
Nicotine dependence	4.41 ± 0.51 [1.59–12.19]	0.81	1.48	–3.72	10.29	0.001
Acute respiratory virus infections	1.96 ± 0.36 [0.95–4.04]	0.66	0.67	1.57	3.48	0.06
Anemia during pregnancy	1.85 ± 0.34 [0.93–3.67]	0.64	0.61	–1.00	3.17	0.07
Toxicosis during pregnancy	1.78 ± 0.34 [0.90–3.52]	0.64	0.57	–1.04	3.62	0.06
Hereditarily burdened disorder	10.07 ± 1.04 [1.29–78.29]	0.90	2.30	6.24	9.03	0.003

Note: OR — odds ratio, S — standard error of the odds ratio, [95 % CI] — 95 % confidence interval of the odds ratio; P_+ — probability of congenital clubfoot; B_1 is the regression coefficient of the independent "risk" factor i; B_0 is the free member in the regression equation; χ^2 — Pearson test; p is the level of statistical significance of the regression level

DISCUSSION

Currently, there is no unity in the views on the etiopathogenesis of congenital clubfoot. Proponents of the mechanical theory (intrauterine immobility) of congenital clubfoot explain the occurrence of the deformity by mechanical effects on the fetus during its intrauterine development. Increased intrauterine pressure, oligohydramnios and, as a result, a reduced volume of the uterine cavity lead to excessive immobilization of joints, disruption of tissue trophism, developmental delay and curvature of developing bones [29]. However, a fairly large group of researchers believes that the role of intrauterine pressure as one of the causes of the development of congenital clubfoot has not been proven [30–31].

The theory of congenital defects of the embryo explains the occurrence of congenital clubfoot by a violation of the anlage and delayed development of the foot at one of the stages of embryogenesis [32]. Proponents of the neuromuscular theory believe that the main cause of congenital clubfoot is associated with a malformation of the spinal cord, namely with improper closure of the medullary tube (dysraphism), which ultimately leads to disruption of the innervation of the lateral and, to a lesser extent, the anterior group of muscles of the leg [33 –35]. Patients with congenital clubfoot show a direct relationship between the severity of the deformity and the level of neurological deficit [36–37].

Our studies have shown that the most significant risk factor for the development of congenital clubfoot, associated with the adverse effects of external factors during pregnancy, is nicotine addiction in women.

The study of the risk factors associated with the adverse effects of external factors during pregnancy showed the following results: nicotine dependence in women (RR = 1.47 ± 0.10 [1.20–1.80], $p = 0.002$), acute history of respiratory viral infection (RR = 1.25 ± 0.11 [0.99–1.56], $p = 0.06$). Risk factors associated with the somatic health of pregnant women leading to congenital clubfoot: toxicosis during pregnancy (RR = 1.22 ± 0.12 [0.96–1.55], $p = 0.09$), anemia of pregnant women (RR = 1.23 ± 0.12 [0.97–1.57], $p = 0.07$). Although the risk indicators were significant, the sensitivity of the occurrence of congenital clubfoot to the action of the identified factors was low and noticeably (1.61 times or more) inferior to their specificity, with the exception of such a factor as nicotine addiction (SE = 0.32; SP = 0.90). A number of factors revealed a cause-and-effect relationship in the occurrence of congenital clubfoot in a newborn according to logistic regression analysis: factors associated with the adverse effects of external factors during pregnancy: nicotine addiction

in women (OR = 4.41 ± 0, 51 [1.59–12.19], p = 0.001). The probability of congenital clubfoot under the influence of this factor was quite high (P_+ = 0.81). A history of acute respiratory viral infection, anemia in pregnant women, and toxicosis in pregnant women did not reveal a statistically significant cause-and-effect relationship with congenital clubfoot according to analysis using the logistic regression method ($p > 0.05$).

Our data confirmed a number of works by foreign authors, who also stated the negative impact of nicotine addiction in pregnant women on the development of congenital clubfoot [38–39]. The domestic literature shows a close relationship between mothers's smoking habit during pregnancy and the occurrence of a variety of developmental defects: intrauterine growth retardation, clefts of the hard and soft palate, cardiovascular system defects, etc., but did not indicate a clear relationship between this bad pregnant women;s habit and the birth of a child with congenital clubfoot [41].

The relationship between the birth of a child with congenital clubfoot and nicotine addiction may be due to the teratogenic effect of nicotine and combustion products. Nicotine easily penetrates the placenta and has a direct effect on fetal tissue. The damaging effect of tobacco smoke derivatives is directed directly at the fetus, which leads to the occurrence of congenital pathological anomalies of the fetus [41].

The second most significant risk factor for the development of congenital clubfoot, according to our data, is a factor associated with a family history of congenital foot pathology among close relatives. The risk of congenital clubfoot associated with a family history of congenital malformations was significant (RR = 1.53 ± 0.09 [1.28–1.83], p = 0.007). At the same time, the highest sensitivity and specificity for the occurrence of congenital clubfoot was determined (SE = 0.16; SP = 0.98). A factor associated with a family history of congenital foot pathology among close relatives (OR = 10.07 ± 1.04 [1.29–78.29], p = 0.003), while the likelihood of congenital clubfoot under the influence of this factor was also residually high (P_+ = 0.90).

The relationship we have identified between congenital clubfoot in a child and a family history of foot developmental anomalies in close relatives is reflected in a number of works by foreign authors who put forward a genetic theory of inheritance of this disease [42]. Currently, the genetic theory is the leading one and has gained support among a large group of researchers [43–45].

CONCLUSION

The greatest sensitivity, specificity and cause-and-effect relationship with congenital clubfoot was shown by adverse effects of such external factor as nicotine dependence during pregnancy and association with a family history of congenital foot pathology in blood relatives ($p < 0.05$). These risk factors, having an adverse impact on the formation and development of the fetus, are the cause of congenital clubfoot and can be used in predicting and preventing congenital clubfoot.

Risk factors such as acute respiratory viral infection during pregnancy, anemia in pregnant women, toxicosis during pregnancy, had low sensitivity, poor specificity and did not show a significant cause-and-effect relationship with congenital clubfoot ($p > 0.05$); and they should not be used as prognostic ones.

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

Funding *The study was conducted without sponsorship.*

Ethical statement *The study was conducted in accordance with the ethical standards of the World Medical Association Declaration of Helsinki "Ethical Principles for Medical Research Involving Human Subjects", as amended in 2013, in compliance with the principles of research safety, awareness, consent, and confidentiality.*

Informed consent *All patients or their legal representatives signed informed consent to participate in the study and publish data without personal identification.*

REFERENCES

1. Baindurashvili AG, Kenis VM, Chukhraeva IY. To a question on early diagnostics of pathology of the musculoskeletal system at newborns. *Traumatology and Orthopedics of Russia*. 2009;(3):108-110. (In Russ.) 2009;(3):108-110. doi: 10.17816/2311-2905-1891
2. Peterlein CD, Bosch M, Timmesfeld N, Fuchs-Winkelmann S. Parental internet search in the field of pediatric orthopedics. *Eur J Pediatr*. 2019;178(6):929-935. doi: 10.1007/s00431-019-03369-w
3. Cady R, Hennessey TA, Schwend RM. Diagnosis and Treatment of Idiopathic Congenital Clubfoot. *Pediatrics*. 2022;149(2):e2021055555. doi: 10.1542/peds.2021-055555
4. Savio SD, Maharjana MA. Accelerated versus standard Ponseti method for idiopathic congenital talipes equinovarus: a systematic review and meta-analysis. *Pediatric Traumatology, Orthopaedics and Reconstructive Surgery*. 2020;8(4): 473-484. doi: 10.17816/PTORS35161
5. Krestyashin IV, Razumovskiy AY, Krestyashin VM, Kuzhelivskiy II. Treatment of Foot Deformities in Children under 3. *Journal of Experimental and Clinical Surgery*. 2020;13(4):348-352. (In Russ.) doi: 10.18499/2070-478X-2020-13-4-348-352
6. Vavilov MA, Blandinsky VF, Gromov IV, et al. Long-term outcomes of atypical clubfoot treated with the Ponseti method. *Genij Ortopedii*. 2022;28(3):372-377. doi: 10.18019/1028-4427-2022-28-3-372-377
7. Baindurashvili AG, Solov'yova KS, Zaletina AV, Lapkin YA. Congenital Abnormalities (developmental defects) and Musculoskeletal System Deformities in Children. *N.N. Priorov Journal of Traumatology and Orthopedics*. 2014;21(3):15-20. (In Russ.) doi: 10.17816/vto20140315-20
8. Engesaeter LB. Increasing incidence of clubfoot: changes in the genes or the environment? *Acta Orthop*. 2006;77(6):837-938. doi: 10.1080/17453670610013105
9. Alimkhanova RS. Treatment of congenital clubfoot in children using a method of traction devices. *Genij Ortopedii*. 2003;(1):94-97. (In Russ.)
10. Heck AL, Bray MS, Scott A, et al. Variation in CASP10 gene is associated with idiopathic talipes equinovarus. *J Pediatr Orthop*. 2005;25(5):598-602. doi: 10.1097/01.bpo.0000173248.96936.90
11. Kruse LM, Dobbs MB, Gurnett CA. Polygenic threshold model with sex dimorphism in clubfoot inheritance: the Carter effect. *J Bone Joint Surg Am*. 2008;90(12):2688-2694. doi: 10.2106/JBJS.G.01346
12. Omarov GG, Rumyantsev NY, Kruglov IY. 300 neonatal clubfeet evaluated at birth: statistical analysis. *Pediatric Traumatology, Orthopaedics and Reconstructive Surgery*. 2015;3(1):27-31. (In Russ.) doi: 10.17816/PTORS3127-31
13. Zionts LE, Jew MH, Ebramzadeh E, Sangiorgio SN. The Influence of Sex and Laterality on Clubfoot Severity. *J Pediatr Orthop*. 2017;37(2):e129-e133. doi: 10.1097/BPO.0000000000000603
14. Krestyashin VM, Nikolaev SN, Letinetskaya OYu, et al. Algorithm for the treatment of congenital clubfoot in children with myelodysplasia syndrome. *Pediatric surgery*. 2008;(4):12-14. (In Russ.)
15. Arkin C, Ihnow S, Dias L, Swaroop VT. Midterm Results of the Ponseti Method for Treatment of Clubfoot in Patients With Spina Bifida. *J Pediatr Orthop*. 2018;38(10):e588-e592. doi: 10.1097/BPO.0000000000001248
16. Stoll C, Alembick Y, Dott B, Roth MP. Associated anomalies in cases with congenital clubfoot. *Am J Med Genet A*. 2020;182(9):2027-2036. doi: 10.1002/ajmg.a.61721
17. Esparza M, Tran E, Richards BS, Jet al. The Ponseti Method for the Treatment of Clubfeet Associated With Amniotic Band Syndrome: A Single Institution 20-Year Experience. *J Pediatr Orthop*. 2021;41(5):301-305. doi: 10.1097/BPO.0000000000001789
18. Badin D, Atwater LC, Dietz HC, Sponseller PD. Talipes Equinovarus in Loeys-Dietz Syndrome. *J Pediatr Orthop*. 2022;42(7):e777-e782. doi: 10.1097/BPO.0000000000002180
19. Khamatkhanova EM, Kucherov YuI. Epidemiological aspects of congenital malformations. *Russian Bulletin of Perinatology and Pediatrics*. 2007;(6):35-39. (In Russ.)
20. Weiner AS, Kudryavtseva EA, Zhechev DA, et al Association between polymorphisms in folate;metabolizing genes and risk of congenital anomalies: a case;control study. *Mother and Baby in Kuzbass*. 2011;(3):10-14. (In Russ.)
21. Honein MA, Paulozzi LJ, Moore CA. Family history, maternal smoking, and clubfoot: an indication of a gene-environment interaction. *Am J Epidemiol*. 2000;152(7):658-665. doi: 10.1093/aje/152.7.658
22. Dodwell E, Risoe P, Wright J. Factors Associated With Increased Risk of Clubfoot: A Norwegian National Cohort Analysis. *J Pediatr Orthop*. 2015;35(8):e104-e1049. doi: 10.1097/BPO.0000000000000449
23. Zhao J, Cai F, Liu P, et al. Gene Environment Interactions Between the COL9A1 Gene and Maternal Drinking of Alcohol Contribute to the Risk of Congenital Talipes Equinovarus. *Genet Test Mol Biomarkers*. 2021;25(1):48-54. doi: 10.1089/gtmb.2020.0196
24. Lou Y, Miao J, Li F, et al. Maternal smoking during pregnancy aggravated muscle phenotype in FHL1-/y offspring mice similar to congenital clubfoot through P2RX7-mediated pyroptosis. *Toxicol Lett*. 2021;345:54-60. doi: 10.1016/j.toxlet.2021.04.014
25. Chen C, Kaushal N, Scher DM, et al. Clubfoot Etiology: A Meta-Analysis and Systematic Review of Observational and Randomized Trials. *J Pediatr Orthop*. 2018;38(8):e462-e469. doi: 10.1097/BPO.0000000000001191
26. Konyukhov MP, Lapkin YuA, Klychkova IYu, Drozhzhina LA. *Congenital and acquired deformities of the feet in children and adolescents. A manual for doctors*. St. Petersburg; 2000:48. (In Russ.)
27. Revkovich AS, Ryjikov DV, Anastasieva EA, et al. Recurrent congenital clubfoot: literature review and evaluation of own observations. *Modern problems of science and education*. 2016;(6). Available at: https://science-education.ru/ru/article/view?id=25680. Accessed March 05, 2024. (In Russ.)
28. Diméglio A, Bensahel H, Souchet P, et al. Classification of clubfoot. *J Pediatr Orthop B*. 1995;4(2):129-136. doi: 10.1097/01202412-199504020-00002
29. Woo SL, Gomez MA, Sites TJ, et al. The biomechanical and morphological changes in the medial collateral ligament of the rabbit after immobilization and remobilization. *J Bone Joint Surg Am*. 1987;69(8):1200-1211.

30. Roye DP Jr, Roye BD. Idiopathic congenital talipes equinovarus. *J Am Acad Orthop Surg*. 2002;10(4):239-248. doi: 10.5435/00124635-200207000-00002
31. Cardy AH, Barker S, Chesney D, et al. Pedigree analysis and epidemiological features of idiopathic congenital talipes equinovarus in the United Kingdom: a case-control study. *BMC Musculoskelet Disord*. 2007;8:62. doi: 10.1186/1471-2474-8-62
32. Kawashima T, Uhthoff HK. Development of the foot in prenatal life in relation to idiopathic club foot. *J Pediatr Orthop*. 1990;10(2):232-237.
33. Psyanchin TS. *Clinical and neurophysiological rationale for surgical tactics for congenital clubfoot in children. Author's abstract Cand. Diss*. Ufa; 1996:17. Available at: https://medical-diss.com/docreader/441536/a?#?page=1. Accessed March 05, 2024. (In Russ.)
34. Vavilov M.A. *Surgical treatment of severe clubfoot in children. Author's abstract Cand. Diss*. Yaroslavl; 2007:15. Available at: https://medical-diss.com/docreader/436275/a?#?page=1. Accessed March 05, 2024. (In Russ.)
35. Klychkova IY, Vinokurova TS, Guseva IA. Electrophysiological substantiation of efficacy of congenital clubfoot surgical treatment. *Traumatology and Orthopedics of Russia*. 2012;18(3):57-66. (In Russ.) doi: 10.21823/2311-2905-2012--3-57-66
36. Timaev MKh, Sertakova AV, Kurkin SA, et al. Talipes equinovarus in children. *Saratov Journal of Medical Scientific Research*. 2017;13(3):514-520. (In Russ.)
37. Shamik VB, Ryabokonev SG. Ekvinusny deformation of feet at children with a cerebral palsy: questions of diagnostics, treatment. *Medical Herald of the South of Russia*. 2018;9(4):6-13. (In Russ.) doi: 10.21886/2219-8075-2018-9-4-6-13
38. Byron-Scott R, Sharpe P, Hasler C, et al. A South Australian population-based study of congenital talipes equinovarus. *Paediatr Perinat Epidemiol*. 2005;19(3):227-37. doi: 10.1111/j.1365-3016.2005.00647.x
39. Sommer A, Blanton SH, Weymouth K, et al. Smoking, the xenobiotic pathway, and clubfoot. *Birth Defects Res A Clin Mol Teratol*. 2011;91(1):20-28. doi: 10.1002/bdra.20742
40. Kelmanson IA. Maternal smoking during pregnancy as a risk factor for the development of a fetus and a child. *Vrach (The Doctor)*. 2017;(8):2-5. (In Russ.)
41. Lambers DS, Clark KE. The maternal and fetal physiologic effects of nicotine. *Semin Perinatol*. 1996;20(2):115-126. doi: 10.1016/s0146-0005(96)80079-6
42. Sharp L, Miedzybrodzka Z, Cardy AH, et al. The C677T polymorphism in the methylenetetrahydrofolate reductase gene (MTHFR), maternal use of folic acid supplements, and risk of isolated clubfoot: A case-parent-triad analysis. *Am J Epidemiol*. 2006;164(9):852-861. doi: 10.1093/aje/kwj285
43. Basit S, Khoshhal KI. Genetics of clubfoot; recent progress and future perspectives. *Eur J Med Genet*. 2018;61(2):107-113. doi: 10.1016/j.ejmg.2017.09.006
44. Khanshour AM, Kidane YH, Kozlitina J, et al. Genetic association and characterization of FSTL5 in isolated clubfoot. *Hum Mol Genet*. 2021 21;29(22):3717-3728. doi: 10.1093/hmg/ddaa236
45. Hordyjewska-Kowalczyk E, Nowosad K, Jamsheer A, Tylzanowski P. Genotype-phenotype correlation in clubfoot (talipes equinovarus). *J Med Genet*. 2022;59(3):209-219. doi: 10.1136/jmedgenet-2021-108040

The article was submitted 19.02.2024; approved after reviewing 01.03.2024; accepted for publication 18.06.2024.

Information about the authors:

Maxim V. Vlasov — Candidate of Medical Sciences, Head of the Department, Footdoc@mail.ru;
Irina V. Musikhina — Candidate of Medical Sciences, orthopaedic surgeon, surgeon, i_musihina@mail.ru.

Original article
https://doi.org/10.18019/1028-4427-2024-30-4-542-551

Comparative analysis of surgical treatment results for osteoporotic burst fractures of thoracolumbar vertebral bodies

V.D. Sinyavin[1], V.V. Rerikh[1,2]✉

[1] Novosibirsk Tsivyan Research Institute of Traumatology and Orthopedics, Novosibirsk, Russian Federation
[2] Novosibirsk State Medical University, Novosibirsk, Russian Federation

Corresponding author: Victor V. Rerikh, rvv_nsk@mail.ru

Abstract

Introduction Surgical methods for osteoporotic burst vertebral body fracture repair have their advantages and shortcomings. The use of circumferential stabilization and corrective vertebrotomies in elderly patients is highly invasive and carries great surgical risk. On the other hand, minimally invasive methods lead to recurrence of the deformity. Thus, in the treatment of patients with such pathology, it is necessary to choose a surgical method that allows achieving optimal results.

Purpose of the work was to compare the results of surgical treatment for osteoporotic burst fractures in thoracolumbar vertebral bodies using the developed method and methods of circular and hybrid stabilization based on clinical and radiological criteria.

Materials and methods The study was retrospective. Three groups of patients were formed according to the type of surgical intervention. Inclusion criteria were patients with primary osteoporosis who did not receive osteotropic therapy before surgery, with osteoporotic fractures (type OF3 and OF4) of the vertebral bodies of the thoracolumbar location (Th10–L2). The follow-up period was 12 months. The following criteria were assessed: the amount of kyphosis correction (according to the Cobb method), the amount of residual postoperative kyphotic deformity, as well as its recurrence in the long-term postoperative period; sagittal balance of the torso (Barrey index), subjective evaluation of the patient's condition (VAS). Quality of life assessment was not performed.

Results There were no statistically significant differences in the dynamics of sagittal balance during the follow-up period between the groups ($p > 0.99$). There was no difference between groups in clinical outcomes (VAS) at follow-up ($p > 0.05$). A statistically significant difference in the magnitude of kyphotic deformity and its correction in the specified postoperative periods was revealed between the hybrid fixation groups and the corrective vertebrotomy group. No difference was found with the circular stabilization group.

Discussion Due to the high risks of poor outcomes of anterior spinal fusion, in particular, implant subsidence, to avoid anterior spinal fusion, we used a method of focal kyphosis correction and posterior spinal fusion with autologous bone. The method proposed by the authors for the correction of focal kyphotic deformity in the treatment of patients with osteoporotic burst fractures of the vertebral bodies combines satisfactory correction of focal kyphosis with minimal surgical invasiveness, which reduces the risks of complications and poor outcomes. The proposed method may also be combined with hybrid fixation.

Conclusion The developed method for focal kyphotic deformity correction in the treatment of osteoporotic burst fractures of vertebral bodies provides satisfactory correction of focal kyphosis, reduces the risks of complications and poor outcomes in comparison with circular and hybrid stabilization.

Keywords: burst fracture, osteoporosis, hybrid stabilization, circular stabilization, vertebrotomy, kyphosis, sagittal balance

For citation: Sinyavin VD, Rerikh VV. Comparative analysis of surgical treatment results for osteoporotic burst fractures of thoracolumbar vertebral bodies. *Genij Ortopedii*. 2024;30(4):542-551. doi: 10.18019/1028-4427-2024-30-4-542-551

© Sinyavin V.D., Rerikh V.V., 2024
© Translator Tatyana A. Malkova, 2024

INTRODUCTION

In the contemporary world, the incidence of osteoporotic vertebral compression fractures has increased, and along with this, the number of patients seeking treatment for acute and chronic pain and progressive spinal deformities has grown [1]. In more than 60 % of cases, the outcome of these injuries is severe painful kyphotic deformities resulting from the pseudarthrosis of the damaged vertebral body [2, 3]. Therefore, spinal surgeons face the task of selecting rational methods of surgical intervention to avoid further compression of the damaged vertebra, achieve correction of focal kyphosis, create conditions for stabilization and consolidation of the fracture, and also prevent neurological disorders. The methods of circular stabilization using anterior spinal fusion in elderly patients with concomitant co-morbidities are highly invasive and carry a greater surgical risk [4, 5, 6, 7]. Minimally invasive methods of posterior stabilization in combination with vertebroplasty of the damaged vertebral body, as an alternative to circular fixation [8, 9], may lead to poor outcomes, such as loss of correction and relapse of pain syndrome [10], which was confirmed in our previous study [11]. In specific and complex cases associated with severe kyphosis (more than 30°) and/or sagittal imbalance, vertebral osteotomies are recommended [12, 13]. Those methods have a high ability to correct the deformity, but are technically complex and have a high risk of complications, which is especially important for patients in the older age group.

The purpose of the work was to compare the results of surgical treatment for osteoporotic burst fractures in thoracolumbar vertebral bodies using the developed method and methods of circular and hybrid stabilization based on clinical and radiological criteria.

MATERIALS AND METHODS

The study included 52 patients. All were admitted to the clinic as emergency cases. Based on clinical and radiographic findings, and MSCT data, vertebral body fractures due to osteoporosis were detected in the thoracolumbar spine. Among the patients there were 40 women (77.7 %) and 12 men (22.3 %). The average age was 64.36 ± 6.74 years. The main causes of osteoporotic fractures were low-energy trauma (falls from body height onto the back or buttocks) in 68.4 % of cases and physical activity (bending work, lifting weights) in 31.6 %.

By simple randomization, all patients were divided into three groups. Group 1 (n = 17) underwent posterior stabilization in combination with cement plasty or osteoplasty of the injured vertebral body (hybrid fixation). Group 2 (n = 18) underwent posterior stabilization combined with anterior spinal fusion (circular stabilization). Groups 1 and 2 were control groups. Patients in group 3 (n = 17, study group) underwent extended posterior fixation in combination with corrective vertebrotomy (authors' method).

A comparative analysis was carried out using a number of radiological and clinical criteria.

Correction of focal kyphotic deformity (RF patent for invention No. 2810182) was performed as follows. At the preoperative stage (Fig. 1 a), the angle of kyphotic deformity was measured according to Cobb. Next, the amount of resection of the articular pairs of vertebrae at the level of injury was determined.

To do this, at the damaged level on both sides, a resection angle was drawn, which corresponds to the angle of kyphotic deformity (Fig. 1 b):

— on one side of the articular pairs of vertebrae, the apex of the angle was determined, which is the caudo-dorsal point of the body of the overlying vertebra from the damaged one;

— the next point was located on the lateral part of the lower articular process of the overlying vertebra from the damaged one;

— the end point of the angle was determined by the lateral surface of the lower edge of the superior articular process of the damaged vertebra.

Next, the points were projected onto the opposite side of the articular pairs of vertebrae (the points marked on the articular processes form the base of the resection angle). The height of the base of the angle of the wedge-shaped defect was measured in order to subsequently perform resection equal to the height of the base.

During the operation, transpedicular screws were first installed in accordance with anatomical landmarks under X-ray control, at least into two segments above and below the apex of the focal deformity. Then, according to preoperative planning, an osteotomy was performed to the full transverse size of the articular processes on both sides, while the lower articular processes of the overlying vertebra and the upper articular processes of the damaged vertebra were removed in the plane to the apex of the resection angle in the anterior and upward direction, thereby forming a wedge-shaped defect (Fig. 1 c). Resection of the articular pairs on the other side was performed in a similar manner. Next, by postural extension, the lower articular process of the overlying vertebra was joined with the upper articular process of the damaged vertebra, thereby achieving correction of the kyphotic deformity, and the angle became equal to 0° according to Cobb (Fig. 1 d, e). Finally, the rods of the transpedicular structure were installed and fixed in the screw heads and the final implantation of the structure was carried out; if necessary, additional contraction was performed to improve the contact of the bone surfaces of adjacent vertebrae in the resection area. The position of the spinal roots was revised. The bone graft obtained during resection was placed along the posterior surface, overlapping the resection line.

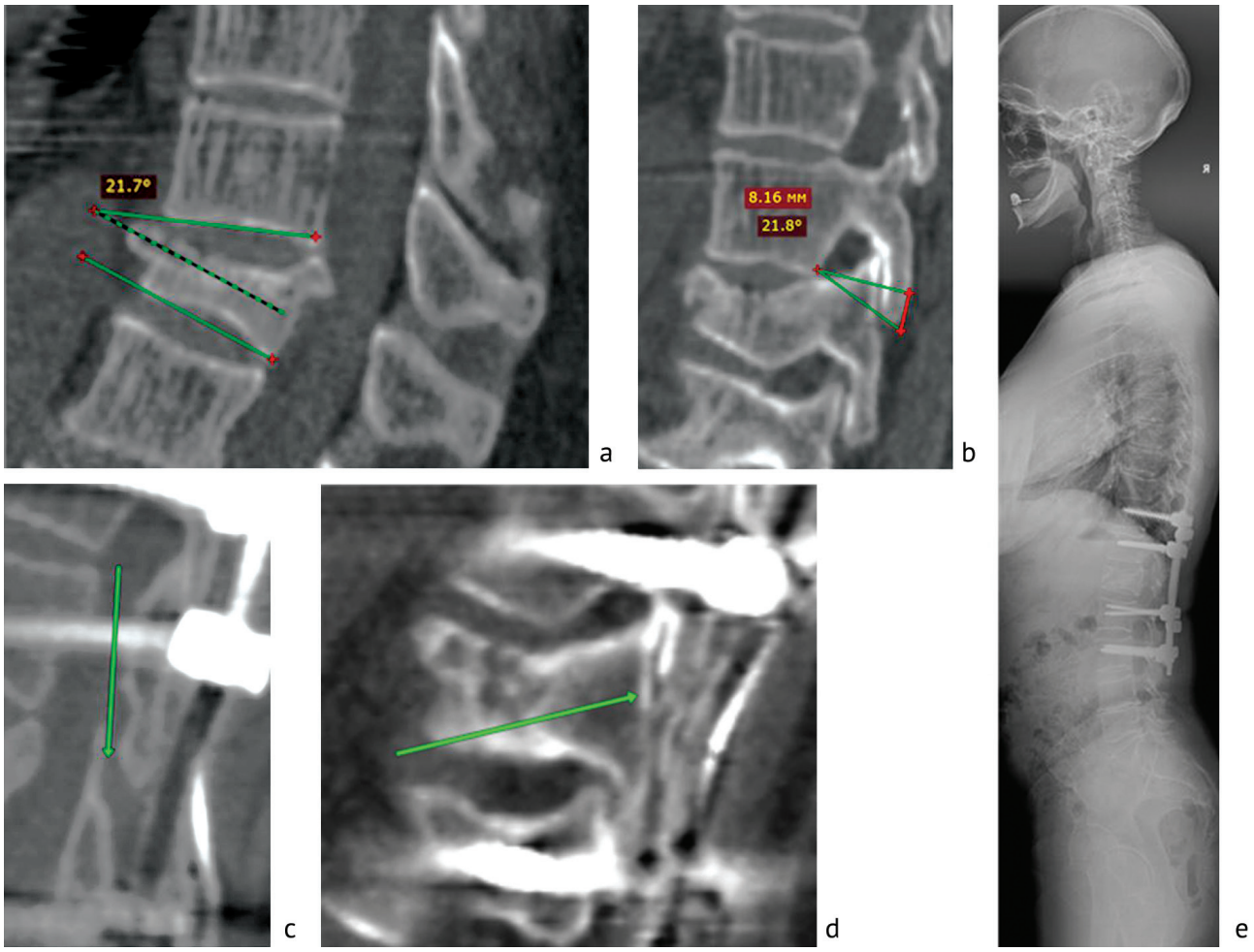

Fig. 1 Stages of the method for correcting focal kyphotic deformity: *a* measuring the angle of kyphotic deformity; *b* calculation of the resection angle; *c* resection zone; *d, e* closure of the defect, correction of kyphotic deformity

Inclusion criteria were primarily diagnosed uncomplicated vertebral body fractures due to osteoporosis in the thoracolumbar spine (Th10–L2); complete and incomplete pathological burst fractures (type OF3 and OF4 according to DGOU) [14]; T-criterion according to densitometry data from –2.5 and lower; lack of osteotropic therapy before surgery; postoperative follow-up of at least 12 months; the initial kyphotic deformity from 20° and more.

Exclusion criteria were complicated spinal injuries (with neurological deficit); presence of secondary osteoporosis.

The following criteria were assessed: the amount of kyphosis correction (according to the Cobb method), the amount of residual postoperative kyphotic deformity. The correction was considered incomplete if its value was > 5°. Recurrence of deformity was assessed after 12 months. The deformity was considered recurrent if it increased by more than 5° throughout the entire postoperative follow-up (the error in the accuracy of radiological measurements of intersegmental relationships is 5°). The sagittal profile was assessed before, immediately after surgery and 12 months after surgery, the Barrey index C7/SFD parameter (–0.9 ± 1) was considered. Sagittal balance was divided as follows: balanced (C7/SFD close to 0); compensated imbalance (0.5 < C7/SFD < 1); decompensated imbalance (C7/SFD > 1) [15]. Subjective assessment of the patient's condition was assessed using the VAS pain score. Quality of life assessment was not evaluated. The average time from injury to surgery was 15 ± 7 days. The duration of operations and blood loss were assessed according to medical documentation. Osteotropic therapy was recommended to all patients after surgery, but its effectiveness in the postoperative period was not assessed in this study.

Statistical methods Continuous data on age, hospital days, rotation center shifts, and VAS and Harris scores were tested for normal distribution using the Kolmogorov method. Due to the small number of normal data, comparisons were made using nonparametric methods.

To describe continuous indicators, medians [first quartile; third quartile] (MED [Q1; Q3]), and as auxiliary — mean ± standard deviation (MEAN ± SD) and minimum – maximum values were used. For categorical and binary indicators, the number of patients (frequency) for each category was determined; for the frequencies of binary indicators of magnitude and kyphosis correction, the error of the 95 % confidence interval (95 % CI) was calculated. Comparisons of continuous measures between groups were performed using the Mann – Whitney U test. To assess the average difference between distributions (effect size), the median of pairwise differences between groups (pMED) was calculated with the construction of 95 % CI and the standardized mean difference (SMD). Categorical measures were compared using two-tailed Fisher's exact test. Statistical hypotheses were tested at a critical significance level of p = 0.05, i.e. the difference was considered significant if $p < 0.05$. Statistical calculations were carried out in R version 4.1.3 2022-03-10 (Vienna, Austria).

RESULTS

The initial kyphotic deformity in the first group was 22.06 ± 1.92° (20–27°), 27.17 ± 5.36° (20–35°) in the second group and in the third it measured 25.94 ± 5, 24° (20–35°). The average T-criterion value according to densitometry in all groups was 3.18 ± 0.59. There were no differences in the sagittal profile (balanced / compensated / decompensated) before surgery between the groups: in groups 1 and 3 $p = 0.16$, in groups 2 and 3 $p = 0.302$. Within the groups, there was a difference in the dynamics of kyphosis; in group 1 (loss of correction) $p = 0.011$ (Table 1, Fig. 2). A statistically significant difference in the magnitude of kyphotic deformity and its correction in the specified periods of the postoperative observation was revealed between groups 1 and 3 (Table 1); comparing groups 2 and 3, no difference was found (Table 1, Fig. 3). There was no statistically significant difference in the dynamics of sagittal balance at the control point of observation between groups 1 and 3, 2 and 3 ($p > 0.99$) (Fig. 4). There was no difference between groups in clinical outcomes (VAS) at the follow-up ($p > 0.05$) (Fig. 5).

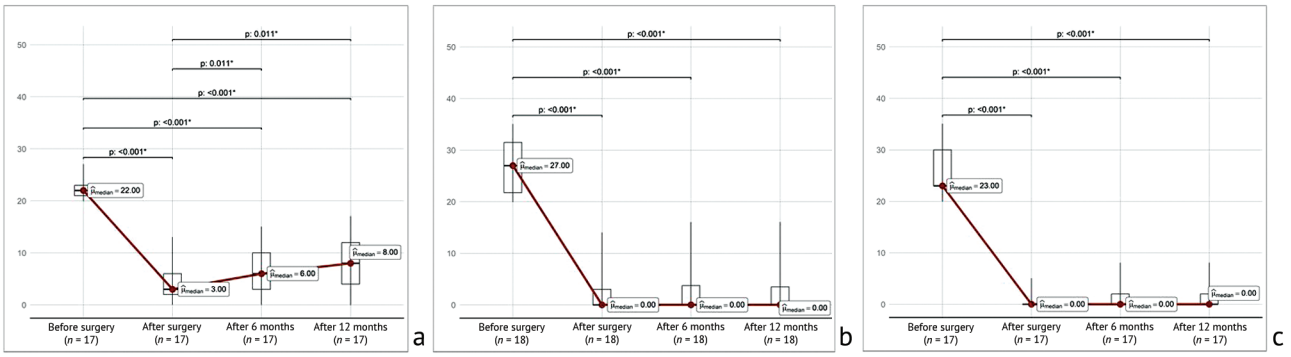

Fig. 2 Dynamics of kyphosis values within groups: *a* — group 1; *b* — group 2; *c* — group 3

Table 1

Comparison of correction values and dynamics of focal kyphosis between groups

Parameter	Group 1 (*n* = 17)	Group 2 (*n* = 18)	Group 3 (*n* = 17)	Comparison	
				Difference	*p*–level
Kyphosis before surgery, MED [Q1; Q3] MEAN ± SD (MIN – MAX)	22 [21; 23] 22.06 ± 1.92 (20 – 27)	27 [21.75; 31.5] 27.17 ± 5.36 (20 – 35)	23 [23; 30] 25.94 ± 5.24 (20 – 35)	пМЕД [95 % ДИ]: 2 [1; 8] СО [95 % ДИ]: –0.98 [–1.7; –0.27]* пМЕД [95 % ДИ]: –1 [–6; 3] СО [95 % ДИ]: 0.23 [–0.43; 0.9]**	0.012*. 0.584**
Kyphosis after surgery, MED [Q1; Q3] MEAN ± SD (MIN – MAX)	3 [2; 6] 4.24 ± 3.51 (0 – 13)	0 [0; 3] 2.5 ± 4.02 (0 – 14)	0 [0; 0] 0.47 ± 1.37 (0 – 5)	пМЕД [95 % ДИ]: –3 [–6; –2] СО [95 % ДИ]: 1.41 [0.66; 2.17]* пМЕД [95 % ДИ]: 0 [–2; 0] СО [95 % ДИ]: 0.67 [–0.01; 1.35]**	< 0.001*. 0.040**
Kyphosis at 6 months post-surgery, MED [Q1; Q3] MEAN ± SD (MIN – MAX)	6 [3; 10] 7.06 ± 4.64 (0 – 15)	0 [0; 3.75] 3.11 ± 4.97 (0 – 16)	0 [0; 2] 1.24 ± 2.28 (0 – 8)	пМЕД [95 % ДИ]: –6 [–9; –3] СО [95 % ДИ]: 1.59 [0.82; 2.37]* пМЕД [95 % ДИ]: 0 [–2; 0] СО [95 % ДИ]: 0.48 [–0.19; 1.15]**	< 0.001*. 0.304**
Kyphosis at 12 months post-surgery, MED [Q1; Q3] MEAN ± SD (MIN – MAX)	8 [4; 12] 7.71 ± 5.27 (0 – 17)	0 [0; 3.5] 3.11 ± 5.06 (0 – 16)	0 [0; 2] 1.29 ± 2.37 (0 – 8)	пМЕД [95 % ДИ]: –6 [–9; –3] СО [95 % ДИ]: 1.57 [0.8; 2.35]* пМЕД [95 % ДИ]: 0 [–2; 0] СО [95 % ДИ]: 0.46 [–0.22; 1.13]**	< 0.001*. 0.331**

Note: * — comparison of groups 1 and 3 (hybrid fixation and corrective vertebrotomy); ** — comparison of groups 2 and 3 (circular fixation and corrective vertebrotomy)

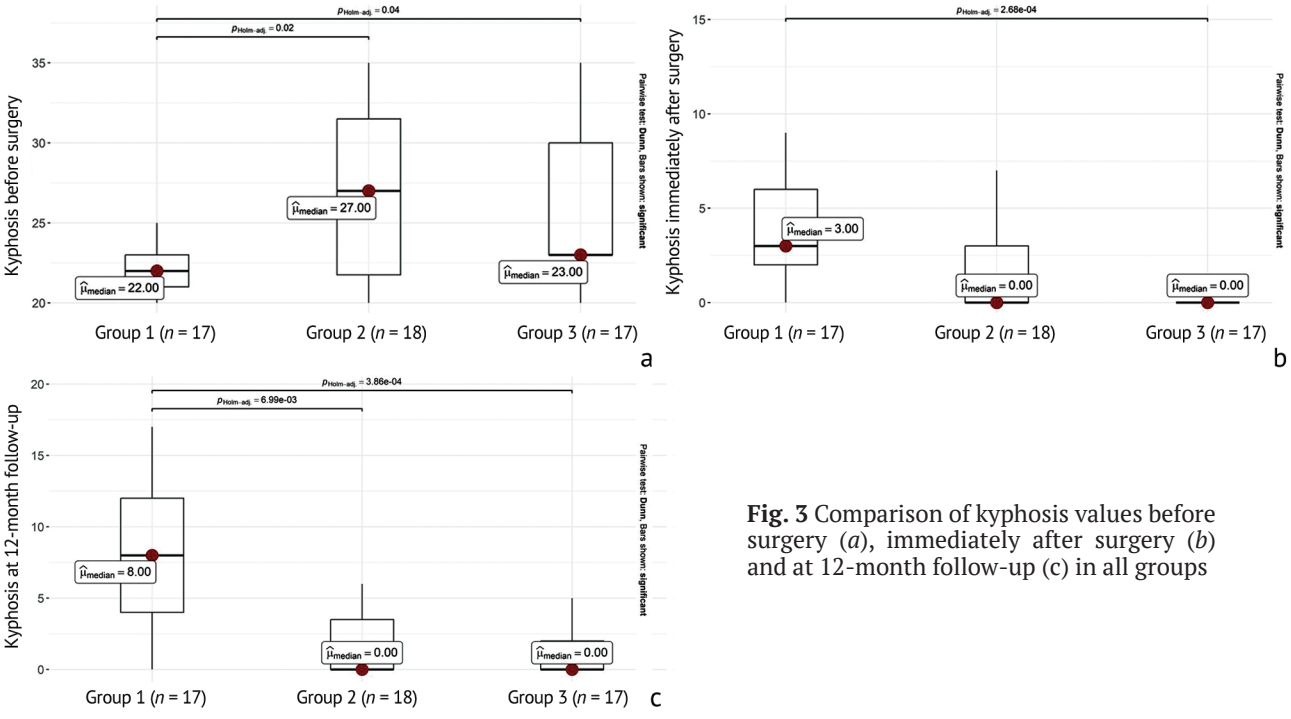

Fig. 3 Comparison of kyphosis values before surgery (*a*), immediately after surgery (*b*) and at 12-month follow-up (c) in all groups

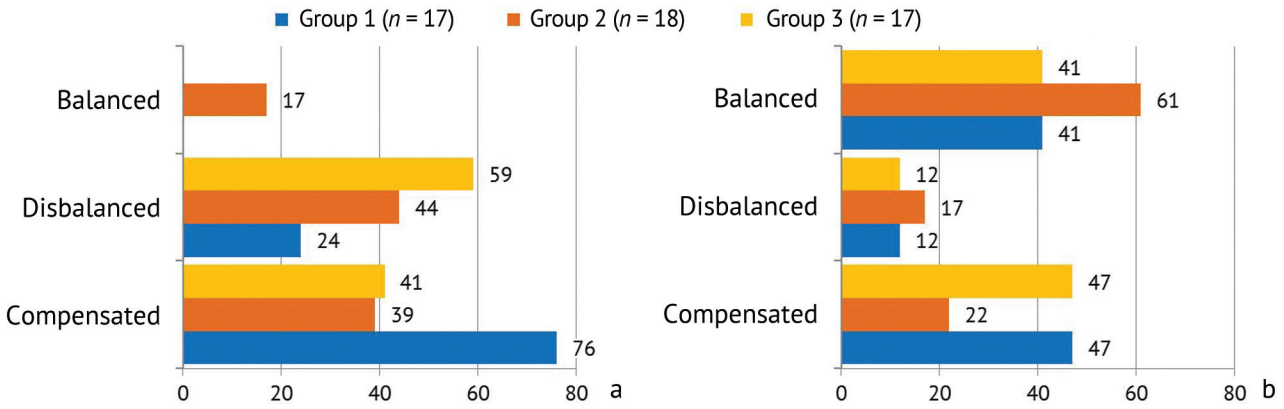

Fig. 4 Dynamics of the sagittal profile before surgery (*a*) and after surgery (*b*) in all groups

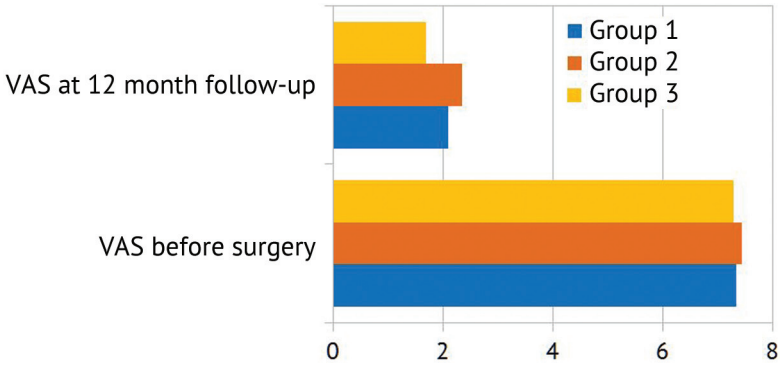

Fig 5 Comparison of VAS score between the groups

There were no complications in groups 1 and 3. In group 2, the early postoperative period in 2 patients (11.1 %) was complicated by brachioplexopathy, and hospital-acquired pneumonia was detected in 1 patient (5.5 %). The average blood loss in group 1 was 233.6 ml, in group 2 — 531.3 ml, in group 3 — 329.2 ml. The average time of surgical intervention in group 1 was 96.6 minutes, in group 2 — 262.3 minutes; in group 3 — 153.5 min.

DISCUSSION

The classification of spinal osteotomies proposed by Schwab et al. [16], as well as the features and principles of surgical methods of their use for vertebral injuries due to osteoporosis remain the same. There is a Smith-Peterson vertebrotomy method [17, 18], which involves resection of at least three spinous processes, separation of the ligamentum flavum, and cutting of the articular surfaces of both pairs of articular processes in the frontal plane. The method involves using the dorsal parts of the vertebral body (middle column) as a rotation point while correcting the deformity through a blocked intervertebral disc. The result is lengthening of the anterior and shortening of the posterior columns of the spine. In this case, the anterior longitudinal ligament ruptures and the vertebral bodies diverge with the formation of some space between them. The manipulation is accompanied by a high risk of damage to large vessels. Another shortcoming of this method is incomplete bone defect closure, which does not ensure consolidation and fusion of the fracture and, as a result, the spine remains unstable. This method is characterized by a low degree of deformity correction (about 10°) and high trauma, which leads to a long postoperative period and a high risk of infection [19]. Along with this, there is a Ponte method of corrective vertebrotomy [20, 21], which is performed in the thoracic spine (levels 11–13): the spinous and articular processes are completely removed, a wide resection of the semi-arches is performed, the ligamentum flavum is completely

removed, and the roots of the arches are resected. The shortcoming of this method is the limitation on its use (only the thoracic spine). High morbidity during its implementation and resection of a large volume of bone structures accompanied by significant blood loss increase the duration of postoperative care and the risk of infection. The spine remains in an unstable position due to resection of the articular processes that is performed in the anteroposterior direction until complete excision.

A number of studies assessed the clinical and radiological results, complications and outcomes of subtraction osteotomy (PSO), including the authors' modifications [22, 23, 24]. In each of them, satisfactory restoration of focal kyphosis and sagittal balance was noted. However, the authors place special emphasis on patients with neurological deficits secondary to trauma, for which decompression of neural structures is important. Therefore, due to the high morbidity, this surgical technique in patients with uncomplicated pathology is not needed [25, 26, 27].

Some researchers also tried to correct the sagittal imbalance using VCR for severe kyphosis. The results of a two-center retrospective study including 17 patients showed significant improvement in segmental kyphosis and regression of pain [28]. In a five-year study of 109 patients, Pehlivanoglu et al. [29] suggested that VCR combined with telescopic cage implantation is a safe and effective procedure that significantly improves clinical outcomes through decompression and reconstruction of the resected vertebra. The telescopic cage provides stabilization of the ventral column, minimizing the load on the posterior structure [30]. In their retrospective study, Sehmisch et al. [31] used the VCR technique on the thoracic spine in patients with osteoporotic fractures and post-traumatic kyphosis of more than 45°. The follow-up period was 36 months. All patients showed correction of kyphotic deformity by 20 ± 10° and a decrease in pain from 8.6 ± 2.0 VAS points to 5.0 ± 1.4. The average kyphosis was 25 ± 14° (5–53°). Bone fusion was achieved within 6 months. Preoperative Oswestry Disability Index (ODI) analysis showed severe disorders in two patients (41–60 %), five patients had very severe functional disorders (61–80 %) and three patients had complete functional failure (81–100 %). After surgery, six patients reported severe impairment (41–60 %), three reported very severe impairment, and one patient reported complete functional failure.

The work of Xu et al. [32] presented a retrospective study involving 238 patients with chronic osteoporotic fractures, 48 of whom had severe kyphotic deformity. Postoperative follow-up in all groups was carried out up to 38 months. According to VAS assessment, the pain syndrome in all patients decreased to 2 points (2.12 ± 0.74), the disability index dropped from 70 (70.18 ± 2.24) to 40 (40.09 ± 2.24). Depending on the level of kyphosis and neurological deficit, Ponte, SPO, PSO, VCR operations were performed. Using all methods, the authors achieved satisfactory results, which correspond to the results of the work of other researchers [33, 34, 35, 36]. However, VCR requires a higher level of surgical skills and longer training for surgeons [37]. Tomita et al. [38] reported that shortening of the posterior column can be divided into three intervals: shortening of the spine to 1/3 of the segment is safe, characterized by the absence of deformity of the dural sac or spinal cord; shortening of the spine from 1/3 to 2/3 of the segment is relatively safe, characterized by corrugation of the dural sac without spinal cord deformity; a dangerous variant involves shortening a spinal segment by more than 2/3 of a segment, which causes deformity of the dural sac and spinal cord with neurological impairment. Despite the high degree of deformity correction, three-column vertebrotomies are accompanied by a long surgical session, much blood loss and big volume of bone tissue resection, as well as the risk of iatrogenic neurological [39] and mechanical complications [40, 41].

The advantages of our method compared to existing versions of spinal osteotomies are that the method has no restrictions on its use and can be performed on any part of the spine. The method is low-traumatic, since a small volume of bone structures is resected with minimal blood loss, which reduces the duration of the early postoperative period and reduces the risk of infection, the spine remains in a stable position. The method ensures planned correction of focal kyphosis in the sagittal plane, minimal volume of bone tissue resection, tight contact of resected areas of adjacent vertebrae in the position of the achieved correction and posterior bone fusion.

Our method of correction of focal kyphotic deformity presented in the study was compared with circular stabilization and there was no statistically significant difference in the amount of deformity correction between the groups. There was a significant difference with the hybrid stabilization group both in the correction of deformity and in the magnitude of kyphosis after surgical treatment and during the specified periods of postoperative follow-up. The results were also assessed within groups. It is noteworthy that the average loss of correction in the hybrid fixation group was 7.7°, which coincides with the results of the authors of this method [42]. In the study group, loss of correction was detected in three patients (13.6 %). In the first case, the initial deformity was 35°, and the residual one was 11°, which indicates the limited corrective capabilities of our method. However, it is worth noting that kyphosis of this magnitude in acute burst fractures is rare and develops mainly into rigid deformities in osteonecrosis of the vertebrae. Two patients had decompensated imbalance both before and after surgery, what again confirms the need for correction of the sagittal profile [43–47].

CONCLUSION

Our method for correcting focal kyphotic spinal deformity in osteoporotic burst fractures of the vertebral bodies, in comparison with circular and hybrid stabilization, demonstrates satisfactory correction of focal kyphosis, with minimal surgical invasiveness, which reduces the risks of complications and poor outcomes. The technique can also be combined with hybrid fixation, but it requires future studies.

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

Funding *Funding for the research was carried out as part of the research work of the state task "Development and improvement of methods and designs for correction of post-traumatic deformities in ankylosing diseases of the spine", registration number 121051100278-4.*

Ethical statement *Based on the results of the conclusion of the Local Ethics Committee (extract from the minutes of the meeting 001/24 of January 15, 2024), this study can be published in the open press and does not contain classified information.*

Informed consent *Not required.*

REFERENCES

1. Abdelgawaad AS, Ezzati A, Govindasamy R, et al. Kyphoplasty for osteoporotic vertebral fractures with posterior wall injury. *Spine J*. 2018;18(7):1143-1148. doi: 10.1016/j.spinee.2017.11.001
2. Formica M, Zanirato A, Cavagnaro L, et al. What is the Current Evidence on Vertebral Body Osteonecrosis?: A Systematic Review of the Literature. *Asian Spine J*. 2018;12(3):586-599. doi: 10.4184/asj.2018.12.3.586
3. Katsuura Y, Osborn JM, Cason GW. The epidemiology of thoracolumbar trauma: A meta-analysis. *J Orthop*. 2016;13(4):383-388. doi: 10.1016/j.jor.2016.06.019
4. Matsuyama Y, Goto M, Yoshihara H, et al. Vertebral reconstruction with biodegradable calcium phosphate cement in the treatment of osteoporotic vertebral compression fracture using instrumentation. *J Spinal Disord Tech*. 2004;17(4):291-296. doi: 10.1097/01.bsd.0000097253.54459.a6
5. Korovessis P, Hadjipavlou A, Repantis T. Minimal invasive short posterior instrumentation plus balloon kyphoplasty with calcium phosphate for burst and severe compression lumbar fractures. *Spine* (Phila Pa 1976). 2008;33(6):658-667. doi: 10.1097/BRS.0b013e318166e0bb
6. Kanayama M, Ishida T, Hashimoto T, et al. Role of major spine surgery using Kaneda anterior instrumentation for osteoporotic vertebral collapse. *J Spinal Disord Tech*. 2010;23(1):53-56. doi: 10.1097/BSD.0b013e318193e3a5

7. Sudo H, Ito M, Kaneda K, et al. Anterior decompression and strut graft versus posterior decompression and pedicle screw fixation with vertebroplasty for osteoporotic thoracolumbar vertebral collapse with neurologic deficits. *Spine J*. 2013;13(12):1726-1732. doi: 10.1016/j.spinee.2013.05.041
8. Josten C, Heyde CE, Spiegl UJ. Complex Pathologies of the Spine: Trauma meets Degeneration. *Z Orthop Unfall*. 2016;154(5):440-448. (In German) doi: 10.1055/s-0042-108344
9. Spiegl UJ, Josten C, Devitt BM, Heyde CE. Incomplete burst fractures of the thoracolumbar spine: a review of literature. *Eur Spine J*. 2017;26(12):3187-3198. doi: 10.1007/s00586-017-5126-3
10. Schnake KJ, Scheyerer MJ, Spiegl UJA, et al. Minimally invasive stabilization of thoracolumbar osteoporotic fractures. *Unfallchirurg*. 2020;123(10):764-773. (In German) doi: 10.1007/s00113-020-00835-1
11. Rerikh VV, Sinyavin VD. Comparative radiological analysis of hybrid and circular stabilization methods for the treatment of osteoporotic vertebral burst fractures. *Russian Journal of Spine Surgery*. 2023;20(3):26-33. doi: 10.14531/ss2023.3.26-33
12. Li J, Xu L, Liu Y, et al. Open Surgical Treatments of Osteoporotic Vertebral Compression Fractures. *Orthop Surg*. 2023;15(11):2743-2748. doi: 10.1111/os.13822
13. Jo DJ, Kim YS, Kim SM, et al. Clinical and radiological outcomes of modified posterior closing wedge osteotomy for the treatment of posttraumatic thoracolumbar kyphosis. *J Neurosurg Spine*. 2015;23(4):510-517. doi: 10.3171/2015.1.SPINE131011
14. Schnake KJ, Blattert TR, Hahn P, et al. Classification of Osteoporotic Thoracolumbar Spine Fractures: Recommendations of the Spine Section of the German Society for Orthopaedics and Trauma (DGOU). *Global Spine J*. 2018;8(2 Suppl):46S-49S. doi: 10.1177/2192568217717972
15. Le Huec JC, Thompson W, Mohsinaly Y, et al. Sagittal balance of the spine. *Eur Spine J*. 2019;28(9):1889-1905. doi: 10.1007/s00586-019-06083-1
16. Schwab F, Blondel B, Chay E, et al. The comprehensive anatomical spinal osteotomy classification. *Neurosurgery*. 2014;74(1):112-120; discussion 120. doi: 10.1227/NEU.0000000000000182o
17. Smith-Petersen MN, Larson CB, Aufranc OE. Osteotomy of the spine for correction of flexion deformity in rheumatoid arthritis. *Clin Orthop Relat Res*. 1969;66:6-9.
18. Dorward IG, Lenke LG. Osteotomies in the posterior-only treatment of complex adult spinal deformity: a comparative review. *Neurosurg Focus*. 2010;28(3):E4. doi: 10.3171/2009.12.FOCUS09259
19. Zhang D, Zhang W, Zhou X, et al. Treatment of chronic thoracolumbar osteoporotic fractures combined with kyphosis with cement-injectable cannulated pedicle screw and multiple level Schwab grade I osteotomy. *Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi*. 2020;34(12):1533-1538. (In Chin.) doi: 10.7507/1002-1892.202006129
20. Ponte A. What is a true Ponte osteotomy? In: *Half-day Courses*. *48th Annual Meeting & Course*. Lion, France; 2013:63-65.
21. Gill JB, Levin A, Burd T, Longley M. Corrective osteotomies in spine surgery. *J Bone Joint Surg Am*. 2008;90(11):2509-2520. doi: 10.2106/JBJS.H.00081
22. Plais N, Mengis C, Gallego Bustos JM, et al. Simplified Pedicle Subtraction Osteotomy for Osteoporotic Vertebral Fractures. *Int J Spine Surg*. 2021;15(5):1004-1013. doi: 10.14444/8129
23. Kim SK, Chung JY, Park YJ, et al. Modified Pedicle Subtraction Osteotomy for Osteoporotic Vertebral Compression Fractures. *Orthop Surg*. 2020;12(2):388-395. doi: 10.1111/os.12589
24. Takenaka S, Mukai Y, Hosono N, Fuji T. Major surgical treatment of osteoporotic vertebral fractures in the elderly: a comparison of anterior spinal fusion, anterior-posterior combined surgery and posterior closing wedge osteotomy. *Asian Spine J*. 2014;8(3):322-330. doi: 10.4184/asj.2014.8.3.322
25. Kobayashi K, Imagama S, Sato K, et al. Postoperative Complications Associated With Spine Surgery in Patients Older Than 90 Years: A Multicenter Retrospective Study. *Global Spine J*. 2018;8(8):887-891. doi: 10.1177/2192568218767430
26. Imagama S, Kawakami N, Tsuji T, et al. Perioperative complications and adverse events after lumbar spinal surgery: evaluation of 1012 operations at a single center. *J Orthop Sci*. 2011;16(5):510-515. doi: 10.1007/s00776-011-0123-6
27. Carreon LY, Puno RM, Dimar JR 2nd, et al. Perioperative complications of posterior lumbar decompression and arthrodesis in older adults. *J Bone Joint Surg Am*. 2003;85(11):2089-2092. doi: 10.2106/00004623-200311000-00004
28. Koepke LG, Weiser L, Stangenberg M, et al. Outcome after Posterior Vertebral Column Resection in Patients with Severe Osteoporotic Fractures-A Retrospective Analysis from Two Centers. *Medicina* (Kaunas). 2022;58(2):277. doi: 10.3390/medicina58020277
29. Pehlivanoglu T, Erdag Y, Oltulu I, et al. Unilateral Posterior Surgery for Severe Osteoporotic Vertebrae Fractures' Sequelae in Geriatric Population: Minimum 5-Year Results of 109 Patients. *Neurospine*. 2021;18(2):319-327. doi: 10.14245/ns.2040812.406
30. Wei H, Dong C, Zhu Y. Posterior Fixation Combined with Vertebroplasty or Vertebral Column Resection for the Treatment of Osteoporotic Vertebral Compression Fractures with Intravertebral Cleft Complicated by Neurological Deficits. *Biomed Res Int*. 2019;2019:4126818. doi: 10.1155/2019/4126818
31. Sehmisch S, Lehmann W, Dreimann M, et al. Posterior vertebral column resection for correction of kyphotic deformity due to osteoporotic fractures of the thoracic spine. *Oper Orthop Traumatol*. 2019;31(4):311-320. (In German) doi: 10.1007/s00064-019-0616-6
32. Xu Z, Hao D, Dong L, et al. Surgical options for symptomatic old osteoporotic vertebral compression fractures: a retrospective study of 238 cases. *BMC Surg*. 2021;21(1):22. doi: 10.1186/s12893-020-01013-1
33. Zhang Y, Zhao Q, Qin X, et al. SRS-Schwab grade IV osteotomy combined with satellite rod for thoracolumbar old osteoporotic fracture with severe kyphosi. *Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi*. 2019;33(3):259-264. (In Chin.) doi: 10.7507/1002-1892.201808022
34. Zhou J, Ma Y, Wang F, et al. Pedicle subtraction osteotomy assisted with anterior column reconstruction for treatment of chronic osteoporotic vertebral compression fracture. *Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi*. 2016 M;30(5):575-579. (In Chin.) doi: 10.7507/1002-1892.20160116
35. Chen JL, Xu Y, Wan L, Yao GX. Surgical choice of posterior osteotomy way for senile osteoporotic thoracolumbar fracture with kyphosis. *Zhongguo Gu Shang*. 2020;33(2):121-126. (In Chin.) doi: 10.12200/j.issn.1003-0034.2020.02.006

36. Li S, Li Z, Hua W, et al. Clinical outcome and surgical strategies for late post-traumatic kyphosis after failed thoracolumbar fracture operation: Case report and literature review. *Medicine* (Baltimore). 2017;96(49):e8770. doi: 10.1097/MD.0000000000008770
37. Cho Y. Corpectomy and circumferential fusion for advanced thoracolumbar Kümmell's disease. *Musculoskelet Surg*. 2017;101(3):269-274. doi: 10.1007/s12306-017-0480-1
38. Tomita K, Kawahara N, Murakami H, Demura S. Total en bloc spondylectomy for spinal tumors: improvement of the technique and its associated basic background. *J Orthop Sci*. 2006;11(1):3-12. doi: 10.1007/s00776-005-0964-y
39. Watanabe K, Katsumi K, Ohashi M, et al. Surgical outcomes of spinal fusion for osteoporotic vertebral fracture in the thoracolumbar spine: Comprehensive evaluations of 5 typical surgical fusion techniques. *J Orthop Sci*. 2019;24(6):1020-1026. doi: 10.1016/j.jos.2019.07.018
40. Hyun SJ, Rhim SC. Clinical outcomes and complications after pedicle subtraction osteotomy for fixed sagittal imbalance patients : a long-term follow-up data. *J Korean Neurosurg Soc*. 2010;47(2):95-101. doi: 10.3340/jkns.2010.47.2.95
41. Barrey C, Perrin G, Michel F, et al. Pedicle subtraction osteotomy in the lumbar spine: indications, technical aspects, results and complications. *Eur J Orthop Surg Traumatol*. 2014;24 Suppl 1:21-30. doi: 10.1007/s00590-014-1470-8
42. Spiegl UJ, Ahrberg AB, Anemüller C, et al. Which anatomic structures are responsible for the reduction loss after hybrid stabilization of osteoporotic fractures of the thoracolumbar spine? *BMC Musculoskelet Disord*. 2020;21(1):54. doi: 10.1186/s12891-020-3065-3
43. Rerikh VV, Borzykh KO, Samokhin AG. Correlations of functional capacity and parameters of sagittal balance in patients with posttraumatic deformities of the spine. *Modern problems of science and education. Surgery*. 2017;(6). (In Russ.) URL: https://s.science-education.ru/pdf/2017/6/27046.pdf.
44. Hu Z, Man GCW, Kwok AKL, et al. Global sagittal alignment in elderly patients with osteoporosis and its relationship with severity of vertebral fracture and quality of life. *Arch Osteoporos*. 2018;13(1):95. doi: 10.1007/s11657-018-0512-y
45. Niu J, Feng T, Huang C, et al. Characteristics of Osteoporotic Low Lumbar Vertebral Fracture and Related Lumbosacral Sagittal Imbalance. *Orthopedics*. 2021;44(1):e7-e12. doi: 10.3928/01477447-20201028-05
46. Le Huec JC, Cogniet A, Demezon H, et al. Insufficient restoration of lumbar lordosis and FBI index following pedicle subtraction osteotomy is an indicator of likely mechanical complication. *Eur Spine J*. 2015;24 Suppl 1:S112-S120. doi: 10.1007/s00586-014-3659-2
47. Fechtenbaum J, Etcheto A, Kolta S, et al. Sagittal balance of the spine in patients with osteoporotic vertebral fractures. *Osteoporos Int*. 2016;27(2):559-567. doi: 10.1007/s00198-015-3283-y

The article was submitted 25.01.2024; approved after reviewing 25.01.2024; accepted for publication 18.06.2024.

Information about the authors:

Vladimir D. Sinyavin — orthopedic traumatologist, junior researcher, Dr.VladimirSinyavin@gmail.com, https://orcid.org/0000-0001-5237-6403;

Victor V. Rerikh — Doctor of Medical Sciences, Head of the Department, Professor of the Department, rvv_nsk@mail.ru, https://orcid.org/0000-0001-8545-0024.

Original article
https://doi.org/10.18019/1028-4427-2024-30-4-552-560

Periprosthetic joint infection in patients with rheumatoid arthritis: case series

L.V. Lyubimova[1]✉, N.N. Pchelova[1], N.S. Nikolaev[1,2], E.V. Preobrazhenskaya[1], E.A. Lyubimov[1]

[1] Federal Center for Traumatology, Orthopedics and Arthroplasty, Cheboksary, Russian Federation
[2] Chuvash State University named after I.N. Ulyanov, Cheboksary, Russian Federation

Corresponding author: Lyudmila V. Lyubimova, borisova-80@mail.ru

Abstract

Introduction The differential diagnosis of periprosthetic joint infection (PJI) is challenging in patients with systemic diseases due to identical clinical and laboratory patterns and activity of the inflammatory process.

The **objective** was to evaluate the diagnostic data and results of debridement of PJI in patients with rheumatoid arthritis using a case series.

Material and methods A retrospective analysis of surgical treatment of PJI was produced in patients with rheumatoid arthritis between 2014 and 2022. PJI was verified based on ICM criteria. A poor outcome included the presence of clinical and laboratory signs of infection on admission to the second stage of treatment and recurrence after successful debridement.

Results Among the 524 cases of PJI, 35 (6.7 %) were patients with rheumatoid arthritis with 48.6 % receiving antibiotics prior to admission. Culture-negative infection was recorded in 38.4 %. PJI was not confirmed in five cases (14.3 %). High average values of inflammatory markers were registered in the blood (ESR, CRP and D-dimer) before and after debridement; decreased ESR and leukocyte count in the synovial fluid was statistically significant. Favorable outcomes were obtained in 82.9 % of cases at mid term with every fifth patient treated with a spacer or arthrodesis.

Discussion The incidence of culture-negative infection in patients with systemic diseases was reported as much as 27–37 %. A systematic review of the literature showed that the percentage of band neutrophils in synovial fluid has a sensitivity of 95.2 % and a specificity of 85.0 %, with an optimal threshold of 78 % sufficient to verify infection. The poor outcomes we identified resulted from two- or three-stage surgical treatment. Other authors reported better outcomes with two-stage debridement.

Conclusion Culture-negative infection was common in cases of PJI observed in patients with rheumatoid arthritis. Favorable outcomes were seen mostly with two-stage surgical treatment. Inflammatory markers ESR, CRP and D-dimer did not reach normal values during diagnosis and treatment of infection indicating the inapplicability of standard diagnostic criteria for PJI in patients with rheumatoid arthritis.

Keywords: periprosthetic joint infection, culture-negative infection, revision joint replacement, rheumatoid arthritis

For citation: Lyubimova LV, Pchelova NN, Nikolaev NS, Preobrazhenskaya EV, Lyubimov EA. Periprosthetic joint infection in patients with rheumatoid arthritis: case series. *Genij Ortopedii*. 2024;30(4):552-560. doi: 10.18019/1028-4427-2024-30-4-552-560

© Lyubimova L.V., Pchelova N.N., Nikolaev N.S., Preobrazhenskaya E.V., Lyubimov E.A., 2024
© Translator Irina A. Saranskikh, 2024

INTRODUCTION

Joint replacement surgery is a medical technique used to treat severe joint disorders of various localizations allowing patients to return to active lifestyle. About 24 % of the patients with rheumatoid arthritis (RA) undergo primary joint replacement within 16–20 years after verification of the diagnosis [1]. The incidence of RA among patients who undergo arthroplasty is 2–7 % [2–4]. Patients with RA are at higher risk of infectious complications, which may have atypical symptoms complicating the diagnosis and treatment of periprosthetic joint infection (PJI) [5]. Studies have shown that RA is an independent risk factor for postoperative prosthetic joint infection [6–8]. The incidence of PJI among patients with RA (3.1–4.2 %) is 1.8–4 times higher than that in patients with conditions of other etiologies [6, 8]. Immunosuppressants, often used in the treatment of RA, may increase the risk of PJI due to a decrease in the immune response [9].

The differential diagnosis of exacerbated RA and an infectious process in the prosthetic joint is another important problem for patients with systemic diseases. Standard diagnostic tests and biomarkers (ESR, CRP, synovial fluid leukocytes, leukocyte esterase or alpha-defensin) may show high values in both cases and may be misleading. In 2019, a systematic review of studies of inflammatory biomarkers in the diagnosis of PJI in patients with arthritis was performed and the authors reported low specificity despite the high sensitivity of many serum and synovial tests [10]. Some patients with systemic arthritis may experience an exacerbation of the underlying process after joint replacement procedure with no PJI. The differential diagnostic signs of PJI can be less informative in patients with RA. The cases of PJI reported in patients with inflammatory arthritis are limited to a small sample. A systematic review of the literature produced by Mirza et al. included a total of 90 cases of arthritis after arthroplasty, including PJI confirmed in 26 cases [10]. The paucity of studies on the diagnosis of PJI in patients with systemic diseases and the lack of clear differential diagnostic criteria for distinguishing between the exacerbation phase of RA and infection in the prosthetic joint aroused interest in analyzing PJI in this group of patients in a federal trauma and orthopaedic centre.

The **objective** was to evaluate the diagnostic data and results of debridement of PJI in patients with rheumatoid arthritis using a case series.

MATERIAL AND METHODS

The study is based on a continuous retrospective analysis of patients treated surgically for PJI between 2014 and 2022 using medical information system (MIS) of the Federal Center for Trauma, Orthopaedics and Joint Replacement (Center, Cheboksary). Inclusion criteria included a history of RA, surgical treatment of PJI using one-, two-, or three-stage revision arthroplasty. Informed consent for the use of anonymized electronic medical record data was obtained from all individuals included in the study. The patients were treated with intravenous antibiotics for two weeks post op, followed by oral antibiotics for 10 weeks with one-stage revision arthroplasty and for four weeks at each phase of two-stage or three-stage treatment. Primary clinical evaluation criteria included medical history, gender and age characteristics, information on the use of antibacterial drugs at the prehospital stage, location of the infected joint, clinical forms and time from verification of the diagnosis of RA to the date of primary joint replacement. Laboratory criteria included microbiological examination of synovial fluid punctate for leukocyte count, tissue samples and swabs from metal constructs after ultrasonic treatment. Monomicrobial PJI included one pathogen in the test samples, polymicrobial

PJI included two or more pathogens isolated. Culture-negative PJI was considered with the absence of pathogen growth in all biomaterial samples. Hematologic examination included blood erythrocyte sedimentation rate (ESR), serum C-reactive protein (CRP) and plasma D-dimer levels. The tests were produced at the stage of diagnosis of PJI and prior to the second stage of debridement. All cases of PJI were assessed in terms of PJI diagnosis criteria, adopted at the International Consensus Meeting on Prosthetic Joint Infection in 2018 including major and minor criteria [11] (Table 1).

Table 1

Diagnostic criteria of periprosthetic joint infection according to the Second International Consensus Meeting (ICM) on PJI (Philadelphia, USA)

<table>
<tr><td colspan="5">Major criteria (at least one of the following)</td><td>Decision</td></tr>
<tr><td colspan="5">Two positive growths of the same organism on standard cultures</td><td rowspan="2">Infected</td></tr>
<tr><td colspan="5">Sinus tract communicating with joint or visible prosthesis</td></tr>
<tr><td rowspan="2">Minor Criteria</td><td colspan="2">Threshold</td><td rowspan="2">Score</td><td rowspan="2">Decision</td></tr>
<tr><td>Acute</td><td>Chronic</td></tr>
<tr><td rowspan="2">Serum CRP, mg/L or D-Dimer, mkg/L</td><td>100</td><td>10</td><td rowspan="2">2</td><td rowspan="8">⩾ 6 Infected;
4 to 5: inconclusive;
3 and less: Not infected</td></tr>
<tr><td>Unknown</td><td>860</td></tr>
<tr><td>Serum ESR, mm/h</td><td>None</td><td>30</td><td>1</td></tr>
<tr><td>Elevated synovial WBC, cells/mkl</td><td>10000</td><td>3000</td><td>3</td></tr>
<tr><td>Elevated synovial PMN, %</td><td>90</td><td>70</td><td>2</td></tr>
<tr><td colspan="3">Single positive culture</td><td>2</td></tr>
<tr><td colspan="3">Positive histology: inflammation of periprosthetic tissue
(> 5 neutrophils in each of 5 fields of view at 400× magnification</td><td>3</td></tr>
<tr><td colspan="3">Intraoperative visualization of purulent contents</td><td>3</td></tr>
</table>

Classification of periprosthetic infection graded by Zimmerli and modified by Li et al. was used in the study [13]. A poor outcome of treatment was rated with clinical and laboratory signs of infection at the time of admission to the second stage of treatment and with signs of infection after successful debridement. The same pathogen isolated as during the first episode of PJI was classified as relapse of PJI, and a different pathogen was classified as reinfection.

Statistical data processing The findings were recorded in the form of spreadsheets and MS Office Excel, 2007 (Microsoft, USA) and the Graf Pad program were used to review the data and visualize the structure. A test for normality of distribution was performed to describe quantitative parameters using the Kolmogorov – Smirnov test. The mean and standard deviation were used for a normal distribution; for a distribution other than normal, the median and upper and lower quartiles Me (Q1–Q3); 95 % CI was used in both cases. The significance of differences was identified with the Student t-test in the case of a normal distribution, and the nonparametric Mann – Whitney test (m–u) was employed in the absence of a normal distribution. Categorical data (sex, type of PJI, outcome) were described by conditional codes of unmeasured categories that were not subject to ordering.

RESULTS

According to the ICM, the primary sample size was detected in 524 cases of PJI with 35 cases (6.7 %) diagnosed with RA. Female patients aged 60 years predominated in the group with an equal ratio

of patients of working age and elderly. By the time of primary arthroplasty, the patients had a late stage of RA (radiologically confirmed stage III–IV arthritis) with a predominance of the seropositive type of the disease (Table 2).

Chronic PIS was hematogenous in most cases with involved knee. About 50 % of patients received antibiotics during preadmission stage. Patients received basic therapy for RA: a combination of cytostatics with hormonal drugs (*n* = 10; 28.6 %), hormonal drugs (*n* = 5; 14.3 %), cytostatics (*n* = 9; 25.7 %), genetically engineered drugs and sulfasalazine (*n* = 2; 5.7 % each), non-steroidal anti-inflammatory drugs only (*n* = 7; 20 %). The average follow-up period after revision arthroplasty was 41/2 years. With use of the ICM diagnostic criteria (2018) PJI was diagnosed in 85.7 % of cases (*n* = 30) including fistulous tract communicating with the cavity of the implants (*n* = 13; 37.2 %), positive cultural growth in at least two biological samples (*n* = 6 cases; 17.1 %), the presence o 6 or > scores (infected cases) according to minor criteria for PJI detected in 11 cases (31.4 %). In the remaining 5 cases (14.3 %), evidence for the diagnosis of PJI was inconclusive or did not meet the criteria for diagnosing an infectious process. Culture-negative infection was most common for the etiology of PJI, coagulase-negative staphylococci (CoNs) was second common for monomicrobial infection and Staphylococcus aureus was third common (Fig. 1).

Table 2

General characteristics of the study group

Description			Values	
Mean age, years			60.2 ± 10.3	
Average time from verification of RA diagnosed to the time of primary arthroplasty, years			21.6 ± 9.9	
Average follow-up period after debridement, months			53.2 ± 31.7	
			abs.	%
Gender	Female		30	86
	Male		5	14
Age, years	Young age (18–44)		3	8.5
	Middle adulthood (45–59)		15	42.9
	Late adulthood (60–74)		15	42.9
	Old age (75–89)		2	5.7
Clinical types of RA	Sero-positive		24	68.6
	Sero-negative		7	20.0
	Juvenile		4	11.4
Localization of PJI	Knee joint		26	74.3
	Hip joint		8	22.8
	Proximal metacarpophalangeal joint		1	2.9
Individuals who received antibiotic therapy at the preadmission stage			17	48.6
Classification of periprosthetic infection graded by Zimmerli [12] and modified by Li et al. [13]	Post-op (< 90 days of surgery)	acute	5	14.3
		chronic	0	0
	Hematogenous (> 90 days of surgery)	acute	0	0
		chronic	30	85.7

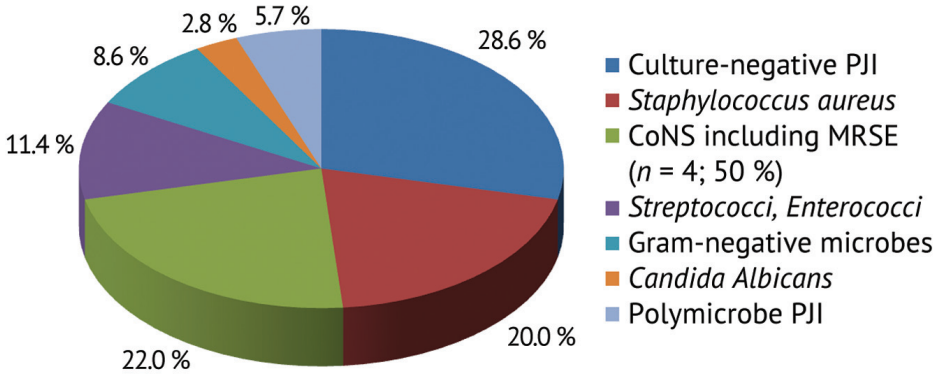

Fig. 1 Microbiological structure of PJI examined with joint fluid punctate in patients with RA

Gram-negative pathogens included *Proteus mirabilis, Escherichia coli, Burkholderia cepacia*. Microbial associations were represented by MRSE combined with *Enterococcus faecalis* and *Enterococcus faecalis* with *Corynebacterium spp*. The maximum number of positive cultures (n = 25, 71.4 %) was seen in the joint fluid punctate taken preoperatively. Intraoperative tissue biopsies showed a positive culture in 20 cases (57.1 %) and in 17 (48.6 %) aspirates from removed implants. MRSE was increased in one case prior to the second stage of treatment. All cases of PJI were treated with surgical debridement and antibiotics. One-stage debridement with replacement of the liner and head component was performed in 4 patients (11.4 %); two- and three-stage debridement was performed (n = 31, 88.6 %) in other cases: an articulating spacer was placed in 26 (83.9 %) cases and a static spacer installed in 5 patients (16.1 %). ESR, CRP and D-dimer showed high average values before and after debridement in all patients with two-stage procedure (Table 3).

Table 3

Results of laboratory tests in patients with RA

Description	Prior to debridement, n = 35	Prior to the second stage of debridement, n = 28*	P < 0,05
Serum			
ESR, mm/hour	45.5 (34.4–56.6)	26.0 (16.0–36.0)	**0.0047****
CRP, mg/mL	34.6 (22.3–46.9)	8.2 (4.0–10.4)**	0.4422
D-Dimer, ng/mL	1670 (1067.9–2272.1)	1749.5 (1161.7–2337.3)	0.9325
Synovium			
First sample			
Leukocytes, cells/μl	9000.0 (1905.0–18495.0)**	320.0 (82.0–825.0)**	0.0017*
Neutrophils, %	88.0 (81.4–94.6)	63.0 (1.5–94.5)	0.0705
Second sample			
Leukocytes, cells/μl	4687.0 (1450.0–9100.0)**	180.0 (45.0–450.0)**	0.0038***
Neutrophils, %	87.0 (75.0–93.0)**	45.0 (22.0–80.0)**	0.1760
Third sample			
Leukocytes, cells/μl	1355.0 (85.0–8150.0)**	130.0 (35.0–225.0)**	0.2637
Neutrophils, %	76.0 (62.0–90.0)**	–	–

Note: * — patients treated with a one-stage procedure (n = 4) and patients with a spacer replacement (n = 3) without subsequent debridement were excluded; ** — Me (Q1–Q3); *** — m–u.

A decrease in all inflammatory markers was noted after debridement with changes in serum ESR and the joint leukocyte count being statistically significant. Favorable results were obtained in the majority of cases with RA (82.9 %) treated for PJI at an average follow-up period of 53.2 ± 31.7 months after debridement (Table 4).

Table 4

Outcomes of treatment of PJI

Poor outcomes, *n* = 6 (17.1 %)	Good outcomes, *n* = 29 (82.9 %)
Recurrent PJI*, *n* = 2 (33.3 %)	Repeated joint replacement**, *n* = 23 (79.4 %)
Three-stage treatment*, *n* = 4 (66.7 %)	Arthrodesis**, *n* = 3 (10.3 %)
	Life with a spacer**, *n* = 3 (10.3 %)

Note: * — among poor outcomes; ** — among good outcomes.

A reinfection caused by a microbial association (*Acinetobacter baumannii, Enterococcus faecalis, Streptococcus mitis*) developed after a primary staphylococcal PJI in one case that resulted in a poor outcome. A recurrent PJI was caused by the same streptococcal infection in the second case. Four patients were treated with a three-stage debridement due to the persistent high levels of inflammatory markers after the second stage of debridement and poor condition of the bone tissue recorded by the operating surgeon, including one patient with isolated MRSE. The three-stage debridement in the patients resulted in arthrodesis (*n* = 1) and repeated joint replacement (*n* = 2) as the fourth stage; one patient lives with a spacer. Every fifth patient with a favorable outcomes is forced to live with a spacer or with fused joint. Static spacers were used in 16.1 % of cases at the first stage of debridement which limited joint mobility.

DISCUSSION

The characteristics of the course of PJI in patients with rheumatoid arthritis indicated the signs and symptoms of systemic diseases as imitating PJI with pain in the joints, swelling of the periarticular tissues, fever, increased serum ESR and CRP, joint leukocytes. The proportion of patients with rheumatoid arthritis among all cases of PJI ranges from 4.5 to 13.3 % [14–16], which is consistent with our data (6.7 %). Hsieh et al. [14] and Berbari et al. [17] identified *Staphylococcus aureus* as the leading pathogen in the development of PJI in patients with rheumatoid arthritis, but we were unable to confirm the data. Culture-negative infection was common in our series. *Coagulase-negative staphylococci* was more common among culture-positive infection being opportunistic pathogens and causing infection and forming biofilms in immunocompromised rheumatoid arthritis patients. Some foreign authors report changes in the leading role of *Staphylococcus aureus* to coagulase-negative strains in the etiology of PJI. Fröschen et al. reported coagulase-negative staphylococci found in 44.61 % and Staphylococcus aureus in 14.31 % of cases [18] and Tai et al. reported bacteria found in 37 and 24 %, respectively [19]. *Candida albicans* was isolated in one case of our series as a rare and difficult to treat pathogen (DTT). Chronic PJI in our series was mostly hematogenous and could be resulted from chronic infection and immunocompromised patients with RA. *Candida albicans* as a saprophyte that colonizes the skin and mucous membranes provoked the development of PJI in a patient with rheumatoid arthritis who received immunosuppressants and antibiotics [20]. Therefore, culturing is practical for patients with rheumatoid arthritis if a PJI is suspected to expand the spectrum of pathogensincluding fungi and acid-fast bacilli and if other traditional pathogens are not identified by routine culturing.

With the frequency of culture-negative PJI of 28.6 % reported we obtained results similar to those reported by Sculco et al. amounting to 27 % [15], while Schrama et al. reported the incidence as high as 37 % [21]. The authors reported the lack of growth of pathogens in the biological materials with the use of antibiotics at the preadmission stage, which was confirmed in our series with almost half of the patients receiving antibiotics prior to verified PJI. We have shown the effect of antibiotics on the results of bacteriological examination in other series [22].

This cohort of patients can be problematic for verifying the diagnosis of PJI. There is a risk of a false diagnosis of infection in the absence of a fistula tract communicating with the joint cavity relying on inflammation markers, which may have high values due to systemic inflammation. In our series, 14.3 % of patients with rheumatoid arthritis surgically treated for PJI did not meet the ICM criteria (2018). A review of 36 cases of PJI in patients with inflammatory arthritis conducted by Sculco et al. showed the absence of microbiological culture growth in 10 patients and 50 % (n = 5) did not meet MSIS criteria for infection [15, 23]. Foreign researchers suggested test strips for leukocyte esterase to be used in doubtful cases including those with rheumatoid arthritis, with a sensitivity of 80.6 % and a specificity of 100 % for PJI [24–26].

The method has not been used at the Center, and differential cell count in synovial fluid is considered to be more informative. A systematic review of the literature on synovial fluid biomarkers for the diagnosis of PJI in patients with inflammatory arthritis showed that the percentage of band neutrophils has the highest sensitivity (95.2 %) and specificity (85.0 %) with an optimal threshold of 78 % sufficient to verify infection [10]. We believe that leukocyte count (no more than 2000 cells / μl) and band neutrophils (no more than 70 %) in the synovial fluid can be a prognostic sign of the effectiveness of debridement prior to the second stage of revision arthroplasty.

Our study showed that a favorable outcome of treatment of PJI with eradication of infection in patients with rheumatoid arthritis could be achieved in most cases. However, a fifth of patients in the cohort who had static spacers or arthrodesis had limited motion in the operated joints and significantly reduced quality of life. The treatment methods were practical for large bone defects and fragile bone due to osteoporosis associated with long-term use of corticosteroids. Poor outcomes resulted from two- or three-stage surgical treatment. On the contrary, Berbari et al. reported better outcomes of two-stage debridement with a five-year disease-free period achieved in 79 % of cases (95 % CI, 66–93 %) [17]. Two-stage debridement was performed in 19 % of PJI, but in our series this figure amounted to 88.6 %. A limitation of our study included the lack of differentiation between patients with acute and chronic PJI in the assessment of laboratory findings in the small sample. It was a retrospective study and did not allow for histological examination to diagnose infection. An expanded prospective study using a larger sample can be more practical to evaluate findings of patients with rheumatoid arthritis and suspected PJI if international diagnostic criteria cannot be applied.

CONCLUSION

Diagnosis of PJI in patients with rheumatoid arthritis and other systemic diseases remains challenging. Favorable surgical outcomes have been achieved in 82.9 % of cases due to two-stage procedure in most cases. Culture-negative infection was most common (38.4 %) among the PJI cases identified. Laboratory serum markers of inflammation (ESR, CRP and D-dimer) could not reach normal values

at stages of diagnosis and treatment of PJI indicating the inapplicability of standard diagnostic criteria in patients with rheumatoid arthritis. A prospective study using histological examination of intraoperative tissues can be considered for a larger cohort of patients with rheumatoid arthritis featuring a primary inflammation history due to reduced reactivity of the body, and inconsistency of diagnostic parameters and international criteria for PJI.

Conflict of interest *Not declared.*

Funding *Not declared.*

REFERENCES

1. Kapetanovic MC, Lindqvist E, Saxne T, Eberhardt K. Orthopaedic surgery in patients with rheumatoid arthritis over 20 years: prevalence and predictive factors of large joint replacement. *Ann Rheum Dis*. 2008;67(10):1412-1416. doi: 10.1136/ard.2007.086710
2. Berbari EF, Hanssen AD, Duffy MC, Steckelberg JM, Ilstrup DM, Harmsen WS, Osmon DR. Risk factors for prosthetic joint infection: case-control study. *Clin Infect Dis*. 1998;27(5):1247-1254. doi: 10.1086/514991
3. Jämsen E, Virta LJ, Hakala M, et al. The decline in joint replacement surgery in rheumatoid arthritis is associated with a concomitant increase in the intensity of anti-rheumatic therapy: a nationwide register-based study from 1995 through 2010. *Acta Orthop*. 2013;84(4):331-337. doi: 10.3109/17453674.2013.810519
4. Khlaboshina VN, Amirdzhanova VN. Biological agents for endoprosthetic joint replacement in patients with rheumatoid arthritis. *Modern Rheumatology Journal*. 2014;8(4):72-75. (In Russ.) doi: 10.14412/1996-7012-2014-4-72-75
5. Gabriel SE, Michaud K. Epidemiological studies in incidence, prevalence, mortality, and comorbidity of the rheumatic diseases. *Arthritis Res Ther*. 2009;11(3):229. doi: 10.1186/ar2669
6. Bongartz T, Halligan CS, Osmon DR, et al. Incidence and risk factors of prosthetic joint infection after total hip or knee replacement in patients with rheumatoid arthritis. *Arthritis Rheum*. 2008;59(12):1713-1720. doi: 10.1002/art.24060
7. Berbari EF, Hanssen AD, Duffy MC, et al. Risk factors for prosthetic joint infection: case-control study. *Clin Infect Dis*. 1998;27(5):1247-1254. doi: 10.1086/514991
8. Jämsen E, Huhtala H, Puolakka T, Moilanen T. Risk factors for infection after knee arthroplasty. A register-based analysis of 43,149 cases. *J Bone Joint Surg Am*. 2009;91(1):38-47. doi: 10.2106/JBJS.G.01686
9. Doran MF, Crowson CS, Pond GR, et al. Frequency of infection in patients with rheumatoid arthritis compared with controls: a population-based study. *Arthritis Rheum*. 2002;46(9):2287-2293. doi: 10.1002/art.10524
10. Mirza SZ, Richardson SS, Kahlenberg CA, et al. Diagnosing Prosthetic Joint Infections in Patients With Inflammatory Arthritis: A Systematic Literature Review. *J Arthroplasty*. 2019;34(5):1032-1036.e2. doi: 10.1016/j.arth.2019.01.051
11. Parvizi J, Tan TL, Goswami K, et al. The 2018 Definition of Periprosthetic Hip and Knee Infection: An Evidence-Based and Validated Criteria. *J Arthroplasty*. 2018;33(5):1309-1314.e2. doi: 10.1016/j.arth.2018.02.078
12. Zimmerli W. Clinical presentation and treatment of orthopaedic implant-associated infection. *J Intern Med*. 2014;276(2):111-119. doi: 10.1111/joim.12233
13. Li C, Renz N, Trampuz A. Management of Periprosthetic Joint Infection. *Hip Pelvis*. 2018;30(3):138-146. doi: 10.5371/hp.2018.30.3.138
14. Hsieh PH, Huang KC, Shih HN. Prosthetic joint infection in patients with rheumatoid arthritis: an outcome analysis compared with controls. *PLoS One*. 2013;8(8):e71666. doi: 10.1371/journal.pone.0071666
15. Sculco P, Kapadia M, Moezinia CJ, et al. Clinical and Histological Features of Prosthetic Joint Infections May Differ in Patients With Inflammatory Arthritis and Osteoarthritis. *HSSJ*. 2023;19(2):146-153. doi: 10.1177/15563316231153395
16. Singh N, Nair R, Goto M, et al. Risk of Recurrent Staphylococcus aureus Prosthetic Joint Infection in Rheumatoid Arthritis Patients-A Nationwide Cohort Study. *Open Forum Infect Dis*. 2019;6(11):ofz451. doi: 10.1093/ofid/ofz451
17. Berbari EF, Osmon DR, Duffy MC, et al. Outcome of prosthetic joint infection in patients with rheumatoid arthritis: the impact of medical and surgical therapy in 200 episodes. *Clin Infect Dis*. 2006;42(2):216-223. doi: 10.1086/498507
18. Fröschen FS, Randau TM, Franz A, et al. Microbiological Profiles of Patients with Periprosthetic Joint Infection of the Hip or Knee. *Diagnostics* (Basel). 2022;12(7):1654. doi: 10.3390/diagnostics12071654
19. Tai DBG, Patel R, Abdel MP, et alJ. Microbiology of hip and knee periprosthetic joint infections: a database study. *Clin Microbiol Infect*. 2022;28(2):255-259. doi: 10.1016/j.cmi.2021.06.006
20. Malyuchenko L.I., Nikolaev N.S., Lyubimova L.V., Preobrazhenskaya E.V., Efimov D.N. A case of treatment of a fungal periprosthetic infection with a carbon-coated implant. *Bulletin of the Medical Institute "REAVIZ" (Rehabilitation, Doctor and Health)*. 2022;12(6):119-126. (In Russ.) doi: 10.20340/vmi-rvz.2022.6.CASE.1
21. Schrama JC, Lutro O, Langvatn H, et al. Bacterial findings in infected hip joint replacements in patients with rheumatoid arthritis and osteoarthritis: a study of 318 revisions for infection reported to the norwegian arthroplasty register. *ISRN Orthop*. 2012;2012:437675. doi: 10.5402/2012/437675
22. Lyubimova LV, Bozhkova SA, Pchelova NN, et al. The role of culture-negative infection among infectious complications after total knee arthroplasty. *Genij Ortopedii*. 2023;29(4):402-409. doi: 10.18019/1028-4427-2023-29-4-402-409
23. Parvizi J, Zmistowski B, Berbari EF, et al. New definition for periprosthetic joint infection: from the Workgroup of the Musculoskeletal Infection Society. *Clin Orthop Relat Res*. 2011;469(11):2992-2994. doi: 10.1007/s11999-011-2102-9

24. Yeganeh MH, Kheir MM, Shahi A, Parvizi J. Rheumatoid Arthritis, Disease Modifying Agents, and Periprosthetic Joint Infection: What Does a Joint Surgeon Need to Know? *J Arthroplasty*. 2018;33(4):1258-1264. doi: 10.1016/j.arth.2017.11.031
25. Parvizi J, Jacovides C, Antoci V, Ghanem E. Diagnosis of periprosthetic joint infection: the utility of a simple yet unappreciated enzyme. *J Bone Joint Surg Am*. 2011;93(24):2242-2248. doi: 10.2106/JBJS.J.01413
26. Tischler EH, Cavanaugh PK, Parvizi J. Leukocyte esterase strip test: matched for musculoskeletal infection society criteria. *J Bone Joint Surg Am*. 2014;96(22):1917-1920. doi: 10.2106/JBJS.M.01591

The article was submitted 01.03.2024; approved after reviewing 21.03.2024; accepted for publication 18.06.2024.

Information about the authors:

Lyudmila V. Lyubimova — clinical pharmacologist, borisova-80@mail.ru, https://orcid.org/0000-0002-5750-4459;

Nadezhda N. Pchelova — bacteriologist, nadyapchelova@mail.ru, https://orcid.org/0000-0001-9507-9118;

Nikolai S. Nikolaev — Doctor of Medical Sciences, Professor RAS, Chief Physician, Head of the Department, nikolaevns@mail.ru, https://orcid.org/0000-0002-1560-470X;

Elena V. Preobrazhenskaya — Head of the department, alenka_22@bk.ru, https://orcid.org/0000-0003-3556-145X;

Evgeniy A. Lyubimov — anesthesiologist-resuscitator, e_lyubimov@mail.ru, https://orcid.org/0000-0001-5262-0197.

Original article
https://doi.org/10.18019/1028-4427-2024-30-4-561-571

Evaluation of the effect of osteosynthesis wires on the structural reorganization of metaepiphyseal cartilage (an experimental and morphological study)

A.A. Korobeinikov, T.A. Stupina✉, O.V. Dyuryagina, M.A. Stepanov, N.I. Antonov

Ilizarov National Medical Research Centre for Traumatology and Orthopedics, Kurgan, Russian Federation

Corresponding author:Tatyana A. Stupina, StupinaSTA@mail.ru

Abstract

Introduction Premature arrest of bone growth is the most common complication of bone fractures at the growth plate level.

The **purpose** of the work was to evaluate the structural reorganization of metaepiphyseal cartilage following its direct injury with metal and biodegradable wires in an experiment.

Materials and methods The metaepiphyseal cartilage of the distal femur of 18 lambs of both sexes was studied. The age of the animals at the beginning of the study was (43.92 ± 0.8) days, by 60 and 120 days (102.63 ± 0.82) and (161.1 ± 0.9) days, respectively. The animals underwent transphyseal insertion of wires/pins: series 1 — Kirschner wires, series 2 — titanium wires, series 3 — poly-L-lactic acid pins. The duration of the experiment was 60 and 120 days. Clinical and radiographic studies were carried out. Histomorphometry was performed using an AxioScope.A1 microscope and Zenblue software (CarlZeissMicroImagingGmbH, Germany).

Results Reactive changes in the growth plate at the interface with the wire were manifested by proliferation of chondrocytes in the zone of proliferating cartilage and in the reserve zone; the minimally expressed changes were noted in series 2, the most pronounced were in series 1. By the end of the experiment, at the interface with the wire in series 1, blood vessels penetrated into the metaepiphyseal cartilage; in series 3 the amount of the fibrous component was increased, which indicates further formation of “bone bridges” and “fibrous bridges,” respectively. In undamaged areas of the growth plate in all series, the zonal structure was preserved. By the end of the experiment, increased values of the thickness of the metaepiphyseal cartilage were noted (1.2 times higher than the control), differences between series were a tendency; in series 2 and 3 the ratio of metaepiphyseal cartilage zones was comparable to the control; in series 1 the proportion of the proliferating cartilage zone was increased by 4 %.

Discussion The main problem with growth plate injuries is the formation of bone tissue or fibrosis, which affects the growing process. Currently, the question of choosing a treatment tactic for growth plate injury depending on the size of the “bone bridges” is debatable. Relevant are future comparative studies of the regeneration of metaepiphyseal cartilage defects after the use of fixators made from different materials.

Conclusion Histomorphometric characteristics of the growth zone reliably showed that the insertion of wires, regardless of their material, was not accompanied by inhibition of the bone-forming function of the distal metaepiphyseal cartilage of the femur.

Keywords: growth plate, metal and biodegradable fixators, histology, morphometry

For citation: Korobeinikov AA, Stupina TA, Dyuryagina OV, Stepanov MA, Antonov NI. Evaluation of the effect of osteosynthesis wires on the structural reorganization of metaepiphyseal cartilage (an experimental and morphological study). *Genij Ortopedii*. 2024;30(4):561-571. doi: 10.18019/1028-4427-2024-30-4-561-571

© Korobeinikov A.A., Stupina T.A., Dyuryagina O.V., Stepanov M.A., Antonov N.I., 2024
© Translator Tatyana A. Malkova, 2024

INTRODUCTION

The bone growth zone (physis, epiphyseal plate, growth plate, metaepiphyseal cartilage) is a highly specialized cartilaginous tissue located between the epiphysis and metaphysis at the proximal and distal ends of long bones. Longitudinal bone growth occurs due to the processes of enchodral ossification in the epiphyseal plate [1, 2]. Metaepiphyseal cartilage has a zonal structure. Different authors distinguish from three (reserve, proliferative, hypertrophic) to six zones; all classifications are based on the proliferative and biosynthetic activity of chondrocytes and the degree of their differentiation. The epiphyseal plate is monopolar, since bone formation runs in one direction [1, 3].

Treatment of injuries (mechanical, infectious, iatrogenic, malignant) to the growth plate is a difficult task due to avascular nature of the metaepiphyseal cartilage [2, 4, 5, 6].

Mechanical injuries to the growth plate are common and account for 15 to 30 % of all bone injuries in children; they are more frequent in boys; the peak of injuries is the age of 11–14 years [7, 8]. The main complication of treatment of the epiphyseal plate injury is premature closure of growth plates, formation of bone bridges, resulting in limb deformation and limb length discrepancy [7, 8, 9]. Deformities of the lower limb account for 43.7 % of all orthopedic disorders in children, of which 21.4 % are changes in the knee joint [10].

To treat growth plate injury, both conservative and surgical methods are used [7, 11, 12, 13]. In the surgical method of treatment, fractures passing through the growth zone are fixed using either metal or biodegradable bone fixators [14, 15, 16, 17].

One of the current areas of pediatric traumatology is the assessment of the state of the growth plate when using various surgical techniques for correcting pathological conditions associated with dysfunction. In the available literature there are no comparative experimental and histological studies on the effect of non-biodegradable and biodegradable wires on the structure of metaepiphyseal cartilage.

Purpose: to evaluate the structural reorganization of metaepiphyseal cartilage following direct injury with metal and biodegradable wires in an experiment.

MATERIALS AND METHODS

The object studied was the metaepiphyseal cartilage of the distal femur in 18 lambs of both sexes after transphyseal insertion of pin fixators. The duration of the experiment was 60 and 120 days after surgery.

The age of the animals at the beginning of the study was (43.92 ± 0.8) days, by 60 and 120 days (102.63 ± 0.82) and (161.1 ± 0.9) days, respectively. The body weight of the lambs on the day of surgery was (14.0 ± 3) kg, on days 60 and 120 it was (21.92 ± 0.85) and (28.92 ± 2.4) kg, respectively.

Exclusion criteria: diseases of the musculoskeletal system.

Animals are divided into 3 series. In series 1 (n = 6), a stainless steel wire, d = 1.5 mm (CITO, Russia), was transphyseally inserted; in series 2 (n = 6), it was a straight elastic intramedullary nail made of titanium, d = 1.5 mm (Rotor Med LLC, Russia); in series 3 (n = 6) a biodegradable pin made of poly-L-lactic acid, d = 1.5 mm (Inion OTPS TM, Finland) was used.

Each animal underwent transphyseal insertion of one fixator through the distal growth plate of the femur of the right pelvic limb. In series 1 and 2, the insertion of the wire/nail was carried out transcutaneously using an osteosynthesis drill. The wire/nail was inserted dorsoventrally in the lateral-medial direction at an angle to the longitudinal axis of the bone of 30–35° through the metaphysis, physis and epiphysis of the bone, without penetrating into the cavity of the knee joint. After X-ray confirmation of the correct insertion of the fixator, its outer part was bitten off with pliers at the level of the cortical plate and hidden under the skin. If necessary, 1–2 interrupted Vicryl tm Plus 3–0 sutures (Ethicon, Johnson & Johnson International, USA) were made on the skin at the injection site.

Animals in series 3 underwent a skin incision in the projection of the pin passage. Next, a canal for pin insertion was formed antegrade using a Kirschner wire, and the direction of the wire was chosen so that the angle of intersection with the growth plate was 30–35° in the frontal plane. The wire passed to the subchondral layer of the bone. A biodegradable 1.5-mm pin was installed in a reusable contact applicator, with the help of which it was inserted into the formed canal to the entire depth of the latter. The excessive end of the pin was bitten off with pliers, and the skin was sutured with interrupted sutures Vicryl tm Plus 3–0 (Ethicon, Johnson & Johnson International, USA).

To prevent the development of inflammatory processes, all animals were prescribed an analgesic anti-inflammatory drug (i/m ketoprofen 50 mg, 0.5 ml) and an antimicrobial agent (i/m ceftriaxone 1.0, 7–10 mg/kg). The surgical wound was treated with a solution of hydrogen peroxide 3 % and furatsilin 1:5000, daily for the first 10 days after surgery, then twice a week. The sutures were removed after 10–14 days.

In all experimental series, the wires and pins remained in situ the entire observation period. Animals were euthanized after premedication with a solution of diphenhydramine 1 % (0.02 mg/kg) and Rometar 2 % (1 mg/kg), followed by the administration of a lethal dose of barbiturates.

Animal care, operations, manipulations and procedures were carried out in accordance with regulatory documents: GOST R 33044-2014. Principles of good laboratory practice; PS SanPiN 3.3686-21 Sanitary and epidemiological requirements for the prevention of infectious diseases; GOST 33215-2014 Guide to the maintenance and care of laboratory animals. Rules for equipping premises and organizing procedures; GOST 34088-2017 Guide to the maintenance and care of laboratory animals. Rules for keeping and caring for farm animals.

For histomorphometric examination, fragments of the distal articular end of the femur were fixed in a 10 % solution of neutral formalin, then washed in running water and decalcified in a mixture of equal volumes of hydrochloric and formic acid solutions, dehydrated in ethyl alcohol, and embedded in paraffin. To obtain objective information about the qualitative and quantitative characteristics of the object being studied, histological sections of adequate orientation and thickness were used [18]. Histological preparations (longitudinal sections along the axis of the femur) with a thickness of 5.00 μm were prepared on an HM 450 Thermo Scientific microtome (USA) and stained with hematoxylin and eosin using the three-color method according to Masson. Light-optical examination and digitization were carried out using an AxioScope.A1 microscope equipped with an AxioCam digital camera (Carl Zeiss MicroImaging GmbH, Germany).

Histological characteristics of the metaepiphyseal cartilage considered its zones, the identification of zones in the direction from the epiphysis to the diaphysis: the zone of resting cartilage (reserve or border zone); zone of proliferating cartilage; zone of vesicular (hypertrophied) cartilage; zone of calcified cartilage [1].

Zenblue software (Carl Zeiss MicroImaging GmbH, Germany) was used for histomorphometry. The thickness of the metaepiphyseal cartilage (hmet.car, μm) was determined as the distance between its upper and lower borders with an interval of about 20 μm, 20 measurements were taken from each case, the percentage of its zones. As a control, the metaepiphyseal cartilage of the distal femur of the contralateral limb was morphometrically measured. The width of the defect zone was determined by taking 30 measurements in each case.

Data analysis was carried out using descriptive statistics methods. Samples were checked for normal distribution of values using the Kolmogorov test. The measure of central tendency is presented as the arithmetic mean and error of the arithmetic mean (M ± m); for samples where the normality hypothesis was rejected, the data are presented as median and quartiles (Me ($p25$–$p75$)). Hypotheses about differences between the compared groups were tested with a normal distribution using the Student's t test, with an asymmetric distribution using the Wilcoxon test; differences were considered significant at $p < 0.05$ (AtteStat program, version 9.3.1).

RESULTS

The lambs of all experimental series had the weight-bearing function of the affected pelvic limb from the following day after surgery until the end of the experiment. Upon examination and palpation, no changes were found in the area of the distal metaphysis of the femur. The function of the knee joint (full flexion and extension) was completely preserved in all experimental animals at all stages of observation. There were no restrictions of mobility in the knee joints.

At the stages of the study, the bone tissue in the area of implantation in the animals of all series had a uniform structure. The contour of the epiphyseal plate was clearly visible. There were no visible areas of closure of the growth plate in the areas adjacent to the implants (Fig. 1).

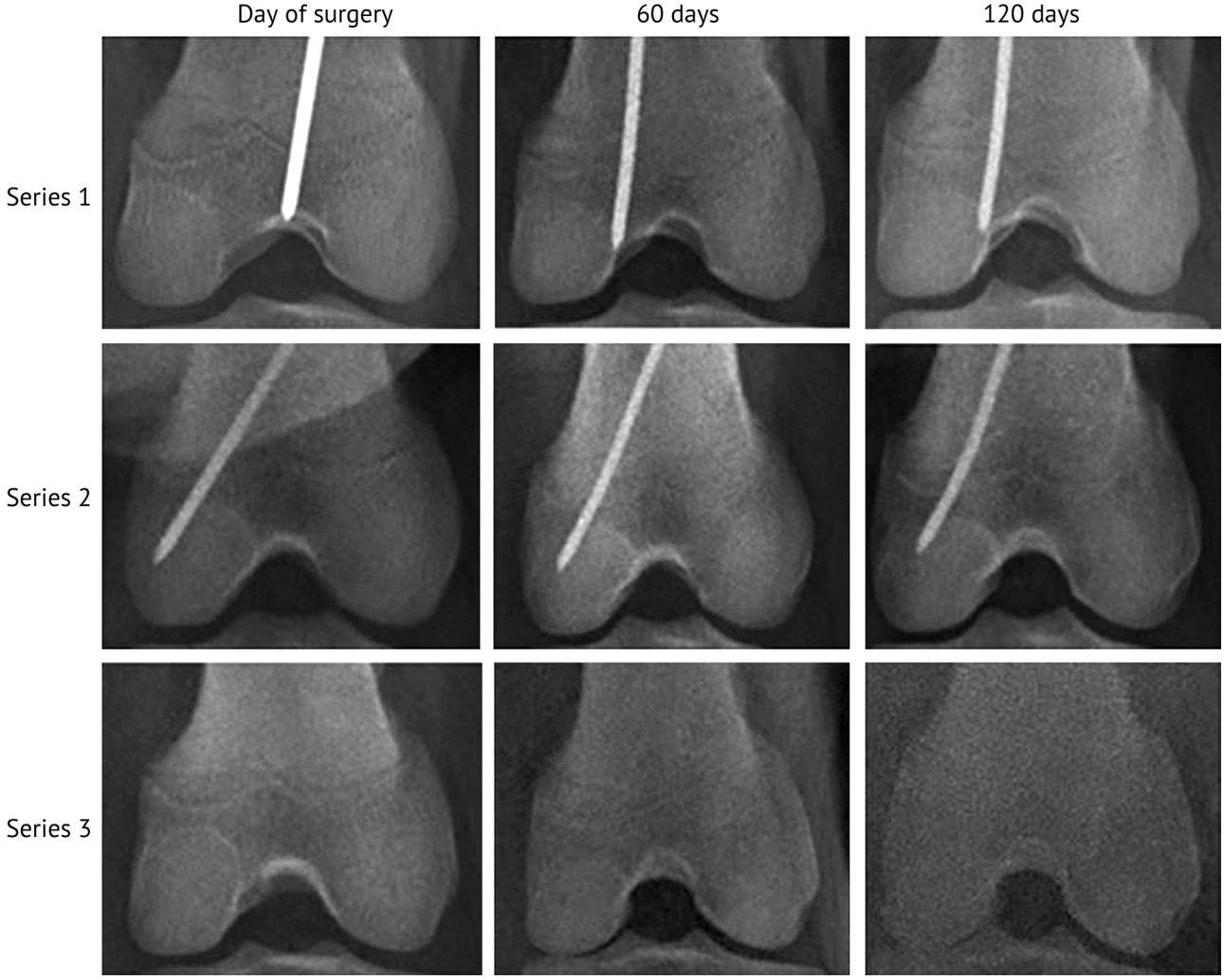

Fig. 1 Radiographic images of wires/pins in the femoral metaphyses at the time-points of the experiment

In the control limb, the metaepiphyseal cartilage of the distal femur maintained a zonal structure throughout the experiment. Its zones were clearly defined: the border (reserve) zone with the epiphysis; zone of proliferating cartilage, proliferating chondrocytes were arranged in columns; the zone of vesicular cartilage, represented by hypertrophied chondrocytes; the zone of calcified cartilage adjacent to the endochondral bone of the diaphysis (Fig. 2).

The thickness of the metaepiphyseal cartilage decreased by an average of 18 % with the growth of lambs (from 3.5 to 5.5 months) (Table 1). The decrease in this parameter was due to a pronounced decrease in the thickness of the reserve zone (Fig. 2, Fig. 5).

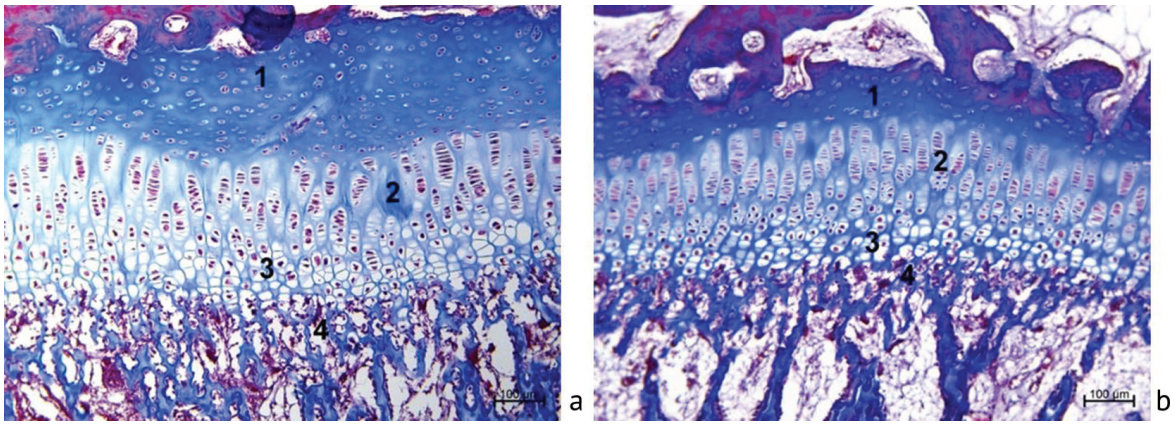

Fig. 2 Metaepiphyseal cartilage of the distal femur of the contralateral limb (control): *a* — age 3.5 months; *b* — age 5.5 months; 1 — reserve zone; 2 — zone of proliferating cartilage; 3 — zone of vesicular cartilage; 4 — zone of calcified cartilage. Paraffin section, stained with the three-color method according to Masson. Magnification ×100

Table 1

Thickness of the metaepiphyseal cartilage of the distal femur at the stages of the experiment
Me (Q1; Q3)

Параметр / Серия		$h_{met.car.}$, мкм
Control	60 days	607.59 (574.25; 644.41)
	120 days	493.08 (446.92; 546.37) $p^{60-120} = 0.001$
Series 1	60 days	797.58 (765.21; 838.95) $p^{c-s1} = 0.0001$
	120 days	592.32 (457.59;649.36) $p^{c-s1} = 0.0188$
Series 2	60 days	732.32 (636.66; 773.02) $p^{c-s2} = 0.003$ $p^{s1-s2} = 0.004$
	120 days	621.11 (518.31; 780.71) $p^{c-s2} = 0.0001$ $p^{s1-s2} = 0.0541$
Series 3	60 days	680.89 (626.01; 708.92) $p^{c-s3} = 0.0111$ $p^{s3-s1} = 0.0001$ $p^{s3-s2} = 0.0578$
	120 days	589.01 (522.13; 632.07) $p^{c-s3} = 0.009$ $p^{s3-s1} = 0.0598$ $p^{s3-s2} = 0.0532$

Note: Wilcoxon test was used, differences were statistically significant at $p < 0,05$, p^{60-12} — comparison of control at the stages, p^{c-s1} — comparison of control and series 1, p^{c-s2} — comparison of control and series 2, p^{s1-s2} — comparison of series 1 and series 2, p^{c-s3} — comparison of control and series 3, p^{s3-s1} — comparison of series 3 and series 1, p^{s3-s2} — comparison of series 3 and series 2.

In the experimental series throughout the study, reactive changes in the metaepiphyseal cartilage at the border with the wire were manifested by the proliferation of chondrocytes (Fig. 3, 4) both in the zone of proliferating cartilage and in the reserve zone, more intensely expressed in series 1. By the end of the experiment, at the border with the wire in all series, functionally active chondrocytes shaped in columns were noted. In series 1, in all animals, the penetration of vessels from the border zone into the zone of proliferating cartilage was seen (Fig. 4 d). In series 3, an increase in the proportion of the fibrous component was noted in the defect zone (Fig. 4 f).

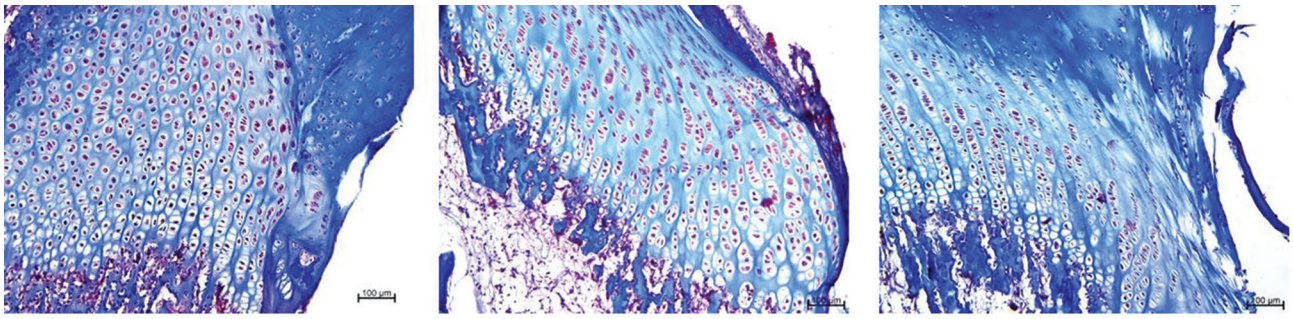

Fig. 3 Reactive changes in the metaepiphyseal cartilage of the distal femur at the border with the wire: *a* — series 1; *b* — series 2; *c* — series 3. Experiment duration: 60 days. Fragments of paraffin sections. Magnification ×100. Staining with three-color method according to Masson

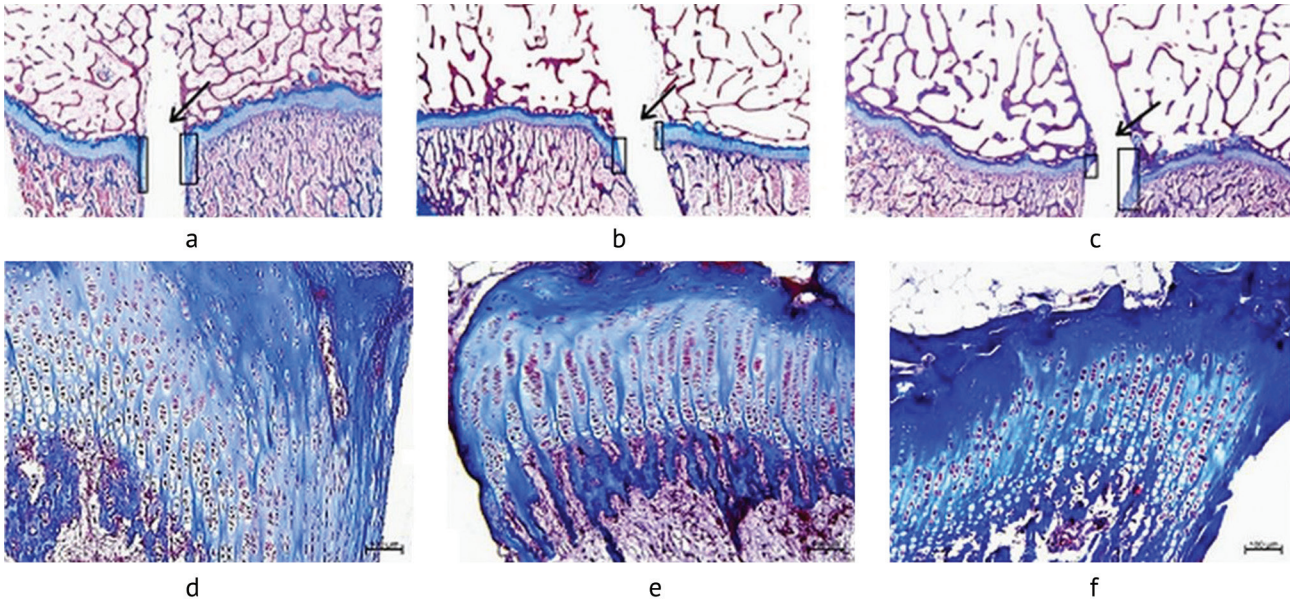

Fig. 4 Reactive changes in the metaepiphyseal cartilage of the distal femur at the border with the wire: *a, d* — series 1; *b, e* — series 2; *c, f* — series 3. The experiment lasted 120 days. The defect area (wire location) is indicated by an arrow. The extent of the zone of chondrocyte proliferation at the border with the wire is shown by a frame. Histotopograms (*a, b, c*). Fragments of paraffin sections. Magnification ×100 (*d, e, f*). Staining with three-color method according to Masson

After 60 and 120 days of the experiment, the width of the defect zone (wire tract) in the metaepiphyseal cartilage (M ± m) was (1404.74 ± 32.58) μm in series 1 and (1491.77 ± 15.37) μm respectively; (1448.41 ± 22.21) μm and (1459.35 ± 13.81) μm in series 2, respectively; and in series 3 (1618.08 ± 36.42) μm and (1639.01 ± 18.47) μm, respectively. There were no significant differences between the experimental periods ($p > 0.05$); the differences between series 1 and 2 were statistically insignificant (p = 0.655), the differences between series 1 and series 3 were at the trend level ($p = 0.0546$), between series 2 and series 3 were significant ($p = 0.0373$).

In the undamaged areas of the metaepiphyseal cartilage, the zonal structure was maintained throughout the experiment; an increase in the proliferative and biosynthetic activity of cartilage cells was noted in the zone of proliferating cartilage and in the border zone. In the border zone and epiphysis, newly formed areas of cartilage were present, represented by isogenic groups and separately located chondrocytes with a formed interterritorial matrix (Fig. 5).

Histomorphometrically, the most pronounced increase in the thickness of the metaepiphyseal cartilage of the distal femur was revealed during the experiment of 60 days in series 1 relative to the control, the differences with series 2 and 3 were statistically significant (Table 1). By the end of the experiment, statistically significant high values of this parameter relative to the control were in all series, the differences between series were at the level of a tendency (Table 1).

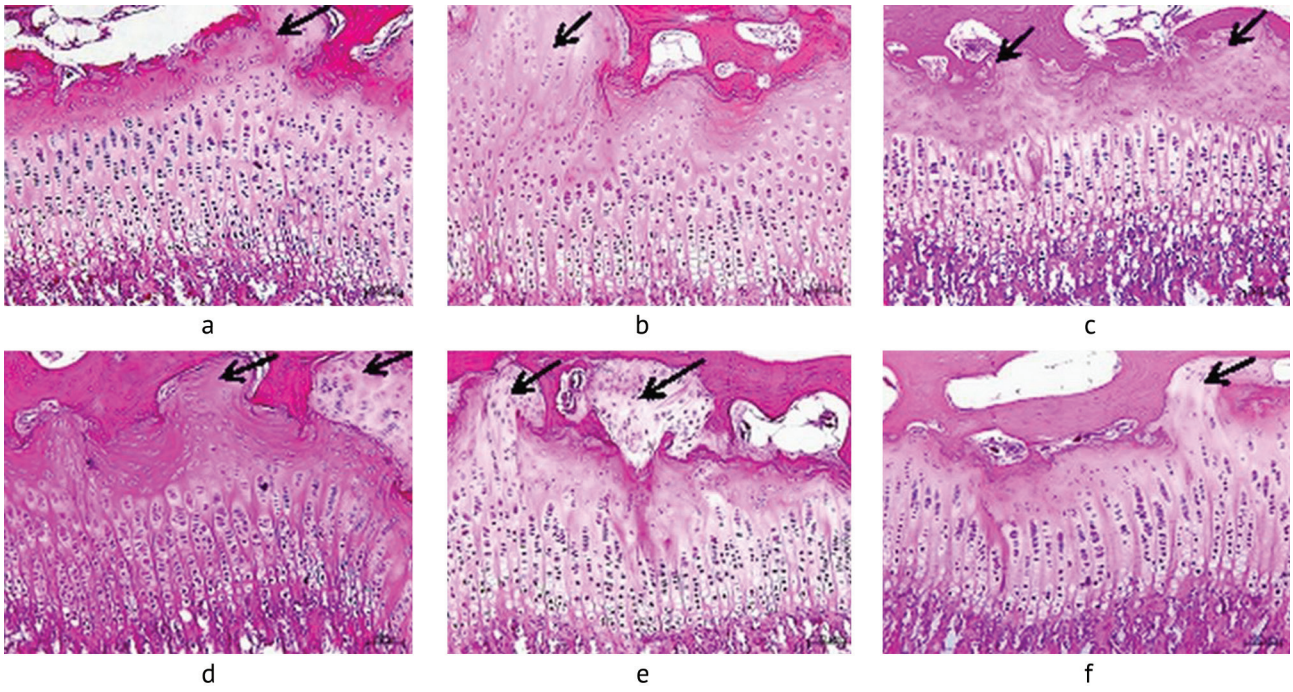

Fig. 5 Metaepiphyseal cartilage of the distal femur: *a, d* — series 1; *b, e* — series 2; *c, f* — series 3. Experiment duration: 60 days (*a, b, c*), 120 days (*d, e, f*). Newly formed areas of cartilage (arrow). Paraffin section, stained with hematoxylin and eosin. Magnification ×100

In the control limb during the growth of lambs, the percentage ratio of the zones of metaepiphyseal cartilage of the distal femur at the age of 3.5 and 5.5 months was 35:29:21:15 and 24:37:24:16 (reserve zone: zone of proliferating cartilage: zone hypertrophied chondrocytes: zone of calcified cartilage), accordingly; there was a pronounced (more than 5 %) decrease in the proportion of the reserve zone and an increase in the proportion of the zone of proliferating chondrocytes.

In experimental series after 60 days compared to the control, the change in the proportion of the reserve zone and zone of proliferating cartilage was more pronounced. Thus, the portion of the reserve zone in series 2 and 3 was reduced by 13 and 9 %, respectively, and in series 1 it was increased by 3 %. The proportion of the proliferating cartilage zone in all series was increased: in series 1 and 3 by 5 %, in series 2 by 15 %. After 120 days of the experiment in series 2 and 3, the ratio of metaepiphyseal cartilage zones was comparable to the control; in series 1 the portion of the zone of proliferating cartilage increased by 4 % (Fig. 6).

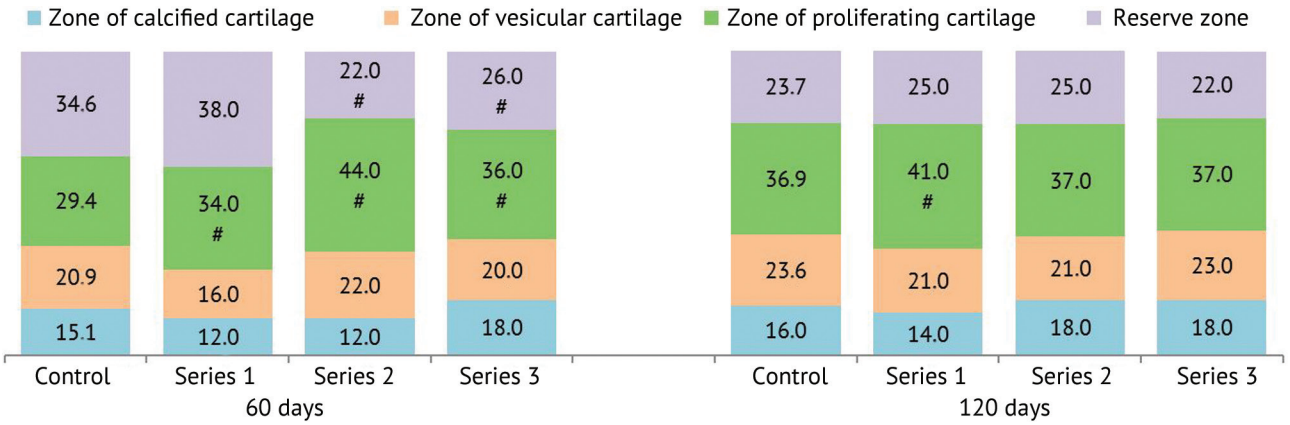

Fig. 6 Diagram showing the percentage of the zones in the metaepiphyseal cartilage of the distal femur at the stages of the experiment; # — significant differences with control at $p < 0.05$

DISCUSSION

The main function of the metaepiphyseal plate is bone growth in length due to balanced proliferation and elimination of chondrocytes [19, 20].

This function is provided by the structural features of the metaepiphyseal plate. The border or reserve zone is in contact with the epiphysis and is characterized by a predominance of intercellular substance in relation to the cells. Cartilage cells in this zone do not proliferate under normal conditions. It is assumed that the cells of this zone are a kind of stem cells that maintain a stable number of cells in the proliferative zone. In the zone of proliferating cartilage, cells are actively dividing. The growth of metaepiphyseal cartilage occurs due to an increase in the number of chondrocytes and the volume of the intercellular substance in this zone. In the zone of hypertrophied cartilage, chondrocytes lose the ability to divide, but retain high metabolic activity that results in a significant increase in size. In the zone of calcified cartilage, the death of chondrocytes and calcification of the matrix occurs, which serves as an ossification framework for osteoblasts [1, 19].

Due to the fact that the epiphyseal plate is an active, dynamic zone of growing bone, it is sensitive to the effects of various exogenous and endogenous factors.

The development of post-traumatic growth deficiency in children is based on two mechanisms: formation of “bone bridges” after vascularization and invasion of osteoblasts; ischemic necrosis of the epiphyseal cartilage due to trauma [15].

In our study, in the experimental series with direct injury to the growth plate of the distal femur with a wire/pin, signs of ischemic necrosis were not found. By the end of the experiment, the values of the width of the metaepiphyseal cartilage defect zone in series 1 and 2 were comparable, the differences between series were not statistically significant ($p > 0.05$); in series 3 the values were significantly higher, which is due to the conditions of pin insertion.

In all series, reactive changes in the form of proliferation of chondrocytes in the border (reserve) zone and the zone of proliferating cartilage were detected in areas of the metaepiphyseal cartilage at the border with the implant. The minimally expressed reactive changes in chondrocytes were noted in series 2, the most pronounced in series 1. In the latter series, by the end of the experiment, at the border with the wire, the penetration of blood vessels into the metaepiphyseal cartilage was revealed, which is prognostically unfavorable for the restoration of the growth zone. The vessels in the metaepiphyseal cartilage on the bone side are a source of osteoblasts that form “bone bridges.” In series 3, by the end of the experiment, in the areas of the metaepiphyseal cartilage adjacent to the pin, an increase in the proportion of the fibrous component was noted, which may indicate the subsequent formation of the so-called “fibrous bridge”.

The obtained histomorphometric characteristics of undamaged areas of the growth zone indicated that the insertion of implants, regardless of their material, was not accompanied by inhibition of the bone-forming function of the distal metaepiphyseal cartilage of the femur. This is confirmed by maintaining during the experiment for 120 days statistically significant increased values of the thickness of the metaepiphyseal cartilage (1.2 times higher than the control), the differences between the series showed only a tendency. The increase in this parameter occurred due to an increase in the proliferative and biosynthetic activity of cartilage cells in the zone of proliferating cartilage and in the border zone.

The works of a number of authors show that the proportions of zones in the metaepiphyseal cartilage are different for each species of mammal (rat, rabbit, pig, calf) [1, 21, 22]. Data on the relationship between the zones of metaepiphyseal cartilage in lambs at different age periods have not been found in the available literature.

In our study, the ratio of zones of metaepiphyseal cartilage in the distal femur was determined for the first time in lambs during growth (at the ages of 3.5 and 5.5 months). The most significant changes in the thickness of the reserve zone (decrease) and the zone of proliferating cartilage (increase) were revealed.

Celarek et al in an experiment on sheep found that at the age of 3.5 months, the most vulnerable zone under mechanical stress is the zone of proliferating cartilage, in which microscopic cracks were identified [23].

It is known that the main factors for the normal growth of metaepiphyseal cartilage are vascular support and the unimpaired function of the proliferating cartilage zone [2, 15, 24].

The main problem with growth plate injuries is the formation of bone tissue (bone bridge) and/or fibrosis (fibrous bridge), which hinders growth and may lead to angular deformities or limb length discrepancy [25, 26, 27].

The effectiveness of surgical removal of bone bridges from the epiphyseal plate is debatable, and the data in the world literature are contradictory. Thus, Peterson reports that the function of the growth plate that underwent surgery may vary from 0 to 200 % relative to the similar zone of the healthy limb [28]. That is, the function of the metaepiphyseal cartilage can be completely arrested or significantly increased.

Surgical methods for treating growth plate injuries are of unconditional interest, but require additional detailed research and analysis [11]. Until now, the choice of tactics for treating growth plate injuries depending on the size of the bone bridges has been debatable. According to some authors, the surgical treatment method is used when the bone bridge occupies more than 33 % of the growth plate; according to others, when the bone bridge occupies more than 50 % [26, 29, 30, 31].

Therefore, comparative experimental and morphological studies of the regeneration of metaepiphyseal cartilage defects after the use of wires/pins made of different materials are relevant in the future.

CONCLUSION

The revealed structural changes in the metaepiphyseal cartilage in the experimental series are characteristic of the reparative phase. At the border with the wires, active proliferative and biosynthetic activity of chondrocytes was observed, more intensely expressed in series 1.

Histomorphometric characteristics of intact areas of the growth plate showed that the insertion of wires, regardless of their material, was not accompanied by inhibition of the bone-forming function of the distal metaepiphyseal cartilage of the femur. In the experimental series, compared to the control limb, the change in the proportion of the reserve zone and the zone of proliferating cartilage was more pronounced. By the end of the experiment, the ratio of metaepiphyseal cartilage zones was comparable to the control in series 2 and 3; in series 1, the proportion of the proliferating cartilage zone increased by 4 %.

Conflict of interest *None.*

Funding *The work was supported by the program of the Ministry of Health of the Russian Federation within the framework of the state assignment of the Federal State Budgetary Institution National Ilizarov Medical Research Center of Traumatology and Orthopedics to carry out the research works for 2024–2026.*

REFERENCES

1. Zavarukhin VI, Morenko ES, Sviridov MK, Govorov AV. Embryonic development and the structure of the growth plate. Pediatric Traumatology, *Orthopaedics and Reconstructive Surgery*. 2015;3(2):61-65. (In Russ.) doi: 10.17816/PTORS3261-65
2. Wang X, Li Z, Wang C, et al. Enlightenment of Growth Plate Regeneration Based on Cartilage Repair Theory: A Review. *Front Bioeng Biotechnol*. 2021;9:654087. doi: 10.3389/fbioe.2021.654087
3. Kazemi M, Williams JL. Properties of Cartilage-Subchondral Bone Junctions: A Narrative Review with Specific Focus on the Growth Plate. *Cartilage*. 2021;13(2_suppl):16S-33S. doi: 10.1177/1947603520924776
4. Takeuchi A, Yamamoto N, Hayashi K, et al. Growth of epiphysis after epiphyseal-preservation surgery for childhood osteosarcoma around the knee joint. *BMC Musculoskelet Disord*. 2018;19(1):185. doi: 10.1186/s12891-018-2109-4
5. Qi L, Jiang Y, Wang Y, et al. The use of the pediatric physeal slide-traction plate in the treatment of neer-horwitz grade IV proximal humeral fractures in children: A case report and literature review. *Front Surg*. 2022;9:960541. doi: 10.3389/fsurg.2022.960541
6. Tiffany AS, Harley BAC. Growing Pains: The Need for Engineered Platforms to Study Growth Plate Biology. *Adv Healthc Mater*. 2022;11(19):e2200471. doi: 10.1002/adhm.202200471
7. Dover C, Kiely N. Growth plate injuries and management. *Orthopaedics and Trauma*. 2015;29(4): 261-267. doi: 10.1016/j.mporth.2015.04.002
8. Sananta P, Lesmana A, Alwy Sugiarto M. Growth plate injury in children: Review of literature on PubMed. *J Public Health Res*. 2022;11(3):22799036221104155. doi: 10.1177/22799036221104155
9. Levine RH, Thomas A, Nezwek TA, et al. Salter-Harris Fracture. In: *StatPearls* [Internet]. Treasure Island (FL): StatPearls Publ.; 2024. Available from: https://www.ncbi.nlm.nih.gov/books/NBK430688/. Accessed May 17, 2024.
10. Brovin DA, Trofimova TN, Kenis VM, Braylov SA. Diffusion-tensor magnetic resonance imaging of the growth plates: substantiation of the method and evaluation of its reproducibility. *Diagnostic radiology and radiotherapy*. 2022;13(3):67-76. (In Russ.) doi: 10.22328/2079-5343-2022-13-3-67-76
11. Sokolovskij OA, Serdjuchenko SN, Brodko GA, Demencov AB. Growth plate surgery: history and prospects. *Medical news*. 2011;7:C.31-35. (In Russ.)
12. Korobeinikov AA, Aranovich AM, Popkov DA. Ilizarov method in the treatment of children with periarticular fractures. *Genij Ortopedii*. 2021;27(4):418-423. doi: 10.18019/1028-4427-2021-27-4-418-423
13. Miyamura S, Tanaka H, Oka K, et al. Physeal bar resection using a patient-specific guide with intramedullary endoscopic assistance for partial physeal arrest of the distal radius. *Arch Orthop Trauma Surg*. 2018;138(8):1179-1188. doi: 10.1007/s00402-018-2985-y
14. Lascombes P, Journeau P, Popkov DA. Resorbable implants in paediatric orthopaedics and traumatology. *Genij Ortopedii*. 2023;29(6):629-634. doi: 10.18019/1028-4427-2023-29-6-629-634
15. Hajdu S, Schwendenwein E, Kaltenecker G, et al. The effect of drilling and screw fixation of the growth plate--an experimental study in rabbits. *J Orthop Res*. 2011;29(12):1834-1839. doi: 10.1002/jor.21463
16. Sheikh Z, Najeeb S, Khurshid Z, et al. Biodegradable Materials for Bone Repair and Tissue Engineering Applications. *Materials* (Basel). 2015;8(9):5744-5794. doi: 10.3390/ma8095273
17. Fan XL, Wang J, Zhang DH, et al. Antegrade intramedullary fixation for adolescent fifth metacarpal neck fracture and its impact on epiphyseal growth. *BMC Musculoskelet Disord*. 2021;22(1):546. doi: 10.1186/s12891-021-04436-w
18. Shhudlo MM, Varsegova TN, Stupina TA, et al. The problem of the Holmes effect in quantitative telepathology (methodological aspects). *News of the Chelyabinsk Scientific Center*. 2003;(1):120-124. (In Russ.)
19. Ağırdil Y. The growth plate: a physiologic overview. *EFORT Open Rev*. 2020;5(8):498-507. doi: 10.1302/2058-5241.5.190088
20. Fernández-Iglesias Á, Fuente R, Gil-Peña H, et al. The Formation of the Epiphyseal Bone Plate Occurs via Combined Endochondral and Intramembranous-Like Ossification. *Int J Mol Sci*. 2021;22(2):900. doi: 10.3390/ijms22020900
21. Villemure I, Stokes IA. Growth plate mechanics and mechanobiology. A survey of present understanding. *J Biomech*. 2009;42(12):1793-803. doi: 10.1016/j.jbiomech.2009.05.021
22. D'Andrea CR, Alfraihat A, Singh A, et al. Part 2. Review and meta-analysis of studies on modulation of longitudinal bone growth and growth plate activity: A micro-scale perspective. *J Orthop Res*. 2021;39(5):919-928. doi: 10.1002/jor.24992
23. Celarek A, Fischerauer SF, Weinberg AM, Tschegg EK. Fracture patterns of the growth plate and surrounding bone in the ovine knee joint at different ages. *J Mech Behav Biomed Mater*. 2014;29:286-294. doi: 10.1016/j.jmbbm.2013.09.010
24. Chung R, Xian CJ. Recent research on the growth plate: Mechanisms for growth plate injury repair and potential cell-based therapies for regeneration. *J Mol Endocrinol*. 2014;53(1):T45-T61. doi: 10.1530/JME-14-0062
25. Shaw N, Erickson C, Bryant SJ, et al. Regenerative Medicine Approaches for the Treatment of Pediatric Physeal Injuries. *Tissue Eng Part B Rev*. 2018;24(2):85-97. doi: 10.1089/ten.TEB.2017.0274.
26. Yu Y, Fischenich KM, Schoonraad SA, et al. A 3D printed mimetic composite for the treatment of growth plate injuries in a rabbit model. *NPJ Regen Med*. 2022;7(1):60. doi: 10.1038/s41536-022-00256-1
27. Guo R, Zhuang H, Chen X, et al. Tissue engineering in growth plate cartilage regeneration: Mechanisms to therapeutic strategies. *J Tissue Eng*. 2023; 14:20417314231187956. doi: 10.1177/20417314231187956
28. Peterson HA. Partial growth plate arrest and its treatment. *J Pediatr Orthop*. 1984;4(2):246-258. doi: 10.1097/01241398-198403000-00015
29. Khoshhal KI, Kiefer GN. Physeal bridge resection. *J Am Acad Orthop Surg*. 2005;13(1):47-58. doi: 10.5435/00124635-200501000-00007

30. Moreta J, Abril JC, Miranda C. Arthroscopy- assisted resection-interposition of post-traumatic central physeal bridges. *Rev Esp Cir Ortop Traumatol*. 2013;57(5):333-339. (In Span.) doi: 10.1016/j.recot.2013.07.004
31. Ladenhauf HN, Jones KJ, Potter HG, et al. Understanding the undulating pattern of the distal femoral growth plate: Implications for surgical procedures involving the pediatric knee: A descriptive MRI study. *Knee*. 2020;27(2):315-323. doi: 10.1016/j.knee.2020.02.003

The article was submitted 19.04.2024; approved after reviewing 15.05.2024; accepted for publication 18.06.2024.

Information about the authors:

Anatoly A. Korobeinikov — Candidate of Medical Sciences, Head of Laboratory, koroban@list.ru, https://orcid.org/0009-0005-0326-8285;

Tatyana A. Stupina — Doctor of Biological Sciences, Leading Researcher, StupinaSTA@mail.ru, https://orcid.org/0000-0003-3434-0372;

Olga V. Dyuryagina — Candidate of Veterinary Sciences, Head of Laboratory, diuriagina@mail.ru, https://orcid.org/0000-0001-9974-2204;

Mikhail A. Stepanov — Candidate of Veterinary Sciences, veterinarian, m-stepanov@mail.ru;

Nikolai I. Antonov — Candidate of Biological Sciences, Senior Researcher, aniv-niko@mail.ru, https://orcid.org/0000-0002-8627-2749

Original article
https://doi.org/10.18019/1028-4427-2024-30-4-572-580

Achilles tendon regeneration after experimental transverse tenotomy with preserved peritenon and the structures

M.V. Vlasov, N.Yu. Shirokova, I.V. Musikhina✉

Privolzhsky Research Medical University, Nizhny Novgorod, Russian Federation

Corresponding author: Irina V. Musikhina, i_musihina@mail.ru

Abstract

Introduction The Ponseti method is the first choice for congenital clubfoot with the possibilities of transverse tenotomy being underexplored in repair of the Achilles tendon in pediatric patients.

The **objective** was to identify specific features of the Achilles tendon repair after experimental transverse intersection and preserved peritenon, vessels and nerves of growing rabbits.

Material and methods The experimental study included 20 Chinchilla rabbits of both sexes aged 1.0–1.5 months used as a biomodel with a weight of 1476.0 ± 114.3 g. Rabbits were sacrificed in groups of five by air embolism under local anesthesia at 15, 30, 60 and 90 days of surgery.

Results The tendon defect zone was represented by small areas of dense fibrous scar tissue with some cellular fibroblasts, and tendon fibers of unremarkable architectonics arranged in a mutually parallel waves could be seen in the layers of connective tissue at 90 days. The thickness of the first-order collagen fibers increased to 8.9 ± 1.32 μm and comparison with the normal value of 9.2 ± 1.88 μm showed no statistically significant difference ($p = 0.38$). The thickness of the second-order collagen fibers increased to 28.1 ± 1.28 μm during the time, and comparison with the standard measurements of 28.3 ± 2.23 μm demonstrated no statistically significant difference ($p = 0.64$).

Discussion According to the literature, the ability of the tenoblast to synthesize structural proteins and regulatory biomolecules after injury decreases with age and leads to fibrous restoration of the tendon and formation of a permanent scar. Our study on growing rabbits showed that the organotypic structure of the experimental tendon restored at the intersection site at 60 days with the Achilles tendon defect being represented by the tendon-like tissue at 90 days.

Conclusion The Achilles tendon was shown to regenerate in optimal conditions after the dissection and preservation of the peritenon, vessels and nerves with tendon tissue being formed within a short time (3 months after the intervention) being identical to the original.

Keywords: congenital clubfoot, Ponseti method, Achilles tendon regeneration, micromorphometry, experiment, rabbit

For citation: Vlasov MV, Shirokova NYu, Musikhina IV. Achilles tendon regeneration after experimental transverse tenotomy with preserved peritenon and the structures. *Genij Ortopedii*. 2024;30(4):572-580. doi: 10.18019/1028-4427-2024-30-4-572-580

© Vlasov M.V., Shirokova N.Yu., Musikhina I.V., 2024
© Translator Irina A. Saranskikh, 2024

INTRODUCTION

Congenital clubfoot treatment has evolved throughout history: from nonoperative management reported by Kite (1972) [1] and various surgical interventions to the Ponseti approach [2–6]. The Ponseti method has become the gold standard of care for the treatment of congenital club foot. It consists of simultaneous correction of the main components of the foot deformity, application of plaster casts, Achilles tendon tenotomy and foot abduction bracing [7–14]. Moreover, in 70–85 % of cases, correction of the equinus of the foot can be corrected through percutaneous transverse Achilles tenotomy [15–19].

Tendon regeneration has been a topic of interest amongst the scientific world [20–22]. Thus, tendon regeneration can occur due to intrinsic resources through proliferation and migration of tenocytes from the epitenon and endotenon to the injury site or extrinsic resources through penetration of cells from the tendon sheath and synovium [23–24]. Tendon healing involves intrinsic and extrinsic mechanisms, with the latter being predominant earlier in the healing process while the intrinsic mechanism can be delayed [25]. The sources of regeneration are important for the synthesis of the extracellular matrix (ECM) and for the establishment of the intrinsic neovascular network [26]. Ultrastructural changes are maintained after 12 months of injury [27]. The tendon regenerate is scar-like and unable to restore the biomechanical properties it had before injury [28]. Frank, McDonald and Shrive [29] reported remodeling of tendon tissue that can continue for several years, and tendons can demonstrate a significant decrease in structural and mechanical properties immediately after injury, followed by a slow, but incomplete restoration to the original parameters.

Although Achilles lengthening is the standard treatment of congenital clubfoot in children using the Ponseti method, there is no data on the reparative processes of the transected calcaneal tendon with the preservation of the peritenon. A practicing orthopaedic surgeon aims to restore pediatric anatomy of the bone and the tendon during surgical intervention. Changes in the Achilles tendon after its intersection are essential in the treatment of congenital clubfoot. The effectiveness of the rehabilitation of the patients would depend on the quality of the calcaneal tendon recovery and the time: the length of immobilization, the safety of mechanical load and exercise therapy programme. Experiments on growing animals were produced to explore changes in the tendon with transverse achillotomy and intact peritenon, vessels and nerves.

The **objective** was to identify specific features of the Achilles tendon repair after experimental transverse intersection and preserved peritenon, vessels and nerves of growing rabbits.

MATERIAL AND METHODS

Achilles tendon repair was explored experimentally in growing animals that underwent transverse tenotomy without crossing the connective tissue sheath, peritenon. The experimental study included 20 Chinchilla rabbits as biomodels of both sexes aged 1–1.5 months with a weight of 1476.0 ± 114.3 g. Conventional animals were kept under standard conditions in the vivarium of a university clinic in accordance with the rules of the European Convention on protection of vertebrate animals used for experiments or other scientific purposes (Strasbourg, 18.05.2014). The experimental part of the work was performed following the requirements set out in the Order of the Ministry of Health and Social Development of the Russian Federation No. 708n dated August 23, 2010 “On approval of the rules of proper laboratory practice.”

Rabbits were sacrificed in groups of five by air embolism under local anesthesia on days 15, 30, 60 and 90 after achillotomy. The timings for the study of the tendon reparative regeneration were selected based on literature data [30]. An Achilles tendon preparation of the intact rabbit

limb was examined in all series of the experiment to determine the parameters of the age norm. The regenerated Achilles area was histologically examined, and collagen fibers of the first and second order were counted.

The experiment reproduced a subcutaneous transverse section of the Achilles tendon with intact peritenon, vessels and nerves. Under general anesthesia, the skin and subcutaneous tissue were dissected longitudinally 0.3–0.5 cm on the posterior tibia at a distance of 1 cm off the attachment of the Achilles tendon to the calcaneal tubercle. Then the tendon sheath and the peritenon were longitudinally dissected with the intersection of all the layers including paratenon and epitenon to the length of the skin incision. The calcaneal tendon was isolated subperitenonially and transected transversely with a scalpel No. 11 causing no injury to the peritenon. Then the animal's paw was dorsiflexed with the ends of the transected tendon diverging by 0.5–0.7 cm inside the connective tissue sheath. The skin wound was not sutured. The limb was fixed with a plaster cast from the upper third of the thigh to the foot for 2 weeks. There was no limitation to weight-bearing with the cast removed.

The tissue samples were fixed in a 10 % solution of buffered neutral formalin and decalcified using Biodec-R medium (Bio-Optica). Histological examination of the specimens was produced according to the generally accepted method using Thermo Excelsior ES Tissue Processor. Paraffin embedded tissue blocks were produced using Thermo Scientific HistoStar Embedding Workstation. Thermo Scientific Microm HM 325 Microtome was used to produce paraffin-embedded sections 4–6 μm thick that were stained with hematoxylin and eosin, and mounted in mounting medium. Microscopy and photographic recording of histological preparations were produced using the Leica DMR morphometric equipment.

Statistical analysis was performed using the Statistika 12.0 package. Normal distribution was statistically identified using the Shapiro – Wilk test. The nonparametric Wilcoxon method was used for the samples that did not correspond to the normal distribution law and had a small volume.

RESULTS

The thickness of collagen fibers of the first and second order measured normally and at the regeneration site of sacrificed animals at different points in time is presented in Table 1.

Table 1

Comparative analysis of the thickness of collagen fibers of the first and second order measured normally and at the regeneration site

Term of animal sacrifice		Thickness of collagen fibers, microns	
		I order	II order
Normal (n = 5)	M ± SD	9.2 ± 1.88	28.3 ± 2.23
14 days (n = 5)	M ± SD	4.8 ± 1.81	16.4 ± 2.27
	p-level	**p^* = 0.005**	**p^* = 0.0003**
30 days (n = 5)	M ± SD	6.9 ± 1.42	20.5 ± 2.49
	p-level	**p^* = 0.002, p^{**} = 0.04**	**p^* = 0.0003, p^{**} = 0.01**
60 days (n = 5)	M ± SD	8.5 ± 1.43	25.2 ± 2.54
	p-level	p^* = 0.13, p^{**} = 0.02	p^* = 0.07, p^{**} = 0.01
90 days (n = 5)	M ± SD	8.9 ± 1.32	28.1 ± 1.28
	p-level	p^* = 0.38, p^{**} = 0.14	p^* = 0.64, p^{**} = 0.07

Note: *M*, mean; *SD*, root-mean-square standard deviation indicating the spread of data over the interval of the characteristic value relative to the mean; p-level (p^*), level of significance (Wilcoxon signed-rank test) of differences in relation to normal parameters; p^{**}, level of significant differences in relation to measurements of the previous day.

The traumatic injury site was represented by acellular areas and lysed collagen fibers at 15 days of surgery. A significant area of the preparation was occupied by thin collagen fibers, forming a felt-like network interspersed with small foci of necrosis. The adipose tissue had a small area. A large number of fibroblastic cells, differing in shape and size, were located along the bundles of collagen fibers or formed proliferates. Tender maturing granulation tissue with predominating histiocytes and fibroblasts and a high content of thin-walled vessels in the cells was identified in some areas of the defect zone. Collagen fibers maintained axial direction in the tendon being adjacent to the injury site at a short distance, but "intercalated" bundles led to disrupted orientation of most fibers with resultant thinned and fragmented bundles of collagen fibers acquiring tortuous contours. Destruction foci or extensive cell proliferation were seen in the zone (Fig. 1).

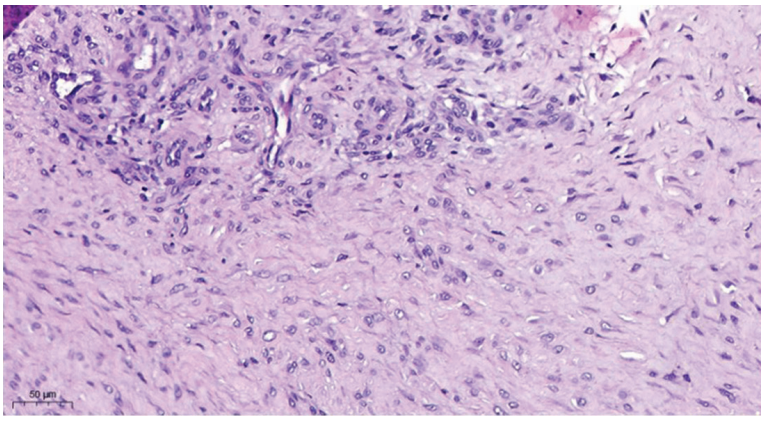

Fig. 1 Longitudinal section of the rabbit's calcaneal tendon in the defect area at 15 days showing an area of granulation tissue being replaced by scar tissue with a large number of fibroblasts. Stained by hematoxylin and eosin, magnification ×200

Areas of tendon destruction were identified at the site with loss of pink color and replacement foci, dense fibrous connective tissue and small areas of loose, abundant cellular tissue with a large number of histiocytic elements. A thinner regenerate with an ordered structure containing no excess collagen structures, was observed at the defect site at the stage of the experiment. The predominance of fibrocytic cells located between parallel bundles of collagen fibers was determined in the scar tissue. The structure of the scar tissue was identical to the original tendon tissue, which was confirmed by the presence of bundles of collagen fibers of the first and second order, tightly adjacent to each other with areas of loose connective tissue and a small number of blood vessels.

The thickness of the first order collagen fibers measured 4.80 ± 1.81 μm at 15 days and was statistically less significant than the normal value of 9.20 ± 1.88 μm, $p = 0.005$. The thickness of the second-order collagen fibers at the time was equal to 16.40 ± 2.27 μm with a statistically significant difference compared to the normal of 28.30 ± 2.23 μm, $p = 0.001$.

Extended sections of mutually parallel bundles of tendon fibers with visible tenocyte nuclei separated by endotendinium were identified in the perifocal zone of the tendon at 30 days. Increased thickness of the collagen fiber bundles was noted at the time, which acquired a wavy configuration characteristic of the normal tendon structure. However, some collagen structures remained less structured with lack of waviness. The representation of adipose tissue was more widespread in the area compared to the previous study period and appeared as focal growths. The defect site was characterized by a growth of dense fibrous connective tissue of a scar nature with a small content of capillary-type vessels and cellular fibroblast-histiocytic elements. There was no unidirectionality and orderliness in the arrangement of collagen fibers in the regenerate structure with areas of low density of fibroblasts differing in the shape and size of the nucleus (Fig. 2).

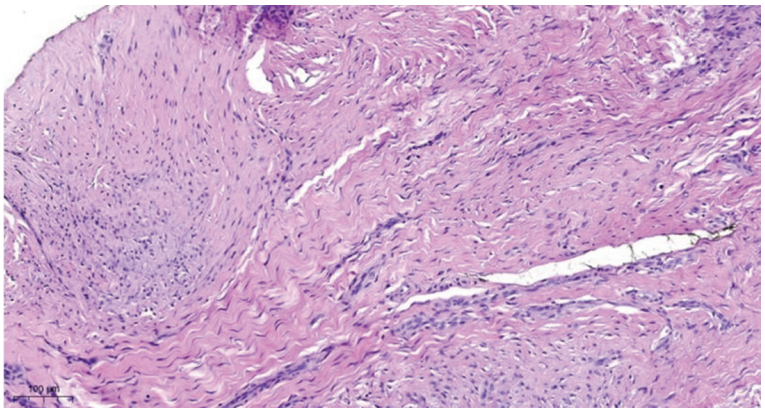

Fig. 2 Longitudinal section of a rabbit's calcaneal tendon at the defect site at 30 days showing areas of parallel bundles of tendon fibers with a wavy configuration, proliferation of scar tissue. Stained with hematoxylin and eosin, magnification ×100

The thickness of the first order collagen fibers increased to 6.90 ± 1.42 μm at 30 days compared to 4.80 ± 1.81 μm measured at 15 days with the statistically significant difference, $p = 0.04$. A significant difference remained with comparison to the normal of 9.20 ± 1.88 μm, $p = 0.002$. The thickness of collagen fibers of the second order statistically increased to 20.50 ± 2.49 μm at 30 days as compared to the parameter measuring 16.40 ± 2.27 μm on the previous day, $p = 0.01$. However, the value of the thickness of collagen fibers of the second order was statistically less in relation to the standard value, p = 0.001.

Extensive layers of preserved tendon tissue and dense bundles of collagen fibers were seen at the injury site at 60 days. Small areas of abundant cellular connective tissue, scars were found over a small area of transections (Fig. 3). The scars were characterized by a typical arrangement of collagen fibers, with some multidirectional areas of compaction and some with loose bundles and isolated degeneration areas. The scars were characterized by a decreased number of blood capillaries and vessels with an enlarged empty lumen.

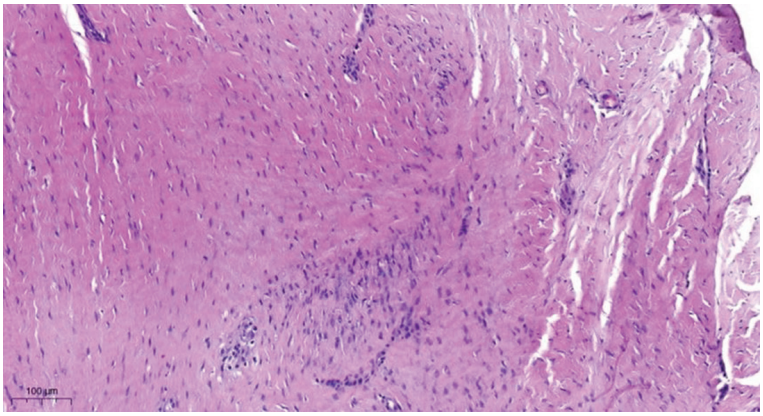

Fig. 3 Tangential section of the rabbit calcaneal tendon at the defect site at 60 days showing areas of parallel tendon fiber bundles with small inclusions of scar tissue. Stained with hematoxylin and eosin, magnification ×100

Areas of dense fibrous tissue included small foci of loose fibers and a small amount of adipose tissue, which appeared as small focal accumulations of lipocytes in the histological specimen. Tendon-like tissue developed in the healing zone over a larger area of the cut at 60 days with densely arranged dark-eosinophilic fibers and small areas of fatty and scar tissue. The bundles of collagen fibers had a unidirectional and orderly arrangement with the fiber thickness being similar to those of the normal tendon.

The thickness of the first order collagen fibers increased to 8.50 ± 1.43 μm at 60 days compared to 6.90 ± 1.42 μm measured at 30 days with a statistically significant difference (p = 0.02). There was a statistically significant increase in the thickness of collagen fibers of the second order measuring 25.20 ± 2.54 μm in comparison to the previous parameter (p = 0.07) at the time. The thickness of collagen fibers of the first and second order became similar to the normal (p = 0.13 and p = 0.07, respectively).

Extended areas of tendon tissue with wavy normally structured light-eosinophilic fibers and thickened peritenonium, small areas of loose fibrous connective tissue with a network of vessels and small foci of adipose tissue were identified in the perifocal zone of the tendon at 90 days (Fig. 4).

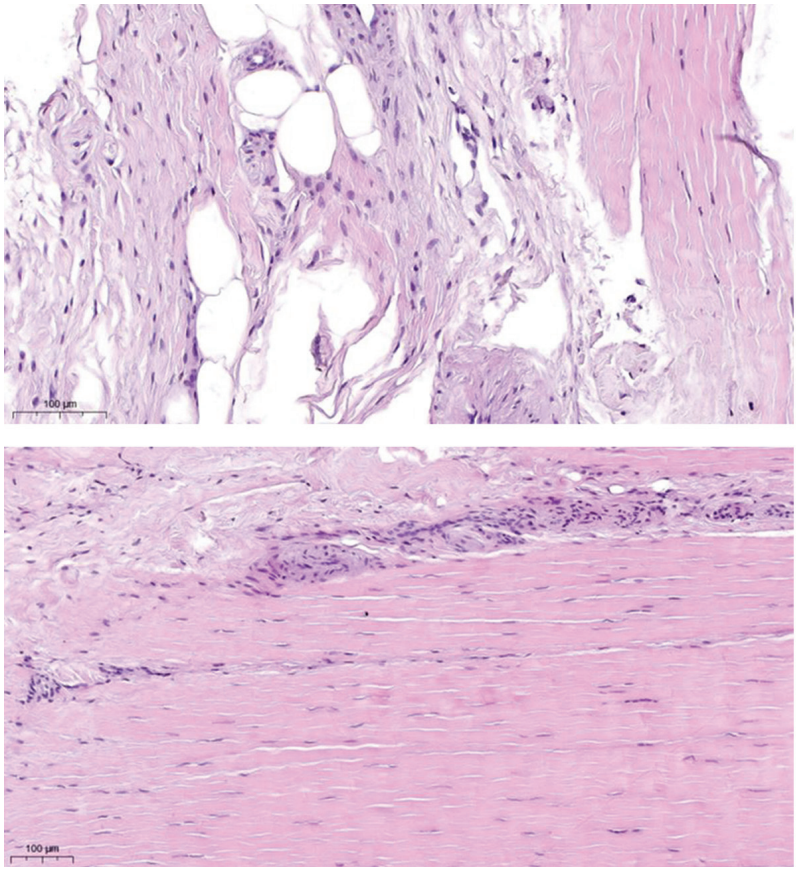

Fig. 4 Longitudinal section of the rabbit's calcaneal tendon at the defect site at 90 days showing (*a*) a fragment of a tendon-like regenerate and areas of loose connective tissue with areas of adipose tissue; (*b*) a fragment of a tendon-like regenerate with areas of vascular proliferation. Stained with hematoxylin and eosin, magnification×200

Tendon fibers of the usual architectonics with parallel wavy arrangement were found in the layers of connective tissue in the defect site at the time. Foci of loose connective tissue and a small number of small-caliber vessels were identified along the periphery in the areas adjacent to the defect zone.

The thickness of the first order collagen fibers increased to 8.9 ± 1.32 μm at 90 days as compared to the parameter measured at 60 day, p = 0.14 with no statistically significant difference (p = 0.38) when compared to the normal of 9.2 ± 1.88 μm. The thickness of the second order collagen fibers increased to 28.1 ± 1.28 μm at the time with no statistically significant difference determined in relation to the previous measurement of 25.2 ± 2.54 μm and the standard parameter of 28.3 ± 2.23 μm (p = 0.07 and p = 0.64, respectively).

DISCUSSION

According to the literature, tendons undergo numerous biochemical, cellular and mechanical changes during the aging process causing a decreased ability of the tendon to recover from injury. There is a decrease in the volumetric density of tenoblasts, decreased tenoblasts per unit surface area of the tendon [31, 32]. In general, the ability of the tenoblast to synthesize structural proteins and regulatory biomolecules after injury decreases with age.

With collagen synthesis and collagenolytic activity decreasing with age, there is a decrease in collagen fiber regeneration [33, 34]. The decrease results in an increased diameter of the collagen fibers and marked variability in thickness. Proliferating fibroblasts lead to fibrotic tendon repair and permanent scar formation in the absence of an effective number of adult tenogenic progenitor cells that would effect the cell production [35, 36].

Our experimental study on growing rabbits showed a thinner regenerate formed after tenotomy with preserved peritenonial membrane in the defect area with an ordered structure not containing excess collagen at 15 days. The predominance of fibrocytic cells located between parallel bundles of collagen fibers was determined in scar tissue. The structure of the scar tissue was almost identical to the original tendon tissue, which was confirmed by the presence of bundles of collagen fibers of the first and second order being tightly adjacent to each other with areas of loose connective tissue in-between with a small number of blood vessels. The organotypic structure of the tendon restored at the site of intersection at 30 and 60 days. The injury site was filled with tendon-like tissue and densely arranged dark eosinophilic fibers with small areas of fatty and scar tissue at 60 days. The bundles of collagen fibers had a unidirectional and orderly arrangement with the thickness of the fibers being identical to the parameters of the normal tendon. The defect zone was represented by small areas of dense fibrous scar tissue with a small number of cellular elements of fibroblasts at 90 days. Among the layers, tendon fibers of ordinary architecture were found in a parallel arrangement of collagen fiber bundles of connective tissue with the thickness being close to standard values.

It can be suggested that the intact connective tissue sheath (peritenon) can prevent the ends of the crossed calcaneal tendon from diverging over a significant distance. In this case, the intact connective tissue sheath (peritenon) actually maintains the tendon in a state of functional tension. Reparative processes in the defect area in the case with preserved functional tension of the injured tendon can occur within a short period of time. In addition to that, an intact tendon sheath (peritenon) with preserved vessels and nerves has a beneficial effect on reparative processes in the Achilles tenotomy site. The factors result in the area of the heel tendon defect being represented by tendon-like tissue over a large area with tendon fibers of ordinary architecture arranged in mutually parallel bundles of collagen fibers with the thickness being similar to standard measurements at 90 days. Based on the results of experimental work, it can be assumed that a patient with congenital clubfoot after Achillotomy performed in a sparing manner with intact peritenon can completely restore the integrity and morphological structure of the calcaneal tendon at 3 months.

CONCLUSION

The experimental study showed that tendon-like tissue with collagen fibers of adequate thickness could form at the site of Achillotomy at 3 months including small islands of fibrous scar tissue and a small number of cellular elements, fibroblasts. The Achilles tendon was shown to regenerate in optimal conditions after the dissection and preservation of the peritenon, vessels and nerves with tendon tissue being identical to the original. Therefore, Achillotomy performed for patients treated with the Ponseti method and preserved connective tissue sheath (peritenon), vessels and nerves can facilitate a positive surgical outcome.

Conflict of interest *Not declared.*

Funding *Not declared.*

REFERENCES

1. Kite JH. Nonoperative treatment of congenital clubfoot. *Clin Orthop Relat Res*. 1972;84:29-38. doi: 10.1097/00003086-197205000-00007
2. Dobbs MB, Gurnett CA. Update on clubfoot: etiology and treatment. *Clin Orthop Relat Res*. 2009;467(5):1146-1153. doi: 10.1007/s11999-009-0734-9
3. Rijal R, Shrestha BP, Singh GK, et al. Comparison of Ponseti and Kite's method of treatment for idiopathic clubfoot. *Indian J Orthop*. 2010;44(2):202-207. doi: 10.4103/0019-5413.61941
4. Kaseke F, Mudawarima T. Comparison of Ponseti and Kite's method of treatment for congenital Talipes Equino using the Pirani scoring system. *Cent Afr J Med*. 2013;59(1-4):14-18.
5. Garcia LC, de Jesus LR, Trindade MO, et al. Evaluation of kite and ponseti methods in the treatment of idiopathic congenital clubfoot. *Acta Ortop Bras*. 2018;26(6):366-369. doi: 10.1590/1413-785220182606183925
6. Bina S, Pacey V, Barnes EH, et al. Interventions for congenital talipes equinovarus (clubfoot). *Cochrane Database Syst Rev*. 2020;5(5):CD008602. doi: 10.1002/14651858.CD008602.pub4
7. Kozhevnikov OV, Kosov IS, Gribova IV, et al. New Tecnology for Correction of Severe Types of Club Foot in Children. *N.N. Priorov Journal of Traumatology and Orthopedics*. 2009;(1):58-64. (In Russ.)
8. Kenis VM, Stepanova YuA. Causes of Non-Optimal Conservative Treatment of Congenital Clubfoot in Children. *Traumatology and Orthopedics of Russia*. 2017;23(3):80-85. (In Russ.) doi: 10.21823/2311-2905-2017-23-3-80-85
9. Morcuende JA. Congenital idiopathic clubfoot: prevention of late deformity and disability by conservative treatment with the Ponseti technique. *Pediatr Ann*. 2006;35(2):128-136. doi: 10.3928/0090-4481-20060201-13
10. Pirani S, Naddumba E, Mathias R, et al. Towards effective Ponseti clubfoot care: the Uganda Sustainable Clubfoot Care Project. *Clin Orthop Relat Res*. 2009;467(5):1154-1163. doi: 10.1007/s11999-009-0759-0
11. Owen RM, Penny JN, Mayo A, et al. A collaborative public health approach to clubfoot intervention in 10 low-income and middle-income countries: 2-year outcomes and lessons learnt. *J Pediatr Orthop B*. 2012;21(4):361-365. doi: 10.1097/BPB.0b013e3283504006
12. Radler C. The Treatment of Recurrent Congenital Clubfoot. *Foot Ankle Clin*. 2021;26(4):619-637. doi: 10.1016/j.fcl.2021.07.001
13. Rieger MA, Dobbs MB. Clubfoot. *Clin Podiatr Med Surg*. 2022;39(1):1-14. doi: 10.1016/j.cpm.2021.08.006
14. Jain AK, Kohli N, Bansal N, et al. Evaluation of Results of Ponseti Technique in Idiopathic Clubfoot using Clinical Evaluation and Radiological Assessment. *Int J Appl Basic Med Res*. 2022;12(1):43-46. doi: 10.4103/ijabmr.ijabmr_281_21
15. Blandinsky VF, Vavilov MA, Torno TE, Donskoy AV. Management of atypical clubfoot by ponseti method. *Traumatology and Orthopedics of Russia*. 2010;16(1):75-79. (In Russ.) doi: 10.21823/2311-2905-2010-0-1-75-79
16. Morcuende JA, Abbasi D, Dolan LA, Ponseti IV. Results of an accelerated Ponseti protocol for clubfoot. *J Pediatr Orthop*. 2005;25(5):623-6. doi: 10.1097/01.bpo.0000162015.44865.5e
17. Terrazas-Lafargue G, Morcuende JA. Effect of cast removal timing in the correction of idiopathic clubfoot by the Ponseti method. *Iowa Orthop J*. 2007;27:24-27.
18. Cohen E, Katz T, Rozen U, et al. The Influence of Achilles Tenotomy and Compliance with Foot Abduction Orthosis on the Relapse Rate of Ponseti Treatment for Idiopathic Clubfoot: A Regional Study. *J Foot Ankle Surg*. 2020;59(4):784-787. doi: 10.1053/j.jfas.2019.12.007
19. Rademan J. Ruptured pseudoanuerysm of the posterial tibial artery after percutaneous Achilles tenotomy. *BMJ Case Rep*. 2022;15(3):e232847. doi: 10.1136/bcr-2019-232847
20. Demichev N.P., Putilin A.A. Cryopreservation and allotransplantation of tendon tissue. *Orthopedics, traumatology and prosthetics*. 1990;(4):22-27. (In Russ.)
21. Conway AM, Dorner RW, Zuckner J. Regeneration of resected calcaneal tendon of the rabbit. *Anat Rec*. 1967;158(1):43-49. doi: 10.1002/ar.1091580106
22. Enwemeka CS, Spielholz NI, Nelson AJ. The effect of early functional activities on experimentally tenotomized Achilles tendons in rats. *Am J Phys Med Rehabil*. 1988;67(6):264-269.
23. Gelberman RH, Manske PR, Vande Berg JS, et al. Flexor tendon repair in vitro: a comparative histologic study of the rabbit, chicken, dog, and monkey. *J Orthop Res*. 1984;2(1):39-48. doi: 10.1002/jor.1100020107
24. Manske PR, Lesker PA. Biochemical evidence of flexor tendon participation in the repair process--an in vitro study. *J Hand Surg Br*. 1984;9(2):117-120.
25. Voleti PB, Buckley MR, Soslowsky LJ. Tendon healing: repair and regeneration. *Annu Rev Biomed Eng*. 2012;14:47-71. doi: 10.1146/annurev-bioeng-071811-150122
26. James R, Kesturu G, Balian G, Chhabra AB. Tendon: biology, biomechanics, repair, growth factors, and evolving treatment options. *J Hand Surg Am*. 2008;33(1):102-112. doi: 10.1016/j.jhsa.2007.09.007
27. Miyashita H, Ochi M, Ikuta Y. Histological and biomechanical observations of the rabbit patellar tendon after removal of its central one-third. *Arch Orthop Trauma Surg*. 1997;116(8):454-462. doi: 10.1007/BF00387577
28. Leadbetter W.B. Cell-matrix response in tendon injury. *Clin Sports Med*. 1992;11(3):533-578.
29. Frank C, McDonald D, Shrive N. Collagen fibril diameters in the rabbit medial collateral ligament scar: a longer term assessment. *Connect Tissue Res*. 1997;36(3):261-269. doi: 10.3109/03008209709160226

30. Lavrishcheva G.I., Onoprienko G.A. *Morphological and clinical aspects of reparative regeneration of supporting organs and tissues*. Moscow: Meditsina Publ.; 1996:208. (In Russ.)
31. Nagy IZ, Von Hahn HP, Verzár F. Age-related alterations in the cell nuclei and the DNA content of rat tail tendon. *Gerontologia*. 1969;15(4):258-264. doi: 10.1159/000211694
32. Moore MJ, De Beaux A. A quantitative ultrastructural study of rat tendon from birth to maturity. *J Anat*. 1987;153:163-169.
33. Neuberger A., Slack H.G. The metabolism of collagen from liver, bone, skin and tendon in the normal rat. *Biochem J*. 1953;53(1):47-52. doi: 10.1042/bj0530047
34. Kannus P., Jozsa L. Histopathological changes preceding spontaneous rupture of a tendon. A controlled study of 891 patients. *J Bone Joint Surg Am*. 1991;73(10):1507-1525.
35. Godwin J.W., Pinto A.R., Rosenthal N.A. Macrophages are required for adult salamander limb regeneration. *Proc Natl Acad Sci U S A*. 2013;110(23):9415-9420. doi: 10.1073/pnas.1300290110
36. Godwin J, Kuraitis D, Rosenthal N. Extracellular matrix considerations for scar-free repair and regeneration: insights from regenerative diversity among vertebrates. *Int J Biochem Cell Biol*. 2014;56:47-55. doi: 10.1016/j.biocel.2014.10.011

The article was submitted 01.03.2024; approved after reviewing 22.05.2024; accepted for publication 18.06.2024.

Information about the authors:

Maxim V. Vlasov — Candidate of Medical Sciences, Head of the Department, Footdoc@mail.ru;

Natal'ya Yu. Shirokova — Doctor of Biological Sciences, Senior Researcher, nush 63@mail.ru;

Irina V. Musikhina — Candidate of Medical Sciences, orthopaedic surgeon, surgeon, i_musihina@mail.ru

Clinical case
https://doi.org/10.18019/1028-4427-2024-30-4-581-587

Fixation of the rotator cuff tendons for the greater tuberosity fracture of the humerus

A.A. Makovskiy✉, L.S. Shnayder, E.S. Popravka

Moscow Clinical Scientific Center of A.S. Loginov, Moscow, Russian Federation

Corresponding author: Alexey A. Makovskiy, Makovskiya@yandex.ru

Abstract

Introduction Strategical approaches to managing patients with a greater tuberosity fracture of the humerus are controversial and there are discussions about surgical treatment options. Nondisplaced fractures require no surgical management. Shoulder replacement can be indicated for the surgical treatment of proximal humeral fractures with limited function of the upper limb and difficulties in refixation of the rotator cuff tendons due to the peculiar anatomical location of the tendon fixation. Solution to this problem can improve the quality of life of patients with greater tuberosity fracture of the humerus.

The **objective** was to evaluate the treatment outcome of a patient with a greater tuberosity fracture of the humerus repaired with open refixation of the rotator cuff tendons and medialization of the border of the articular surface of the humerus.

Material and methods A 46-year-old patient presented with limited movements and severe pain in the left shoulder after humerus dislocation and a greater tuberosity fracture.

Results The condition was repaired with an open repair of the rotator cuff tendons and medialization of the border of the articular surface of the humerus. The patient reported neither pain nor limited movements in the left shoulder at the one-year follow-up.

Discussion Treatment options for patients with a greater tuberosity injury remains controversial. The effectiveness and results of organ-saving surgery have not been explored and require scientific evaluation using a larger cohort of patients.

Conclusion Excellent functional results were achieved in a patient with injury to the greater tuberosity using surgical refixation of the rotator cuff tendons and medialization of the cartilaginous surface.

Keywords: humerus fracture, rotator cuff tear, rotator cuff repair

For citation: Makovskiy AA, Shnayder LS, Popravka ES. Fixation of the rotator cuff tendons for the greater tuberosity fracture of the humerus. *Genij Ortopedii*. 2024;30(4):581-587. doi: 10.18019/1028-4427-2024-30-4-581-587

© Makovskiy A.A., Shnayder L.S., Popravka E.S., 2024
© Translator Irina A. Saranskikh, 2024

INTRODUCTION

Proximal humerus fractures are a common injury with the greater tuberosity fracture of the humerus accounting for approximately 16.5 % of all proximal humerus fractures [1, 2]. About 30 % of greater tuberosity fractures are caused by dislocation of the humerus [3]. Shoulder dislocation can be accompanied by a characteristic set of injuries including fracture of the glenoid cavity of the scapula, impression fracture of the humeral head, damage to the capsule, ligaments and cartilaginous lip of the joint, damage to the rotator cuff, as well as fractures of the proximal humerus [3].

Satisfactory reduction can occur with the tendons of the rotator cuff attaching to the tubercle. According to the literature, non-displaced fractures of the greater tubercle of the humerus can be treated conservatively using immobilization, rehabilitation and physical therapy, and bone displacement of 3–5 mm and greater requires surgical intervention with bone reduction and fixation of the greater tubercle of the humerus including arthroscopic techniques [4–10].

The site of tendon fixation is important with the bone injury [11–13]. The bone at the fracture site is susceptible to osteoporotic changes and does not have a cortical plate for anchors, and fixation to the articular surface does not have adequate biological capabilities for fusion [11, 12]. Therefore, the patients can be treated with reverse shoulder arthroplasty to restore function and reduce pain [14, 15]. Joint replacement can be postponed for as long as possible with preserved shoulder joint, the cartilaginous surface of the scapula and humerus in the attempts to restore the shoulder functions, in younger patients, in particular. Solution of the problem will help improve outcomes for patients with injury to the greater tuberosity without the use of reverse arthroplasty.

The objective was to evaluate the treatment outcome of a patient with a greater tuberosity fracture of the humerus repaired with open refixation of the rotator cuff tendons and medialization of the border of the articular surface of the humerus.

MATERIAL AND METHODS

A 46-year-old patient was seen at the consultative and diagnostic department of the Moscow Loginov Scientific Research Center in September 2022. She sustained an injury from a fall off the motorcycle in June 2022 and was admitted to a 24-hour emergency hospital in Moscow. She was diagnosed with a closed displaced fracture of the plateau of the right tibia and fracture dislocation of the left humerus. The shoulder dislocation was eliminated and a tibial plateau fracture was surgically treated in the hospital. The fracture of the left upper limb was immobilized with a scarf bandage for 6 weeks. Then the patient was referred to a rehabilitation center for a 4-week rehabilitation course. Rehabilitation resulted in no improvement in the upper limb function with the pain increased, and the patient was referred to the Moscow Loginov Scientific Research Center for consultation. The patient reported severe pain during the day and at night, significantly limited movements in the left shoulder joint.

Local status: no signs of inflammation at the shoulder joint, no deformity observed. Movements are limited: abduction 20°, adduction 25°, internal rotation 40°, external rotation 0°. Movements are also limited because of severe pain. Passive abduction 120°. There are no neurocirculatory disorders in the upper limb.

Results of X-ray examination methods Radiographs showed the absence of anatomical contours of the greater tubercle of the humerus, rarefied bone tissue in its projection, the atypical position of the bone fragment, presumably a fragment of the greater tubercle (Fig. 1). Conclusion: non-united displaced fracture of the greater tubercle of the humerus with. MRI of the shoulder joint showed injury to the greater tubercle of the humerus, absence of anatomical attachment of the rotator cuff tendons, greater tubercle bones dislocated posteriorly and upward and aseptic necrosis of the greater tubercle bone (Fig. 1).

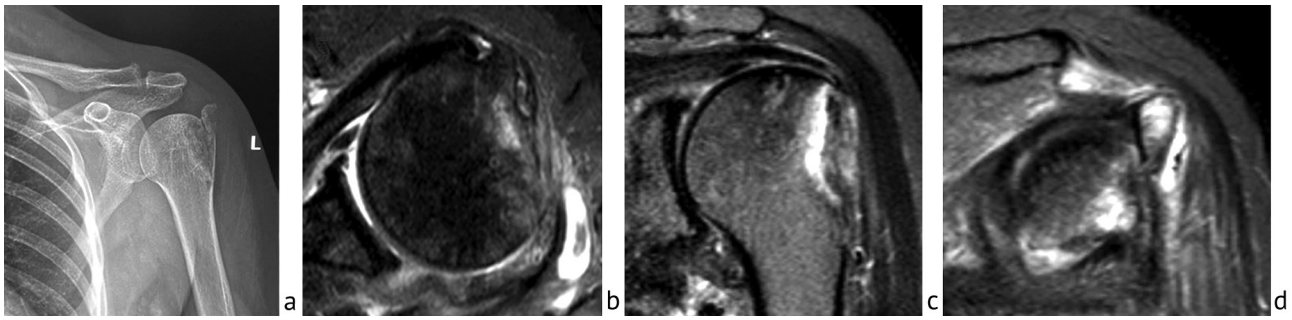

Fig. 1 (a) anteroposterior view of the shoulder joint at 3 months of a traumatic shoulder dislocation; (b) axial T2 MRI of the shoulder joint with fat suppression demonstrating the absence of the greater tubercle of the humerus; (c) coronal T2 MRI of the shoulder joint with fat suppression showing the absence of the greater tubercle and the loose-lying supraspinatus tendon; (d) coronal T2 MRI of the shoulder joint with fat suppression showing the greater tubercle remnants dislocated into the subacromial space with signs of avascular necrosis

The beach chair position was used for surgical intervention. The patient was positioned at the edge of the operating table with the shoulder joint hanging down to allow manipulation of the limb. A direct incision was made according to a standard technique using an anterolateral transdeltoid approach extending 1 cm onto the acromial process of the scapula. The deltoid muscle was cut off from the acromial process of the scapula using an electric knife, and the muscle was separated along the fibers in a blunt manner. The absence of the greater tubercle of the humerus was detected during repair of the subdeltoid, subacromial space and joint, a bone fragment as the remnant of the greater tubercle, which was located in the subacromial space, was mobile and limited movement in the shoulder joint positioned in extreme abduction (Fig. 2). The rotator cuff tendons and a bone fragment, the remnant of the greater tubercle of the humerus, were isolated from the scars. The tendons were mobilized using a blunt levator. Tendon mobility was checked using traction with a capsular clamp (Fig. 2).

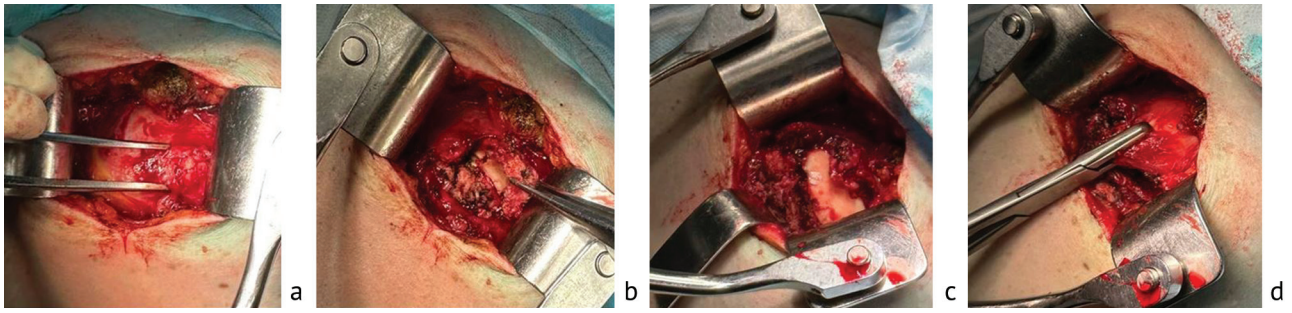

Fig. 2 Appearance of surgical wound: (a) the remnant of the greater tubercle of the humerus fixed to the rotator cuff tendons after access to the proximal humerus with jaws of tweezers; (b) a bone fragment of the greater tubercle of the humerus seen between the branches of the tweezers; (c) cartilaginous surface of the humerus and the absence of the greater tubercle of the humerus seen in the wound; (d) the rotator cuff tendons released from the scars; checking tendon mobility with traction

With scars removed and the rotator cuff tendons released, markings in the form of a 1 cm strip were made on the articular surface along the cartilage line using an electric knife [10]. The cartilage was removed using a sharp rasp with the subchondral bone trimmed until honeycomb appeared (Fig. 3). Three canals were then formed in the humerus, similar to those formed in the greater tubercle of the humerus during transosseous fixation of the rotator cuff tendons. Shuttle threads were inserted into the channels (Fig. 3). Rip-stop suturing of the rotator cuff tendons was performed using the Mason-Allen technique; ligatures coming out of the tendons at the site of the articular surface passed through the humerus along the channels using shuttle threads. The threads were tied with tension on the tendons. A double-row suture was applied with crossed threads to ensure a strong and reliable fixation, pressing a large tendon area to the bone (Fig. 3), and the wound was sutured layer-by-layer.

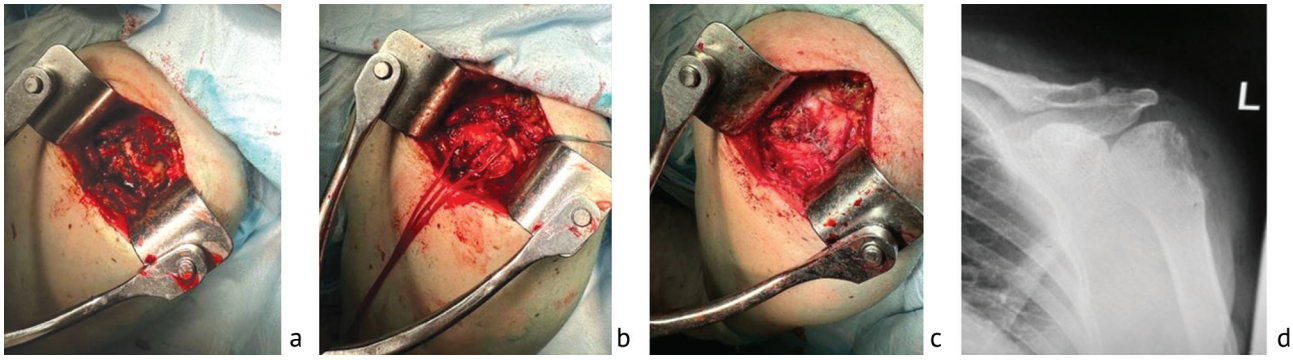

Fig. 3 Appearance of surgical wound: (a) the cartilage removed from the lateral edge of the articular surface of the proximal humerus; (b) the shuttle threads passed through the humeral head; (c) the threads tightened and tied to fix the rotator cuff tendons to the humeral head; (d) postoperative AP view

The patient was recommended to use scarf bandage for 3 weeks post op to be followed by a course of standard rehabilitation for patients after repair of the rotator cuff tendons.

RESULTS

The patient reported no complaints for the left upper limb at one-year follow-up. She had no pain in the shoulder joint or limitations in its movements. Local status: no signs of inflammation at the shoulder joint, no deformity observed. Range of motion measured 170° flexion, 40° extension, 180° abduction, 25° adduction, 70° internal rotation, 60° external rotation (Fig. 4). No neurocirculatory disorders were registered.

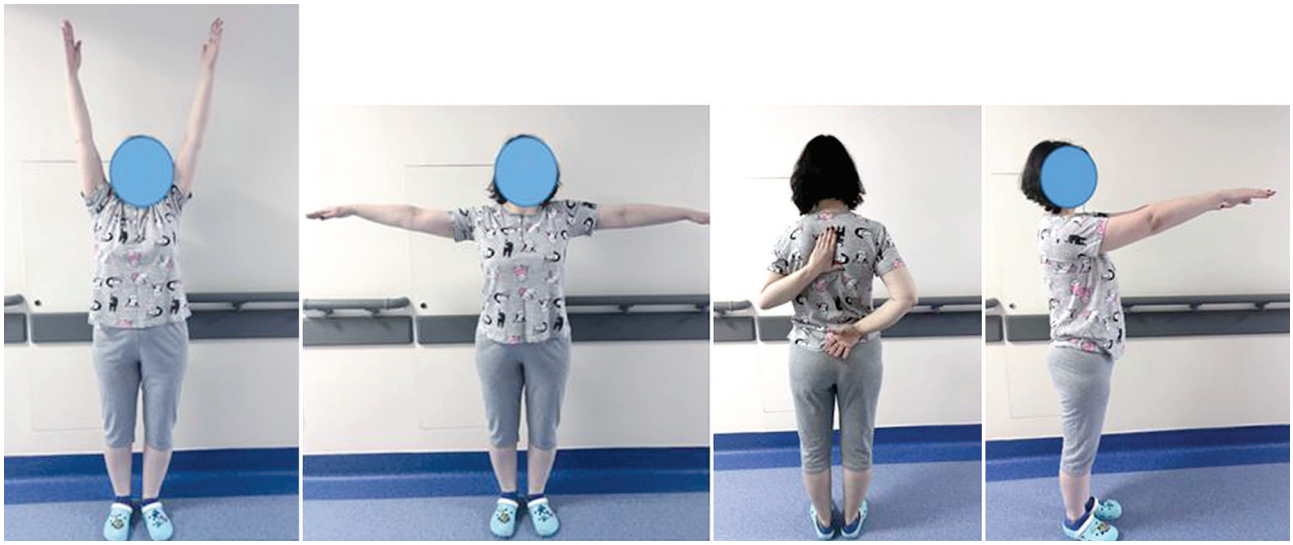

Fig. 4 Range of motion in the shoulder joints at one-year follow-up

DISCUSSION

The clinical instance demonstrated an alternative surgical strategy for the management of patients with injury to the greater tuberosity of the shoulder. The pain could be caused by injured tendons of the shoulder joint, by capsulitis and inflammation. The limited movements were caused by the lack of fixation of the rotator cuff muscles, and a bone fragment of the humerus tubercle displaced into the subacromial space limiting abduction in the extreme position only. The articular cartilage was preserved. Reverse shoulder arthroplasty was offered for the patient with fractured greater tubercle in other medical organizations with the impossibility of fixing the tendons to the humerus. The young patient refused the treatment offered. The intervention suggested the articular medialization by removing cartilage from the humeral head to form an analogue of the greater tubercle of the humerus and ensure fixation of the tendons to the humeral head. Tendons at the site of the native tubercle could not be fixed in the fracture zone due to the lack of good quality bone tissue for suturing the tendons transosseously and using anchors. Considering that the articular surface of the shoulder is approximately 160° with the center displaced medially of about 6 mm, the strategy chosen allowed us to preserve the main part of the articular surface. With the tip of the greater tuberosity being distally located 8 mm, the force lever changed slightly due to the medialization of the tendon insertion point [16, 17]. Medialization can reduce the area of the articular surface and the range of movements in the shoulder joint, but the residual range of movements is sufficient for everyday loads [16, 17]. The intervention facilitated delayed shoulder arthroplasty in a 46-year-old patient.

Despite a significant number of studies devoted to this topic, establishing indications for surgical treatment and determining surgical strategy in patients with shoulder dislocation and a fracture of the greater tuberosity remains challenging, which makes it difficult to choose the correct algorithm for the management of such patients [18–20].

Reduction and blood supply are major problems in the conservative management of patients with a fracture of the greater tubercle of the humerus. Bone displacement is noted in 50–60 % during conservative treatment [13, 15, 20] which can be associated with a decrease in soft tissue swelling. Inaccurate reduction of the displaced tubercle can result in limited ROM in the shoulder joint, disturbed movement of the rotator cuff muscles with and in impingement syndrome with the acromion process of the scapula at the time of shoulder abduction [13].

Clinicians can control complications due to accurate reduction and reliable fixation, which is not the case with blood supply of the broken humeral fragment. The issue remains unexplored and uncontrollable. The extent of impaired blood supply cannot be identified in the broken humerus at diagnosis to determine an appropriate strategy for managing this cohort of patients.

The existing evidence suggests that adequate reduction and reliable fixation can influence the blood supply to a bone fragment, reducing the risks of a bone lesion or fracture nonunion [2, 4, 6, 10, 13]. But lesion of the greater tubercle has also been described in the conservative treatment of non-displaced fractures [12].

Three surgical interventions using the method were produced for patients with similar clinical manifestations at our hospital. The patients aged 28, 46 and 53 years. The technique facilitated excellent functional results in all patients. The question of whether all fractures of the greater tubercle of the humerus should be fixed to avoid lesion of the fragment remains unexplored. The difficulties with the treatment described above can occur even in young

patients. There are many minimally invasive techniques that are not a technically complex intervention to fix the tubercle. This topic requires further study and synthesis of clinical material for scientific evaluation.

CONCLUSION

Medialization of the articular line, removal of a strip of the articular cartilage allowed us to create a place for fixation of the rotator cuff tendons in a patient with lesion of the greater tuberosity of the humerus. The surgical fixation of the rotator cuff tendons offered in the clinical case was shown to be a good alternative to reverse arthroplasty with excellent functional results achieved.

Conflict of interest *None of the authors has any potential conflict of interest.*

Informed consent *The patient gave informed consent for publication of the findings without identification.*

REFERENCES

1. Bergdahl C, Ekholm C, Wennergren D, et al. Epidemiology and patho-anatomical pattern of 2,011 humeral fractures: data from the Swedish Fracture Register. *BMC Musculoskelet Disord*. 2016;17:159. doi: 10.1186/s12891-016-1009-8
2. Rudran B, Little C, Duff A, et al. Proximal humerus fractures: anatomy, diagnosis and management. *Br J Hosp Med* (Lond). 2022 2;83(7):1-10. doi: 10.12968/hmed.2021.0554
3. Robinson CM, Shur N, Sharpe T, et al. Injuries associated with traumatic anterior glenohumeral dislocations. *J Bone Joint Surg Am*. 2012;94(1):18-26. doi: 10.2106/JBJS.J.01795
4. Rouleau DM, Mutch J, Laflamme GY. Surgical Treatment of Displaced Greater Tuberosity Fractures of the Humerus. *J Am Acad Orthop Surg*. 2016;24(1):46-56. doi: 10.5435/JAAOS-D-14-00289
5. Huntley SR, Lehtonen EJ, Robin JX, et al. Outcomes of surgical fixation of greater tuberosity fractures: A systematic review. *Orthop Traumatol Surg Res*. 2020;106(6):1119-1126. doi: 10.1016/j.otsr.2020.05.005
6. Kumar S, Mishra A, Singh H, et al. Surgical fixation of isolated greater tuberosity fractures of the humerus- systematic review and meta-analysis. *J Clin Orthop Trauma*. 2021;23:101670. doi: 10.1016/j.jcot.2021.101670
7. Hohmann E, Keough N, Glatt V, Tetsworth K. Surgical treatment of proximal humerus fractures: a systematic review and meta-analysis. *Eur J Orthop Surg Traumatol*. 2023;33(6):2215-2242. doi: 10.1007/s00590-022-03436-3
8. Huntley SR, Lehtonen EJ, Robin JX, et al. Outcomes of surgical fixation of greater tuberosity fractures: A systematic review. *Orthop Traumatol Surg Res*. 2020;106(6):1119-1126. doi: 10.1016/j.otsr.2020.05.005
9. Ji JH, Jeong JJ, Kim YY, et al. Clinical and radiologic outcomes of arthroscopic suture bridge repair for the greater tuberosity fractures of the proximal humerus. *Arch Orthop Trauma Surg*. 2017;137(1):9-17. doi: 10.1007/s00402-016-2586-6
10. Li R, Cai M, Tao K. Arthroscopic reduction and fixation for displaced greater tuberosity fractures using the modified suture-bridge technique. *Int Orthop*. 2017;41(6):1257-1263. doi: 10.1007/s00264-017-3461-y
11. Hess F, Bohnert L, Jaberg L, et al. Tuberosity union in patients with proximal humerus fractures treated with reverse shoulder arthroplasty: a technical note and exploratory analysis. *Int Orthop*. 2020;44(12):2711-2717. doi: 10.1007/s00264-020-04831-3
12. Miyamura S, Lans J, Min KS, et al. Bone resorption of the greater tuberosity after open reduction and internal fixation of complex proximal humeral fractures: fragment characteristics and intraoperative risk factors. *J Shoulder Elbow Surg*. 2021;30(7):1626-1635. doi: 10.1016/j.jse.2020.09.014
13. Su F, Tangtiphaiboontanam J, Kandemir U. Management of greater tuberosity fracture dislocations of the shoulder, *JSES Reviews, Reports, and Techniques*. 2023. doi: 10.1016/j.xrrt.2023.07.007
14. Giul'nazarova SV, Mamaev VI, Zubareva TV. Complications of the shoulder arthroplasty in patients with inveterate fractures and fracture-dislocations of the proximal humerus. *Genij Ortopedii*. 2016;(1):48-51. (In Russ.) doi: 10.18019/1028-4427-2016-1-48-51
15. Chandra Mohapatra N, Sahoo US, Sahoo MM. Effect of tuberosity repair on functional outcome of reverse shoulder arthroplasty in proximal humerus fractures. *Chin J Traumatol*. 2023;26(2):94-100. doi: 10.1016/j.cjtee.2022.12.001
16. Mizuki Y, Senjyu T, Ito T, et al. Extreme Medialized Repair for Challenging Large and Massive Rotator Cuff Tears Reveals Healing and Significant Functional Improvement. *Arthroscopy*. 2023;39(10):2122-2130. doi: 10.1016/j.arthro.2023.03.030
17. Lee KW, Moon KH, Ma CH, et al. Clinical and Radiologic Outcomes After Medializing and Not Medializing Rotator Cuff Tendon Attachment Site on Chronic Retracted Rotator Cuff Tears. *Arthroscopy*. 2018;34(8):2298-2307. doi: 10.1016/j.arthro.2018.03.015
18. Guo S, Zhu Y, Lu Y, et ak. Clinical and radiologic outcomes after tendon insertion medialized repair of large-to-massive rotator cuff tears. *Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi*. 2023;37(4):391-397. (In Chin.) doi: 10.7507/1002-1892.202212019

19. Iglesias-Rodríguez S, Domínguez-Prado DM, García-Reza A, et al. Epidemiology of proximal humerus fractures. *J Orthop Surg Res*. 2021;16(1):402. doi: 10.1186/s13018-021-02551-x
20. Brorson S, Palm H. Proximal Humeral Fractures: The Choice of Treatment. In: Falaschi P, Marsh D, editors. Orthogeriatrics: *The Management of Older Patients with Fragility Fractures* [Internet]. 2nd ed. Cham (CH): Springer; 2021. doi: 10.1007/978-3-030-48126-1_10

The article was submitted 20.12.2023; approved after reviewing 20.02.2024; accepted for publication 18.06.2024.

Information of authors:

Alexey A. Makovskiy — orthopedic traumatologist, junior researcher, Makovskiya@yandex.ru, https://orcid.org/0000-0002-0794-2485;

Lev S. Shnayder — Candidate of Medical Sciences, orthopedic traumatologist, shnayderlev@gmail.com, https://orcid.org/0000-0001-8060-5074;

Ekaterina S. Popravka — orthopedic traumatologist, popravka@yandex.ru, https://orcid.org/0009-0008-2725-2263.

Clinical case
https://doi.org/10.18019/1028-4427-2024-30-4-588-596

Multidisciplinary approach to repair of intra-articular fractures of the distal radius in a complicated setting (prehabilitation)

A.A. Khromov[1,2]✉, E.K.Gumanenko[3], S.A. Linnik[1], A.N. Tkachenko[1], A.G. Kravtsov[2], A.V. Melnichuk[3], A.S. Lazutin[3], A.V. Zhulyabin[2]

[1] North-Western State Medical University named after I.I. Mechnikov, St. Petersburg, Russian Federation
[2] North-Western District Scientific and Clinical Center named after L.G. Sokolov, St. Petersburg, Russian Federation
[3] St. Petersburg State Pediatric Medical University St. Petersburg, Russian Federation

Corresponding author: Aleksandr A. Khromov, Khromov_alex@mail.ru

Abstract

Introduction Treatment of malunited periarticular fracture of the distal metaepiphysis of the radius in a complicated setting is challenging and involved orthopaedic care and related specialties of neurologists, neurosurgeons and rehabilitation specialists. New methods are offered for repair of the distal radius fractures but the results obtained to date cannot be considered satisfactory, since the treatment is aimed at the restoration of the anatomical relationships and the hand function.

The **objective** was to demonstrate the role of prehabilitation preparing patients for elective reconstructive surgery, to present a multidisciplinary approach to the treatment of malunited radius fracture complicated by posttraumatic compression ischemic multineuropathy.

Material and methods The medical history of a 56-year-old patient with distal radius malunion complicated by posttraumatic compression ischemic multineuropathy was reviewed. Outcome criteria included absence of complaints and restored function of the hand and the wrist.

Results A positive functional outcome was recorded after prehabilitation and surgery. Early postop, the DASH scored 35, palmar flexion measured 64° with dorsiflexion of 61° and dynamometry of 30 kg seen with the left involved hand. A faster recovery of the hand function occurred due to regression of neurological disorders.

Discussion Treatment of the distal radius malunion in a complicated setting suggests the involvement of related specialists including neurologists, neurosurgeons, professionals in functional and diagnostic radiology, rehabilitation specialists so that the approach must be multidisciplinary. A preoperative course of prehabilitation supervised by a neurologist and a rehabilitation specialist is essential for the patient to achieve a higher basic level of functionality. Surgical treatment must be a stage of multi-stage multidisciplinary treatment of distal radius malunion in a complicated setting.

Conclusion The clinical case showed an effective multidisciplinary approach in the treatment of distal radius malunion in a complicated setting. Preoperative preparation (prehabilitation) had a positive effect on the postoperative recovery and functional results.

Keywords: radius malunion, compression ischemic multineuropathy, prehabilitation

For citation: Khromov AA, Gumanenko EK, Linnik SA, Tkachenko AN, Kravtsov AG, Melnichuk AV, Lazutin AS, Zhulyabin AV. Multidisciplinary approach to repair of intra-articular fractures of the distal radius in a complicated setting (prehabilitation). *Genij Ortopedii*. 2024;30(4):588-596. doi: 10.18019/1028-4427-2024-30-4-588-596

© Khromov A.A., Gumanenko E.K., Linnik S.A., Tkachenko A.N., Kravtsov A.G., Melnichuk A.V., Lazutin A.S., Zhulyabin A.V., 2024
© Translator Irina A. Saranskikh, 2024

INTRODUCTION

The upper limb sustains a wide variety of fractures [1–7]. The upper limbs have been in the process of evolutionary change developing specific professional skills of a modern human with an effect on working capacity and life support. Since the early 19th century, the collection of knowledge respective to fractures of the distal radius has expanded exponentially. This is confirmed by the famous statement of Guillaume Dupuytren: "This fracture is so common, the results are so poor, that one should not be surprised at such a great interest that I personally and my contemporaries show in relation to the fracture of the distal radius" [8]. Despite obvious advances in medicine, the treatment of the cohort of patients is of relevance. There is an increase in the number of patients suffering injuries to the distal metaepiphysis of the radius that constitute 11.6 to 36.3 % of all fractures of the locomotor apparatus [9–14]. Distal radius fractures account for 18 % in elderly patients [15, 16]. Although children and the elderly are at greater risk for the injury, distal radius fractures occur in individuals of working age. With the low incidence of the fractures, complications can lead to long-term disability in younger healthy people. In a 30-year follow-up study of young adults in Sweden with distal radius fractures, the authors found that of the 28 % of study participants who had extra-articular fractures (average age of 31 at time of fracture, range 18–40), only 37 % had even minor complaints of pain, decreased mobility [16]. The social significance of the problem is due to frequent complications (on average about 30 %, as reported by many authors) after inadequate surgical treatment and physical rehabilitation and high rates of poor functional results [17]. Most patients recover and regain function, but almost a fifth have residual symptoms including pain, neurological symptoms and disability after one year [18, 19]. Malunion is the main cause of residual symptoms and occurs in approximately 5 % of fractures [20]. Any malunion that results in discrepancy at the distal wrist joint can cause pain on the ulnar side of the joint and reduce rotation of the forearm bones. Patients may suffer from decreased grip strength, decreased hand and forearm function and cosmetic impairment [19]. Although most patients regain satisfactory wrist function, 23–31 % of distal radius fractures cause permanent limitation of function due to pain, lost range of motion and grip strength [21, 22]. Although malunion is recognized as a relative indication for surgery, corrective surgery may be challenging and fail to restore a "normal" wrist even with careful preoperative planning [21, 23, 24]. Complications arising after corrective osteotomy account for 18.2 % [25]. Candidates for surgery should be patients with persistent pain and dysfunction associated with inconsistency of the articular surfaces of the distal wrist joint [23, 26]. The timing of the operation should be carefully considered. A targeted physical therapy program for the wrist stretching and strengthening should be the first-line treatment for functional limitations [23]. A complete neurological examination is intended to rule out carpal tunnel syndrome, which occurs in 17 % of patients, and signs of complex regional pain syndrome [26]. Consultations with specialists of related specialties are essential in the treatment of patients in the cohort if we are guided by the principle that surgery should be the last argument: "Ultima ratio". Prehabilitation is a relatively new direction including individual preparation of patients for the upcoming operation "A major operation, just like a marathon, requires preparation" [27]. To date, protocols have been developed for the prehabilitation of patients who are planning to undergo large joint replacement [28, 29, 30]. In our opinion, a similar practice can be applied to patients with radius malunions in a complicated setting. Moreover, these are not urgent operations placing the patient at risk by postponing the procedure. Comparative studies of early fixation of distal radius fractures and delayed corrective osteotomy showed that the results of corrective osteotomy are not inferior to the results of early internal fixation [31]. Most authors agree that patients with persistent symptoms should be recruited only six months after injury [23]. Some authors [32] report improved postoperative scores with a shorter interval between injury and corrective osteotomy. Over the past 100 years, new techniques have been offered for distal radius fractures and, despite this, the results obtained to date cannot be considered satisfactory. Treatment of distal radius fractures remains a challenging problem. The purpose of the work was to demonstrate the importance of prehabilitation

during the period of preparing patients for planned reconstructive operations, to present the result of a multidisciplinary approach in the treatment of a patient with an improperly healed fracture of the radius, complicated by post-traumatic compression-ischemic multineuropathy.

The objective was to demonstrate the role of prehabilitation preparing patients for elective reconstructive surgery, to present a multidisciplinary approach to the treatment of malunited radius fracture complicated by posttraumatic compression ischemic multineuropathy.

MATERIAL AND METHODS

The study included a medical history of a patient with a distal radius malunion in a complicated setting.

A 56-year-old patient R. sustained an injury to her left upper limb as a result of a fall on May 25, 2022 and was diagnosed with a closed comminuted intra-articular extension fracture of the distal metaepiphysis of the radius graded as AO 23-C1, Fernandez III (Fig. 1).

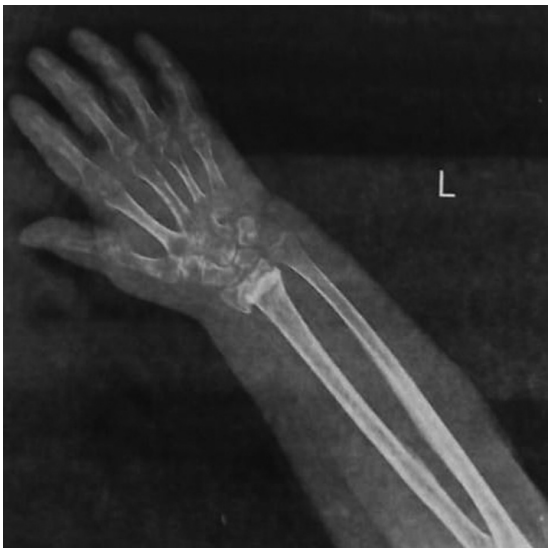

Fig. 1 Preoperative radiograph of the bones of the hand and forearm bones of patient R. taken in the emergency room

A closed reduction of the forearm bones was performed under local anesthesia after examination. The limb was fixed with a circular plaster cast for 4 weeks. With the plaster cast removed, contact dermatitis and impaired sensitivity in the left hand were revealed. Neuromyography was performed and consultation with a neurologist arranged. Polyneuropathy of the left upper limb was detected. Conservative treatment, exercise therapy were administered by the neurologist. The patient was admitted to the North-Western Regional Scientific and Clinical Center named after. L.G. Sokolov (NWRSCC) after 5 months (October 31, 2022) due to weak positive dynamics and dissatisfaction with the results of treatment.

Outcome criteria included positive dynamics in the clinical manifestations, restored hand function.

A multidisciplinary approach was used preoperatively.

RESULTS

Upon admission, the patient presented with swelling of the left hand and lower third of the left forearm; limited movements in the interphalangeal joints of the hand with flexion of 45°, extension of 0° and in the wrist joint with flexion of 35° and extension od 60°. The patient experienced numbness on the lateral surface of the lower third of the left forearm, in the V, IV, III fingers of the left hand; a feeling of tension spreading on the lateral surface of the left shoulder and the forearm. The patient was diagnosed with malunited intra-articular comminuted fracture of the left radius graded AO 23-C1, Fernandez III; 5 mm radius shortening; dorsal angular displacement 30° (Fig. 2), osteoporosis and polyneuropathy of the left upper limb. Concomitant diseases indluded stage 3 hypertension, type 2 diabetes; contact dermatitis; grade 1 obesity.

The disability of the upper limb measured with the DASH questionnaire scored 68, VAS pain syndrome scored 6, hand grip strength was 37 kg on the right side and 22 kg on the left. Thickening of the lig. collaterale carpi ulnare and ultrasound signs of edema with a possible indirect external effect on the trunk of the left ulnar nerve were detected with ultrasound dopplerography.

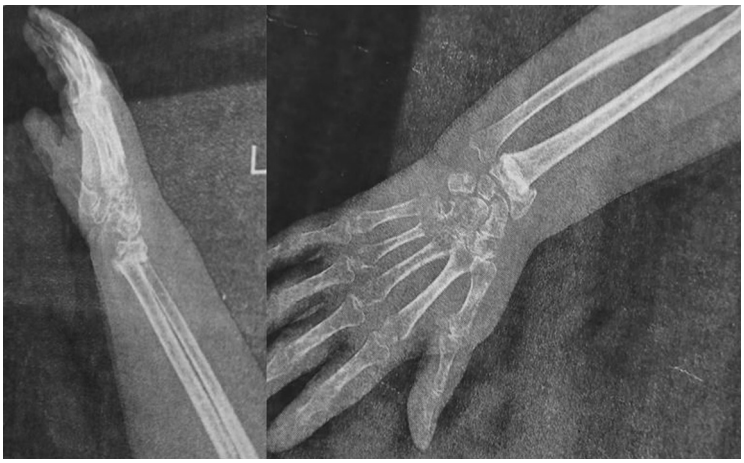

Fig. 2 Radiographs of the wrist joint of patient R. produced on admission to the hospital

ENMG of 01.11.22 showed moderate neuropathy of the median nerve at the level of the carpal tunnel on the left with moderate dysfunction of sensory fibers and mild dysfunction of motor fibers. The injury indicated mixed, mild axonal-demyelinating lesion of the superficial radial nerve on the left, moderate axonal lesion of the distal sensory fibers of the nerves of the upper extremities of the PSP type. There were no signs of damage to the ulnar nerve or motor fibers of the radial nerve.

The patient was examined by a neurologist and diagnosed with post-traumatic compression-ischemic multineuropathy of the median and superficial radial nerves on the left with mild motor and sensory impairment; axonal distal sensory polyneuropathy of the upper extremities. Recommended: intravenous infusion of saline solution with thiogamma, trental No. 10; intramuscular injections of milgamma and neuromidin No. 10; tablet drug Tebantin 300 mg Day 1, 1 tablet at night, increasing to 1 tablet 3 times a day if needed.

A decision on surgical treatment with corrective osteotomy and bone grafting was associated with such factors as regional osteopenia of the distal radius diagnosed by radiography, the absence of severe pain and the presence of contact dermatitis at the site of surgery. Conservative treatment included infusion therapy to improve microcirculation and reduce edema, vitamin therapy, a course of physical therapy and exercise therapy. The patient was discharged from the hospital at two weeks to continue treatment as an outpatient.

A prehabilitation course with the participation of neurologists, rehabilitation specialists and physical therapists was recommended. Medication prescribed included 100 mcg of calcitonin per day, 1000 mg of elemental calcium in the form of calcium carbonate and 400 IU (10 mcg) of vitamin D3 for 12 weeks; physiotherapy, classes with a rehabilitation specialist to achieve a satisfactory range of motion in the wrist joint, bone strength and improve radiological signs of regional osteopenia. The patient was re-hospitalized 6 months later to undergo corrective osteotomy. Physical examination showed improved condition of the soft tissues, no swelling, no symptoms of contact dermatitis. Numbness in the 5th and 4th fingers of the left hand and deformity at the level of the left wrist joint persisted. Regional osteopenia of the distal radius, diagnosed radiographically at 6 months, decreased (Fig. 3).

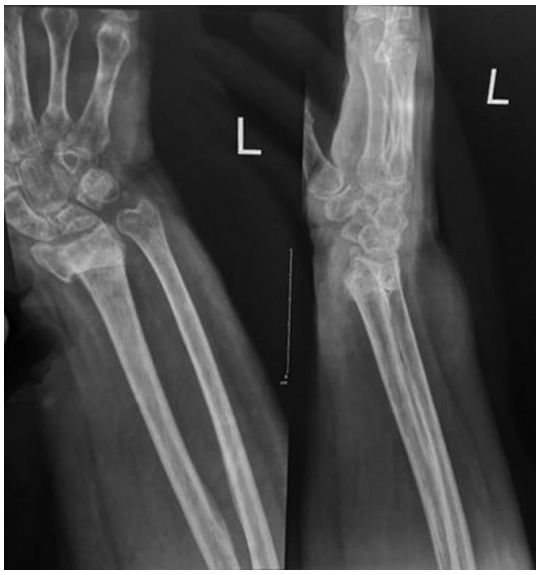

Fig. 3 Radiographs of the wrist joint of patient R. showing no signs of osteopenia

Surgical treatment performed on June 16, 2023 included corrective osteotomy and bone grafting of the radius. A pre-curved plate with polyaxial screws was used to address angulation. The plate was first attached to the distal fragment and the stem of the plate was used as a joystick to translate and reduce the bone length allowing for a gentle and gradual realignment by stretching the soft tissue. Using the plate attached to the distal fragment as a joystick could be complicated by cutting through the screws or by a broken distal fragment, but the adverse event was prevented by a preoperative treatment of regional osteopenia of the distal radius (Fig. 4).

The wound healed by primary intention early post op with the radius realigned and reduced. The cosmetic defect was repaired (Fig. 5). Neurological disorders resolved shortly after surgery, movements in the fingers were within normal limits (Fig. 6).

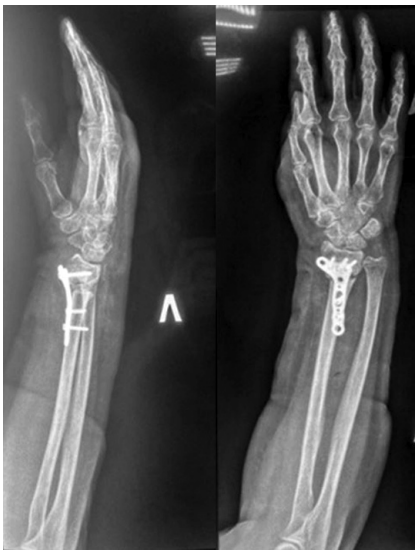

Fig. 4 Postoperative radiographs of the hand and the forearm bones of patient R. showing fixation of the radius fracture

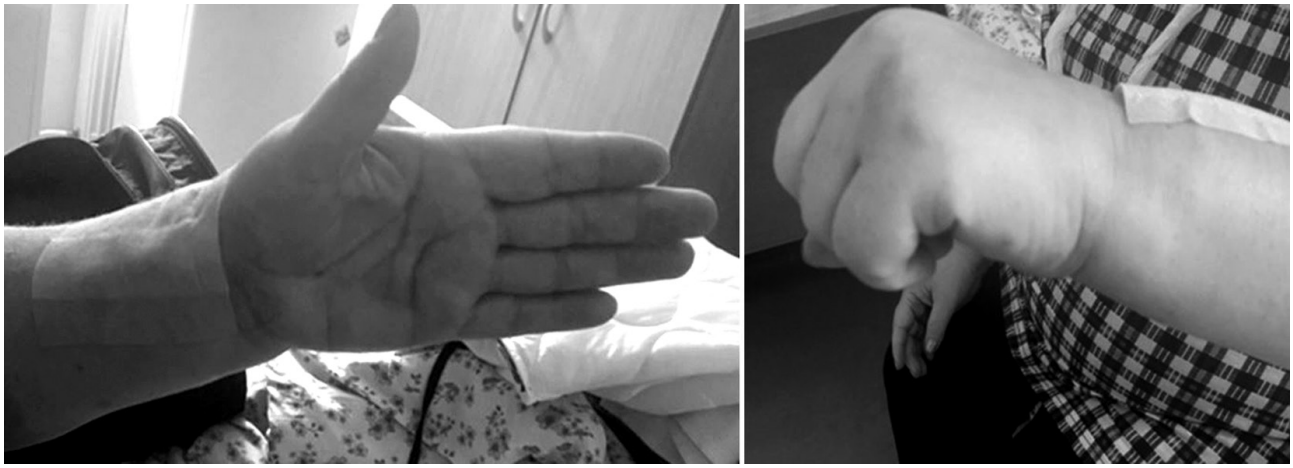

Fig. 5 Clinical outcome of surgery at one week

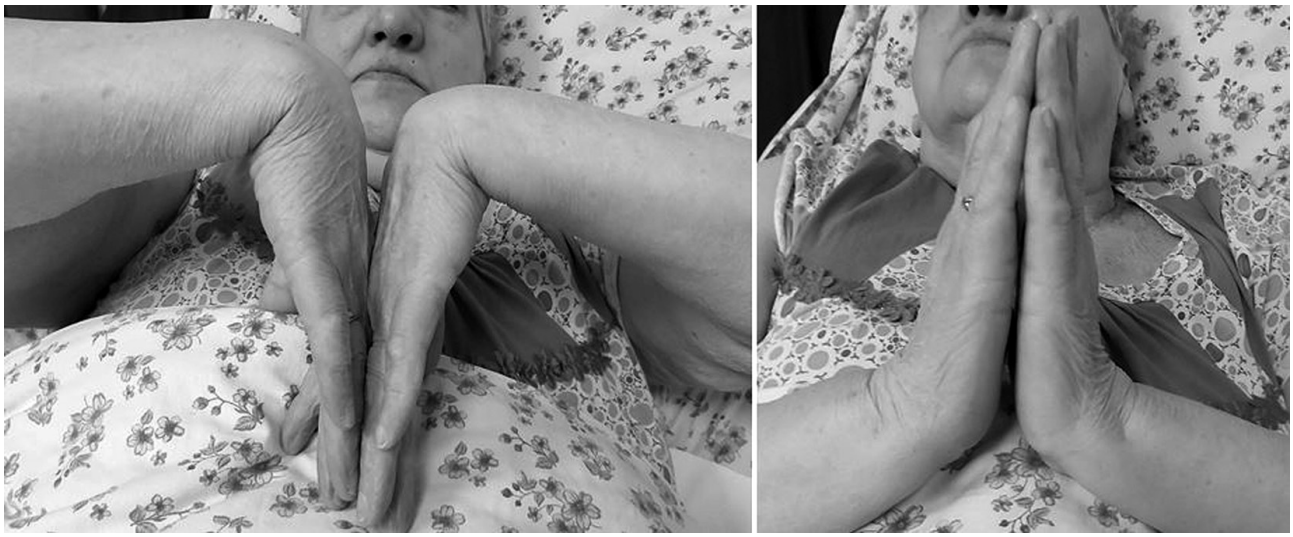

Fig. 6 Clinical outcome of surgery at 4 weeks

DISCUSSION

Distal radius fractures, like most periarticular and intraarticular fractures, are difficult to treat that require an individual approach in each case [9, 10]. With such fractures, it is necessary to take into account the degree of The extent of bone displacement, their number, relationship to the articular surface and timing are essential [6]. Distal radius fractures can be treated conservatively or surgically [7]. The surgical treatment has become more common [5, 13]. Patients who are surgically treated in the irst hours after injury prior to swelling have more favorable conditions for wound healing, a shorter rehabilitation period and recovery timing. A fracture pattern and the surgical strategy play a role in the scenario [2]. Comminuted intra-articular fractures with displaced bone at the site of the wrist joint are technically difficult for adequate reduction and stable fixation. External fixation devices can be used in such cases relying on ligamentotaxis [33]. A satisfactory reduction of intra-articular bone fragments can be associated with failure in fracture healing due to excessive distraction between the distal and proximal fragments of the radius. The risk of post-immobilization osteoporosis can cause difficulties with bone grafting of the radius nonunion in elderly patients and conservative treatment can be an option for the reasons with use adaptive capabilities of the body [6, 15]. The large group of patients with distal radius malunions can suffer accompanying conditions including neurodystrophic, tunnel syndromes, neurological disorders [10, 26]. The outcomes of the patients are often poor. The existing opportunities for the rehabilitation of such cases have not been realized. There is no continuity in observation and further treatment of the patients. This can lead to contractures and stiffness in the hand joints and persistent neurological disorders. New, more effective approaches to the treatment of patients with malunited intra-articular fractures of the distal radius with a complicated course are essential to reduce the rate of poor outcomes. Corrective osteotomy and bone grafting are used for the majority of patients. The overall incidence of complications after corrective osteotomy of the radius varies from 27 to 57 % even after surgical treatment [23]. Nonunions occur in 10.5 % of cases [34], delayed consolidation in 5.6 % of cases [35]. A high incidence of neuropathy and carpal tunnel syndrome are reported in patients with volar plate fixation [36]. Assessment of the functional and radiological outcomes after corrective osteotomy shows 18.2 % complications at five years [25].

At 5 months of the injury, the patient reported was diagnosed with post-traumatic compression-ischemic multineuropathy of the median and superficial radial nerve on the left with mild motor and sensory impairments, persisting post-immobilization osteoporosis of the distal radius, and other associated complications in the form of contact dermatitis at the site of the proposed surgical intervention. Surgical treatment in the condition was considered inappropriate. The management included prehabilitation, intensive neurological treatment, vascular infusion therapy, improvement of microcirculation of soft tissues and active exercising with rehabilitation specialists and physical trainers. The patient was re-admitted to the hospital with positive dynamics at 6 months of conservative treatment. Physical examination showed improved soft tissues, no swelling, no symptoms of contact dermatitis. Movements in the interphalangeal joints were within normal limits. Numbness persisted in the 5th and 4th fingers of the left hand. The signs of osteoporosis were radiologically reduced. Therefore, the physical condition facilitated a surgical option. A positive functional result was achieved within a relatively short period of time after prehabilitation and surgery. Early post op, the DASH scored 35, palmar flexion was 64°, dorsiflexion was 61°, hand grip strength on the left side was 30 kg. There was a faster recovery of hand function as a result of regression of neurological disorders., we have not found a description and evaluation of a multidisciplinary approach in the literature reporting patients with malunited fractures of the distal radius with a complicated course.

No prehabilitation protocol in the treatment of this cohort of patients have been described. Rehabilitation of patients with periarticular and intra-articular fractures is challenging. The complexity and responsibility in treating such patients increases many times over when we address the upper limb conditions due to the functional role. The treatment of malunited periarticular fracture of the distal metaepiphysis of the radius is more difficult with associated neurological disorders, stiff joints of the fingers and limited movements in the wrist joints. The treatment strategy for patients with malunited fractures of the distal radius with a complicated setting requires a multidisciplinary approach. The maximum treatment effect can be achieved through the concept of prehabilitation with involvement of several specialists.

CONCLUSIOPN

The case report of a patient with malunited fracture of the distal radius in a complicated setting has demonstrated the advantages of a multidisciplinary approach and the possibilities of prehabilitation in this cohort of patients.

Conflict of interest *None of the authors has any potential conflict of interest.*

Funding *The authors received no financial support for the research and/or authorship of this article.*

Informed consent *The team of authors obtained consent from the patient for the publication of anamnestic data, examination and treatment results.*

REFERENCES

1. Gumanenko EK, Khromov AA, Linnik SA, et al. New technologies in treatment of fractures of the upper extremities in patients with severe multiple and polytrauma. *Grekov's Bulletin of Surgery*. 2016;175(5):46-51. (In Russ.) doi: 10.24884/0042-4625-2016-175-5-46-51
2. Zubi Yu.Kh, Abujazar UM, Kilybaev AK, et al. Treatment outcome of forearm bones fractures. *Vestnik KazNMU*. 2015;(4):153-156. (In Russ.)
3. Aspenberg P, Sandberg O. Distal radial fractures heal by direct woven bone formation. Acta Orthop. 2013;84(3):297-300. doi: 10.3109/17453674.2013.792769
4. Jakubietz RG, Gruenert JG, Kloss DF, et al. A randomised clinical study comparing palmar and dorsal fixed-angle plates for the internal fixation of AO C-type fractures of the distal radius in the elderly. *J Hand Surg Eur Vol*. 2008;33(5):600-604. doi: 10.1177/1753193408094706
5. Karimi Nasab MH, Shayesteh Azar M, Fazel Moghaddam S, Taghipour M. Success Rate and Complications of Comminuted Intra-Articular Distal Radius Fracture Treatment via Closed Reduction and Use of a Mini-External Fixator. *Trauma Mon*. 2015;20(4):e18885. doi: 10.5812/traumamon.18885
6. Malets V. L., Volotovsky A.I. Results of surgical treatment of posttraumatic deformities of the distal metaepiphysis of the radius using bone autoplasty and decompression of the distal metaepiphysis of the radius. *Military medicine*. 2019;(4):21-25. (In Russ.)
7. Anzarut A, Johnson JA, Rowe BH, et al. Radiologic and patient-reported functional outcomes in an elderly cohort with conservatively treated distal radius fractures. *J Hand Surg Am*. 2004;29(6):1121-1127. doi: 10.1016/j.jhsa.2004.07.002
8. Dupuytren's M. Leçons Orales de Clinique Chirurgicale, faites à l'Hôtel Dieu de Paris. *Med Chir Rev*. 1834;21(42):289-330.
9. Melnikov VS, Korshunov VF. Methods of surgical treatment of improperly fused fractures of the distal epimetaphysis of the radius. *The journal of general medicine*. 2008;(3):78-84. (In Russ.)
10. Semenkin OM, Izmalkov SN, Golubtsov VI. Correcting osteotomy for intra-articular malunion of the distal radius. *Traumatology and orthopedics of Russia*. 2015;21(2):16-23. (In Russ.)
11. Volotovsky AI. Adaptive collapse of the wrist: notion, classification, modern methods of diagnostics. *Medical journal*. 2012;(3):26-31. (In Russ.)
12. Gilev MV. Surgical management of intra-articular impression distal radius fracture. *Genij Ortopedii*. 2018;24(2):134-141. doi: 10.18019/1028-4427-2018-24-2-134-141
13. Shershneva OG, Varentsov DS, Kryukova AS, et al. Operative and conservative methods of treatment of fractures of the distal metaepiphysis of the radius. *Young Scientist*. 2019;(23):179-183. (In Russ.)

14. Matveev RP, Bragina SV, Shneiveis AM. Differentiated approach to repair of displaced distal radial metaepiphyseal fractures. *Genij Ortopedii*. 2017; 23 (4): 396-400. doi: 10.18019/1028-4427-2017-23-4-396-400
15. Huetteman HE, Zhong L, Chung KC. Cost of Surgical Treatment for Distal Radius Fractures and the Implications of Episode-Based Bundled Payments. *J Hand Surg Am*. 2018;43(8):720-730. doi: 10.1016/j.jhsa.2018.05.007
16. Nellans KW, Kowalski E, Chung KC. The epidemiology of distal radius fractures. *Hand Clin*. 2012;28(2):113-125. doi: 10.1016/j.hcl.2012.02.001
17. Panova G, Panov N, Panova B, et al. Epidemiology of distal radius fracture. *III Congress of general medicine doctors of R. Macedonia with international participation, April 26-29, 2012*. Ohrid. URI: https://eprints.ugd.edu.mk/id/eprint/5390
18. Abramo A, Tagil M, Geijer M, Kopylov P. Osteotomy of dorsally displaced malunited fractures of the distal radius: no loss of radiographic correction during healing with a minimally invasive fixation technique and an injectable bone substitute. *Acta Orthop*. 2008;79(2):262-268. doi: 10.1080/17453670710015085
19. MacDermid JC, Roth JH, Richards RS. Pain and disability reported in the year following a distal radius fracture: a cohort study. *BMC Musculoskelet Disord*. 2003;4:24. doi: 10.1186/1471-2474-4-24
20. Cooney WP 3rd, Dobyns JH, Linscheid RL. Complications of Colles' fractures. *J Bone Joint Surg Am*. 1980;62(4):613-619.
21. Abramo A, Tagil M, Geijer M, Kopylov P. Osteotomy of dorsally displaced malunited fractures of the distal radius: no loss of radiographic correction during healing with a minimally invasive fixation technique and an injectable bone substitute. *Acta Orthop*. 2008;79(2):262-268. doi: 10.1080/17453670710015085
22. McQueen MM, Wakefield A. Distal radial osteotomy for malunion using non-bridging external fixation: good results in 23 patients. *Acta Orthop*. 2008;79(3):390-395. doi: 10.1080/17453670710015300
23. Haines SC, Bott A. Current Concepts: Corrective Osteotomy for Extra-Articular Deformity Following a Distal Radius Fracture. *Cureus*. 2023;15(10):e47019. doi: 10.7759/cureus.47019
24. Flinkkilä T, Raatikainen T, Kaarela O, Hämäläinen M. Corrective osteotomy for malunion of the distal radius. *Arch Orthop Trauma Surg*. 2000;120(1-2):23-26. doi: 10.1007/pl00021237
25. Cibula Z, Hrubina M, Melišík M, et al. Osteotomy after Distal Radius Fractures - Five-Year Clinical and Radiological Outcomes. *Acta Chir Orthop Traumatol Cech*. 2018;85(4):254-260. (In Slovak.)
26. Gaspar MP, Kho JY, Kane PM, et al. Orthogonal Plate Fixation With Corrective Osteotomy for Treatment of Distal Radius Fracture Malunion. *J Hand Surg Am*. 2017;42(1):e1-e10. doi: 10.1016/j.jhsa.2016.10.012
27. Wynter-Blyth V, Moorthy K. Prehabilitation: preparing patients for surgery. *BMJ*. 2017;358:j3702. doi: 10.1136/bmj.j3702
28. Swank AM, Kachelman JB, Bibeau W, et al. Prehabilitation before total knee arthroplasty increases strength and function in older adults with severe osteoarthritis. *J Strength Cond Res*. 2011;25(2):318-325. doi: 10.1519/JSC.0b013e318202e431
29. Franz A, Queitsch FP, Behringer M, et al. Blood flow restriction training as a prehabilitation concept in total knee arthroplasty: A narrative review about current preoperative interventions and the potential impact of BFR. *Med Hypotheses*. 2018;110:53-59. doi: 10.1016/j.mehy.2017.10.029
30. Bikchurin NM, Takhavieva FV, Aidarov VI, Akishin EM. Prehabilitation in the prevention of injuries of musculoskeletal system. *Practical medicine*. 2017;(8):36-39. (In Russ.)
31. Gouk C, Bairstow M, Thomas M, et al. A comparison of early fixation of distal radius fractures versus late corrective osteotomy of distal radius malunion. *ANZ J Surg*. 2022;92(12):3319-3324. doi: 10.1111/ans.18122
32. Mahmoud M, El Shafie S, Kamal M. Correction of dorsally-malunited extra-articular distal radial fractures using volar locked plates without bone grafting. *J Bone Joint Surg Br*. 2012;94(8):1090-1096. doi: 10.1302/0301-620X.94B8.28646
33. Neverov VA, Khromov AA, Kravchenko IN, et al. Surgical treatment of patients with fractures of distal metaepiphysis of the radial bone. *Grekov's Bulletin of Surgery*. 2009; 168 (1): 66-70. (In Russ.)
34. Disseldorp DJ, Poeze M, Hannemann PF, Brink PR. Is Bone Grafting Necessary in the Treatment of Malunited Distal Radius Fractures? *J Wrist Surg*. 2015;4(3):207-213. doi: 10.1055/s-0035-1558831
35. Gradl G, Jupiter J, Pillukat T, et al. Corrective osteotomy of the distal radius following failed internal fixation. *Arch Orthop Trauma Surg*. 2013;133(8):1173-1179. doi: 10.1007/s00402-013-1779-5

36. Wei J, Yang TB, Luo W, et al. Complications following dorsal versus volar plate fixation of distal radius fracture: a meta-analysis. *J Int Med Res*. 2013;41(2):265-275. doi: 10.1177/0300060513476438

The article was submitted 05.09.2023; approved after reviewing 12.02.2024; accepted for publication 18.06.2024.

Information about the authors:

Aleksandr A. Khromov — Doctor of Medical Sciences, Professor, Khromov_alex@mail.ru, https://orcid.org/0000-0002-8489-4202;

Evgeny K. Gumanenko — Doctor of Medical Sciences, Professor, gumanenko@inbox.ru, https://orcid.org/0000-0001-5974-503X,

Stanislav A. Linnik — Doctor of Medical Sciences, Professor, stanislavlinnik@mail.ru, https://orcid.org/0000-0002-4840-6662;

Alexandr N. Tkachenko — Doctor of Medical Sciences, Professor, altkachenko@mail.ru, https://orcid.org/0000-0003-4585-5160;

Aleksandr G. Kravtsov — Candidate of Medical Sciences, kravt@med122.com, https://orcid.org/0009-0002-7063-6023;

Artem V. Melnichuk — assistant of the Department, melin@inbox.ru, https://orcid.org/0009-0006-9148-1306;

Andrey S. Lazutin — assistant of the Department, lazutin.as@yandex.ru, https://orcid.org/0009-0000-3222-9895;

Anatoliy V. Zhulyabin — orthopaedic surgeon, AV-Zhulyabin@yandex.ru, https://orcid.org/0009-0003-3009-2831.

Review article
https://doi.org/10.18019/1028-4427-2024-30-4-597-607

Nerve injury associated with shoulder surgery

A.O. Tuturov[1], A.S. Petrosyan[2], M.A. Panin[2], B.I. Zakharyan[2], O. Al-Bawareed[2]✉

[1] City Clinical Hospital named after S.S. Yudin, Moscow, Russian Federation
[2] City Clinical Hospital No. 17, Moscow, Russian Federation

Corresponding author: Omar Al-Bawareed, vduort@gmail.com

Abstract

Introduction Progress in shoulder surgery is associated with improved operating rooms equipment, advanced surgical products and minimally invasive techniques. There are rare injuries to nerves and vessels being intersected or pulled into the sutures. However, marginal tears, compression and nerve entrapment of trunks during access retraction, catheterization, inadequate correct of the patient on the operating table and errors in rehabilitation can be common.

The **purpose** was to identify factors predisposing to peripheral nerve injury to the upper limb during shoulder surgery and offer prevention options.

Material and methods Major studies in the field of shoulder anatomy and surgery published between 1984 and 2023 were reviewed to identify anatomical, biomechanical and perioperative factors leading to peripheral nerve injuries. The original literature search was conducted on key resources including GoogleScholar, PubMed, ScienceDirect, RSCI, Scopus. Four approaches were used for structuring and informative presentation of the data to include types of the peripheral nerve injury in the upper limb.

Results and discussion Factors predisposing to the peripheral nerve injury in the upper limb during shoulder surgery were identified in the review. Prevention measures include the patient positioned on the operating table with adequate fixation of the head and torso, regardless of the chosen position; traction of the involved upper limb with a load of not greater than 9 kg using a specialized clamp; preoperative marks of the surgical field and staining of bone landmarks; the arthroscopic ports 1–2 cm to be shifted more distally minimizing the fluid flow into the joint during a long operation. Postoperative consultation with rehabilitation specialists is essential to develop an early activation program and assess the risks of neurological disorders.

Conclusion The shoulder anatomy and the localization of unsafe zones of the shoulder, the risks associated with a particular manipulation were explored for effective preoperative planning and prevention of neurological complications in the treatment of surgical pathology of the shoulder joint.

Keywords: shoulder joint, nerve surgery, nerve injury, arthroscopy, arthroplasty

For citation: Tuturov AO, Petrosyan AS, Panin MA, Zakharyan BI, Al Bawareed O. Nerve injury associated with shoulder surgery. *Genij Ortopedii*. 2024;30(4):597-607. doi: 10.18019/1028-4427-2024-30-4-597-607

© Tuturov A.O., Petrosyan A.S., Panin M.A., Zakharyan B.I., Al Bawareed O., 2024
© Translator Irina A. Saranskikh, 2024

INTRODUCTION

Various injuries and surgical procedures about the shoulder are known to place the nerves at risk. Iatrogenic nerve injuries are among the more commonly cited complications associated with shoulder surgery.

The incidence of nerve injury depends on the skill and experience of the surgeon, the type of surgery and the approach used. Neurological symptoms can be detected after 0.2–3 % of arthroscopic procedures, 4 % of arthroplasties, and 8 % of open surgeries performed for shoulder instability [1]. Most of the injuries are paresthesias or hypoesthesias and transient neuropraxia [2]. Severe neurological complications result from injury to the main trunks of the suprascapular (SS), musculocutaneous (MCN), axillary nerves (AS) and cranial nerves (CN) [3]. There are many classifications of nerve injury based on etiology, location, form and degree of damage. Iatrogenic injuries are characterized by pronounced polymorphism and can be caused by compression from retraction or edema, thermal dissection from inadequate ablation/coagulation of surrounding tissues, entrapment in the sutures and anchors, etc.

Nerve trauma is difficult to be detected during surgery and there is no need for intraoperative neuromonitoring in most cases, and there are no obvious visual signs as with intersected blood vessels. Neurological symptoms can be revealed the next day after surgery and often raise doubts for a long time, which may be associated with preoperative plexus blockade. A thorough preoperative preparation and adequate intraoperative and postoperative manipulations are essential for preventing a neurotraumatic factor.

The **objective** was to identify factors predisposing to damage to the peripheral nerves of the upper limb during shoulder surgery and offer options for their elimination.

MATERIAL AND METHODS

Major studies in the field of shoulder anatomy and surgery published between 1984 and 2023 were reviewed to identify anatomical, biomechanical and perioperative factors leading to eripheral nerve injuries. The original literature search was conducted on key resources including GoogleScholar, PubMed, ScienceDirect, RSCI, Scopus. Four approaches were used for structuring and informative presentation of the data to include types of the peripheral nerve injury in the upper limb: placement of the patient on the operating table, arthroscopic surgery of the shoulder, open surgery of the shoulder joint, multifactorial complication of shoulder surgery. Each of them included possible options for damage to the peripheral nerve of the upper limb identifying nerve topography and associated risks of a damage during preoperative, intraoperative manipulations and rehabilitation. Thus, ways to minimize nerve damage could be recommended.

RESULTS

Placing the patient on the operating table

J.R. Andrews et al. [4] concluded that improper port placement can damage neurovascular structures and identified the main complicating factors to include inadequate patient positioning and traction greater than 9 kg. Shoulder surgery can be performed with two main positions: the beach-chair position and the lateral decubitus position [4].

Beach-chair position

Nerve injury is uncommon with beach-chair position with the upper limb being lowered due to the mass, and the brachial plexus is not stretched and maximally displaced downwards to the axillary region, and therefore damage to the MCN and AS is the least likely scenario [5].

The beach-chair position has a disadvantage of providing instability to the head. There is evidence of postoperative neurological symptoms due to compression of the lesser occipital and greater auricular nerves due to head supports [6] and mid-cervical quadriplegia [7]. Other iatrogenic nerve damage can be associated with the use of a belt to hold the head, the assistant or surgeon relying on the neck area with compression to the angle of the lower jaw, excessive lateral flexion and excessive head movements during muscle relaxation with loss of fixation (compression of the XII cranial nerve) [8]. A. Cogan et al. [9] suggested that any change in the angle formed by the torso and head other than 180° increases the risk of injury to the XII cranial nerve.

Recommendations

The head in the beach-chair position must be carefully secured with side supports or a specialized fixator to protect the neck. It is important to monitor the location throughout the operation, as well as any touch at the site [10].

Lateral decubitus

Another position, lateral decubitus, has the advantages of a better cerebral perfusion with no greater risk of hypotension and bradycardia. Bubbles in the joint fluid from coagulation move away from the field of view providing free access to the posterior and upper regions of the shoulder, better visualization of the subacromial space [eleven]. Most of the benefits are due to lateral traction of the upper limb securing the patient in a lateral position. Tension in the brachial plexus can increase the risk of damage to the MCN and AS performing arthroscopic ports, and the traction force leads to compression of soft tissues, vessels and nerves, and the load on the contralateral shoulder can lead to compression injuries.

Recommendations

Lateral decubitus suggests a traction of 9 kg at most, the patient positioned with a dorsal rotation of the body up to 30°, abduction of the arm of 45° to be reduced when working in the subacromial space [12].

Arthroscopic shoulder surgery

Arthroscopic surgery minimizes soft tissue dissection compared to open shoulder surgery. However, placement of ports is associated with the risk of direct nerve injury [4]. The incidence of intraoperative or iatrogenic nerve injury is directly correlated with several factors. First, a lot depends on the experience of the surgeon, the number of operations performed, the knowledge and skills acquired during cadaver courses. Second, the anatomy of the patient is essential [13]. Maldevelopments, abnormalities post-traumatic conditions can cause the complications. The risk of nerve injury can be minimized through the knowledge of the anatomy of the nerve trunks described in the literature.

Formation of accesses

Marking is to be produced first (Fig. 1) to facilitate an adequate access. The landmarks may become erroneous in the case of a long procedure. With the tissues filled with water the markers move and can lead to various complications. In this case, it is more appropriate to consider previous ports as a starting point [14].

Posterior port

The posterior port is usually placed first by palpating and puncturing the soft spot. The landmark for the skin incision is approximately 2 cm inferior and 1 cm medial to the posterolateral angle of the acromion [15].

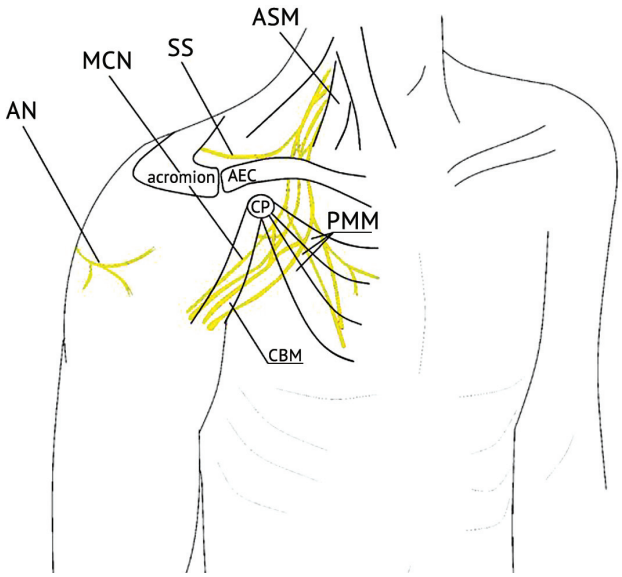

Fig. 1 Schematic representation of preoperatively marked musculoskeletal landmarks of the shoulder for identifying the location of the nerves. Abbreviations: AN, axillary nerve; MCN, musculocutaneous nerve; SS, suprascapular nerve, AEC, acromial end of the clavicle; CP, coracoid process; CBM, coracobrachial muscle; PMM, pectoralis minor muscle; ASM, anterior scalene muscle (illustrated by the author)

Description of the technique

With the skin cut, the trocar is directed towards the coracoid process. If the port is too low and/or the trocar is directed below the shoulder joint, there is a high risk of injury to the AN. If the port is too medial, the SS is likely to be affected. For the adequate trocar placement, the following technique can be used. The first finger of the right or left hand to be placed near the entry site, depending on which shoulder is being operated on. The second finger is to be placed at the apex of the coracoid process. The direction of the instrument placement will be controlled based on the effect of a palpable and easily visualized vector [14]. The port can be 1 cm more proximal in some cases. This technique is used when the main manipulations occur in the subacromial space. The arthroscope is placed subacromially, almost parallel to the acromion, which will not interfere with the movement of the instrument increasing the viewing area [16]. The port is more practical for a short procedure (within 1 hour). Longer procedures will result in extravasation and the approach will be ineffective.

Posterior port

The next port is formed at the anterior aspect. The procedure must be performed with extreme caution to avoid complications [3].

Anatomy

There is a risk of damage to the AN and MCN with placement of the anterior port. A greater traumatic risk for AN is associated with the placement of ports during arthroscopy in an anterior-inferior position: the transsubscapular port used in labral complex reconstruction, can be located at a distance of 1.5 cm from the AN [17]. Therefore, surgeons are advised to maintain a minimum “safe zone” distance of 1 cm from the glenoid applying capsular sutures. The MCN is vulnerable proximally lying on the subscapularis muscle. The nerve entry point into the coracobrachialis muscle is unpredictable and the nerve can bifurcate [18]. The distance between the CP and the nerve entry point into the muscle ranges from 3.1 to 8.2 cm. Placement of any anterior ports medial to the CP and the conjoined tendon can result in traumatic injury to the MCN and the lateral trunk of the brachial plexus. A permanent injury to the nerves is rare with experienced surgeons during shoulder arthroscopy (< 0.1 %) [3].

Technique

The anterior port is used with inside-out technique and a Wiesinger rod or by puncturing the skin anteriorly under direct arthroscope view from the posterior port. MCN can be at risk with the anterior port placed too medially and low from the coracoid process. The port, which is located superior and lateral to the CP and the lateral edge of the short head of the biceps tendon, is relatively safe [3].

Lateral port

The lateral port is installed next in most surgical interventions with the knowledge of the location of the final branches of the AN [19].

Anatomy

The AN is located on average 5.5 cm inferior to the posterior angle of the acromion, 8 cm from the middle part of the acromion, 7 cm from the anterolateral angle of the acromion, and 5.8 cm distal to the acromioclavicular joint. Abduction in the shoulder joint to 90° brings the nerve closer to the edge of the acromion by approximately 30 % [20]. Violation of the boundaries can lead to inadequate placement of the lateral port and is associated with damage to the sensory branches of the AN in 10 % of cases [21]. The SS lies on the undersurface of the supraspinatus and infraspinatus tendons being close to the surgical site, approximately 2.9 cm from the superior border of the glenoid and 1.8 cm from the spine of the scapula. The SS can be damaged by compression from anchors located in the superior part of the glenoid during SLAP operations [22]; the SS is usually located at a distance of 2 cm from the insertion points of the anchors [23].

Technique

The lateral port is positioned under visualization from the posterior port, approximately 4 cm distal to the midportion of the lateral edge of the acromion [21]. We recommend a needle test puncture to understand the cutting point. It is performed in the direction of the lower surface of the acromion.

Time factor

Extravasation is another intraoperative factor that can cause a nerve damage. Large incisions for an access in the capsule and synovial membrane creating prerequisites for the fluid releasing into the surrounding tissue and resulting in edema. This is not only an imprudent approach to port placement that leads to this. Extravasation can be aggravated by increased operating time, increased pressure in the joint cavity for better visualization, and arthroscopy in conditions of acute injury and severe inflammation. Decreased extensibility of the joint cavity can be the most negative consequence of extravasation limiting operating capacity of the instruments preventing adequate placement through the ports with a risk to the neurovascular structures [24]. The difficult to predict intraoperative phenomenon requires more attention to the anatomical structures near the ports. The ports can be relocated with a risk of extravasation in a prolonged surgery.

Open shoulder surgery

Open shoulder surgery is associated with a risk of peripheral nerve injury because of the use of retractors located anterior to the glenoid near the brachial plexus extending 10–25 mm medial to the glenoid [25]. As mentioned earlier, intraoperative positioning of the hand can cause stress to the brachial plexus creating preconditions for an injury. Open shoulder surgeries include rotator cuff repair, shoulder stabilization, total or partial joint replacement, and osteosynthesis of fractures. Adequate surgical access is practical in avoiding complications [26].

Anterior approach

is common in surgery of the anterior shoulder joint, anterior instability, osteosynthesis of the proximal humerus and joint replacement [27].

Technique

The anterior (deltopectoral) approach involves widening the interval between the deltoid and pectoral muscles. The cephalic vein is retracted superiorly and laterally along with the deltoid muscle to expose the conjoined tendon formed by the coracobrachialis tendon and the short head of the biceps. The subscapularis muscle is located underneath it. Divided or transected fibers of the subscapularis muscle allows access to the joint capsule. Open operations stabilizing the shoulder joint are more common using the deltopectoral approach and modifications. The reported incidence of neurological injury varies from 0.8 to 8.2 % [28]. A deltopectoral approach is associated with minimally displaced conjoined tendon with the MCN penetrating in the muscle fibers below. The MCN is at risk due to compression by the retractors located under the conjoined tendon. Caution is recommended when retracting muscles. The AN passes under the subscapularis muscle and is directed through the quadrangular space, therefore it is recommended to preserve the lowest quarter of the subscapularis muscle to protect this nerve. The Bristow-Latarjet operation is indicative in terms of the risks of damage to several nerves using the approach [29]. The bone autoplasty of a defect in the articular surface of the scapula is used to stabilize the shoulder joint. An osteotomy of the coracoid process is performed and the joint tendon attached is shifted to the anteroinferior glenoid defect [28]. A systematic review published in 2013 showed 21 cases of nerve injury with 1904 operations (1.2 %): MCN was the most commonly injured nerve followed by AN and diffuse brachial plexopathy [29]. There were reports of injury to the glenoid due to screws passing through the glenoid impinging on it as it is guided along the posterior edge of the articular process of the scapula, or due to excessive penetration during drilling. Medial deviation of the glenoid screws should be avoided according to anatomical studies [30].

Lateral approach

The lateral approach suggests an incision parallel to the lateral edge of the acromion to allow wide visualization of the subacromial space. Other approaches include Neer (anterolateral), Mackenzie (more laterally displaced), Bigliani incisions starting from the acromioclavicular joint and including split variants [31, 32]. They can be used for rotator cuff injuries, impingement syndrome, for joint replacement and osteosynthesis of the proximal humerus. Minimally invasive plate osteosynthesis (MIPO) techniques are performed through a delta split in case of proximal humerus fractures. An intact position of the AN is essential for a low-traumatic plating [33].

Anatomy

It is not recommended to cut the deltoid muscle 5 cm below the acromion to avoid damage to the AN. Yildirim et al. reported an influence of the upper limb length to the phenomemon with a safe range being at least 5.5 cm [34]. The distance between the acromion and the anterior ramus of the AN can vary [35] and decrease with abduction [36]. Wilkinson et al. reported 755 MRIs of the shoulder joints showing the lower articular edge of the humeral head as a horizontal landmark for the passage of the axillary neurovascular bundle and a window measuring 22 mm below this projection being the most dangerous zone [37].

Technique

The lateral approach and delta split involve subperiosteal cut of the deltoid muscle from the acromion or separation of its fibers, respectively. Suturing is important for MIPO access to protect the AN [33]. The suture prevents further separation of the muscle tissue with access retraction.

Posterior approach

The approach is performed during surgery of the posterior part of the shoulder to repair injuries to the posterior portion of the rotator cuff and posterior instability [31].

Technique

The posterior approach involves the use of the space between the infraspinatus muscle and the teres minor muscle. The deltoid muscle is separated from the spine of the scapula or split directly (according to Rockwood) [38]. The posterior capsule of the shoulder lies below them. Excessive medial retraction of the infraspinatus muscle can damage the SS [3].

Multifactorial complication of shoulder surgery

Distal peripheral neuropathy (DPN) is a rare neurological postoperative disorder [39]. The complication can be associated with a surgical shoulder manipulation and is difficult for differential diagnosis of the injury and the level (Fig. 2).

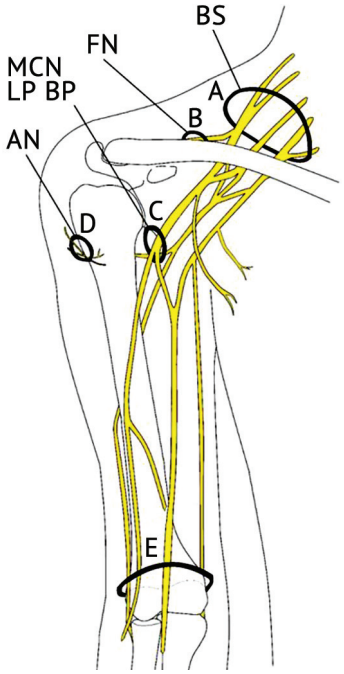

Fig. 2 Schematic representation of common injuries to nerve structures of the upper limb during shoulder surgery: (A) interscalene blockade of the brachial plexus, positioning of the patient on the operating table, intraoperative manipulations and movements of the surgeon with more proximal injuries leading to damage to the X and XII cranial brain nerves; (B) posterior approaches and arthroscopic ports; (C anterior approaches, deltopectoral in particular; (D) lateral approaches and arthroscopic ports; (E) area of the distal peripheral nerves, which can be damaged during intraoperative positioning of the patient and the upper limb, extravasation, tourniquet application, inadequate immobilization and rehabilitation. Abbreviations: BS, brachial plexus; FN, suprascapular nerve, MCN, musculocutaneous nerve; LP BP, lateral fascicle of the brachial plexus, AN, axillary nerve (illustrated by the author)

DPN was identified in 0–0.24 % of anatomical shoulder arthroplasties [39], 0.9 to 5.2 % in reverse arthroplasty [40], and 0 to 2 % after arthroscopic shoulder surgery. Although a direct cause-and-effect relationship with shoulder surgery has not been established there are prerequisites reported for the development of DPN including positioning of the upper limb, interscalene brachial plexus block [41], fluid extravasation, tourniquet application and prolonged immobilization. DPN after shoulder surgery is a multifactorial disease.

Tourniquet application

Tourniquets are inflated to high pressures that can damage nerves through mechanical compression and/or ischemia. Larger nerves are predominantly affected, and high pressure can lead to temporary loss of motor function and deterioration of sensory perception [42].

Prolonged immobilization

Nerve damage can be associated with prolonged immobilization using orthosis. Several cases of anterior interosseous nerve injury have been described in patients wearing a Robert Jones type orthosis or bandage after clavicle osteosynthesis [43]. A follow-up examination at 6 weeks reveals dysfunction of the patient's first finger. T2-weighted MRI shows marked swelling in the forearm muscle innervated by the anterior interosseous nerve. Post-immobilization contracture develops due to a traumatic disease represented by functional and morphological denervation of tissues

and muscle atrophy, leading to shortening of muscle fibers, a decreased elasticity of the joint capsule and rigidity [44]. Compartment syndrome develops in the elbow and the wrist due to swelling, mechanical compression with intrasurgical hand rests or inadequate use of orthosis and lack of early rehabilitation. Typical tunnel syndromes of the radial, ulnar, median nerves and their branches can develop to be treated with conservative treatment or surgical decompression in some cases [38].

DISCUSSION

Intraoperative injuries to the nerves of the shoulder are not common, but lead to catastrophic consequences. They can occur during operations performed for instability of the anterior shoulder, joint replacement and during fixation of multi-fragmental fractures of the proximal humerus. Preoperative preparation is essential and includes proper anesthesia and adequate positioning of the patient on the operating table with sufficient fixation of the head and torso. The operating team must have proper knowledge of the shoulder anatomy and specific features of the neurovascular formations. Particular care must be taken when establishing access through “secure areas”. Preoperative palpation of the bony landmarks outlining the contours for safe access, maintaining an “anatomy map” in case of edema are important. Operative time must be carefully monitored, especially during arthroscopy, to reduce the risk of nerve damage from extravasation. Any hand positioning must be physiological and consistent.

Despite advances in surgical technology, including the use of instruments that allow for less invasive procedures, the risk of nerve damage cannot be completely eliminated. Knowledge of the perioperative factors to developing neuropathy remains important. Increased intraoperative awareness and knowledge of anatomy, irrespective of open or arthroscopic surgery, necessitate careful postoperative assessments to determine whether injury has occurred [45]. Continuous intraoperative nerve monitoring is practical for avoiding risky manipulations having knowledge of safe zones. In 2005 A.N. Esmail et al. [46] and 2007 S.H. Nagda et al. [47] used this method for arthroscopy and replacement of the shoulder joint. Episodes of impaired impulse transmission during surgery were recorded in 17 out of 30 patients after arthroplasty. Removal or release of the retractor pressure was ineffective. It was initially assumed that this caused the equipment’s response. The hand returned to a neutral position led to improved condition in 77 % of cases. It was concluded that monitoring may be useful during surgery on a stiff joint or in patients with a history of open shoulder surgery. Pre- and intraoperative careful monitoring avoids the risk of further complications. A peripheral nerve damage is difficult to detect early after surgery due to immobilization with orthosis. An electrophysiological study can be practical in dubious cases. Earlier studies can help to determine whether the injury is electrophysiologically partial or complete with the presence of a single motor unit indicating a partial nerve injury [48]. If an acute nerve injury is suspected, stimulation electroneuromyography is recommended 10–14 days after injury [49]. Examinations performed approximately three months after injury may indicate early reinnervation through the presence of nascent potentials. The peripheral nerve surgery is normally scheduled no earlier than 3–6 months after injury, unless there is clinical or electrophysiological evidence of reinnervation during this period [50, 51]. Surgeons operating on the shoulder have skills in microsurgical nerve suturing. Early repair of nerve injury has been reported to achieve better functional outcomes [52, 53, 54, 55]. A secure fastening and wearing the orthosis is essential for rehabilitation. The patient should be informed by the operating surgeon about the timing of its use, how often it should be removed and how to perform exercises safely. This will reduce the risk of elbow and wrist contractures and minimize the likelihood of creating preconditions for the tunnel syndromes and other neuropathies.

CONCLUSION

The review allowed us to identify factors predisposing to damage to the peripheral nerves of the upper limb during shoulder surgery. Every stage is important, from preparation for surgery to the implementation of the adequate rehabilitation protocol. Adequate fixation of the head and torso is important for the patient in the lateral decubitus or the beach-chair position on the operating table with traction on the operated upper limb measuring 9 kg at most and using a specialized fixator. Careful preoperative marking of the surgical field and staining of bone landmarks should be produced after estimation of the expected length of operation. Arthroscopic ports are advised to move 1–2 cm distally during a long procedure to minimize the flow of intra-articular lavage fluid. An early ambulation programme can be discussed postoperatively with rehabilitation specialists to prevent neurological disorders.

Conflicting Interests *The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.*

Funding *The authors received no financial support for the research and/or authorship of this article.*

REFERENCES

1. Carofino BC, Brogan DM, Kircher MF, et al. Iatrogenic nerve injuries during shoulder surgery. *J Bone Joint Surg Am*. 2013;95(18):1667-1674. doi: 10.2106/JBJS.L.00238
2. Lafosse T, Lafosse L. Neurological Complications in Shoulder Arthroscopy. In: Lafosse L, Agneskirchner J, Lafosse T. (eds) *Complications in Arthroscopic Shoulder Surgery*. Springe: Cham Publ.; 2020:139-148. doi: 10.1007/978-3-030-24574-0_14
3. Rashid A., Abdul-Jabar H., Lam F. Nerve injury associated with shoulder surgery. *Current Orthopaedics*. 2008;22(4):284-288. doi: 10.1016/j.cuor.2008.04.009
4. Andrews JR, Carson WG Jr, Ortega K. Arthroscopy of the shoulder: technique and normal anatomy. *Am J Sports Med*. 1984;12(1):1-7. doi: 10.1177/036354658401200101
5. Murphy GS, Greenberg SB, Szokol JW. Safety of Beach Chair Position Shoulder Surgery: A Review of the Current Literature. *Anesth Analg*. 2019;129(1):101-118. doi: 10.1213/ANE.0000000000004133
6. Park TS, Kim YS. Neuropraxia of the cutaneous nerve of the cervical plexus after shoulder arthroscopy. *Arthroscopy*. 2005;21(5):631. doi: 10.1016/j.arthro.2005.02.003
7. Rains DD, Rooke GA, Wahl CJ. Pathomechanisms and complications related to patient positioning and anesthesia during shoulder arthroscopy. *Arthroscopy*. 2011;27(4):532-541. doi: 10.1016/j.arthro.2010.09.008
8. Hung NK, Lee CH, Chan SM, et al. Transient unilateral hypoglossal nerve palsy after orotracheal intubation for general anesthesia. *Acta Anaesthesiol Taiwan*. 2009;47(1):48-50. doi: 10.1016/S1875-4597(09)60022-9
9. Cogan A, Boyer P, Soubeyrand M, et al. Cranial nerves neuropraxia after shoulder arthroscopy in beach chair position. *Orthop Traumatol Surg Res*. 2011;97(3):345-348. doi: 10.1016/j.otsr.2010.09.020
10. Higgins JD, Frank RM, Hamamoto JT, et al. Shoulder Arthroscopy in the Beach Chair Position. *Arthrosc Tech*. 2017;6(4):e1153-e1158. doi: 10.1016/j.eats.2017.04.002
11. Li X, Eichinger JK, Hartshorn T, et al. A comparison of the lateral decubitus and beach-chair positions for shoulder surgery: advantages and complications. *J Am Acad Orthop Surg*. 2015;23(1):18-28. doi: 10.5435/JAAOS-23-01-18
12. Hamamoto JT, Frank RM, Higgins JD, et al. Shoulder Arthroscopy in the Lateral Decubitus Position. *Arthrosc Tech*. 2017;6(4):e1169-e1175. doi: 10.1016/j.eats.2017.04.004
13. Cate G, Barnes J, Cherney S, et al. Current status of virtual reality simulation education for orthopedic residents: the need for a change in focus. *Global Surg Educ*. 2023;2(1):46. doi: 10.1007/s44186-023-00120-w
14. Burkhart SS. Shoulder arthroscopy: a bridge from the past to the future. *J Shoulder Elbow Surg*. 2020;29(8):e287-e296. doi: 10.1016/j.jse.2020.04.011
15. Park J, Kim JY, Kim D, et al. Single-Portal Arthroscopic Posterior Shoulder Stabilization. *Arthrosc Tech*. 2021;10(12):e2813-e2817. doi: 10.1016/j.eats.2021.08.031
16. Dunn ASM, Petterson SC, Plancher KD. The Shoulder Trans-pectoralis Arthroscopic Portal Is a Safe Approach to the Arthroscopic Latarjet Procedure: A Cadaveric Analysis. *Arthroscopy*. 2021;37(2):470-476. doi: 10.1016/j.arthro.2020.09.044
17. Bharati S, Karmakar M, Ghosh S. Ipsilateral paralysis of hypoglossal nerve following interscalene brachial plexus block. *J Anaesthesiol Clin Pharmacol*. 2014;30(3):446-447. doi: 10.4103/0970-9185.137304
18. Shah AC, Barnes C, Spiekerman CF, Bollag LA. Hypoglossal nerve palsy after airway management for general anesthesia: an analysis of 69 patients. *Anesth Analg*. 2015;120(1):105-120. doi: 10.1213/ANE.0000000000000495
19. Meyer M, Graveleau N, Hardy P, Landreau P. Anatomic risks of shoulder arthroscopy portals: anatomic cadaveric study of 12 portals. *Arthroscopy*. 2007;23(5):529-536. doi: 10.1016/j.arthro.2006.12.022
20. Leechavengvongs S, Teerawutthichaikit T, Witoonchart K, et al. Surgical anatomy of the axillary nerve branches to the deltoid muscle. *Clin Anat*. 2015;28(1):118-122. doi: 10.1002/ca.22352

21. Segmüller HE, Alfred SP, Zilio G, et al. Cutaneous nerve lesions of the shoulder and arm after arthroscopic shoulder surgery. *J Shoulder Elbow Surg*. 1995;4(4):254-258. doi: 10.1016/s1058-2746(05)80017-5
22. Kim SH, Koh YG, Sung CH, et al. Iatrogenic suprascapular nerve injury after repair of type II SLAP lesion. *Arthroscopy*. 2010;26(7):1005-1008. doi: 10.1016/j.arthro.2010.01.005
23. Chan H, Beaupre LA, Bouliane MJ. Injury of the suprascapular nerve during arthroscopic repair of superior labral tears: an anatomic study. *J Shoulder Elbow Surg*. 2010;19(5):709-715. doi: 10.1016/j.jse.2009.12.007
24. Memon M, Kay J, Gholami A, Simunovic N, Ayeni OR. Fluid Extravasation in Shoulder Arthroscopic Surgery: A Systematic Review. *Orthop J Sports Med*. 2018;6(5):2325967118771616. doi: 10.1177/2325967118771616
25. McFarland EG, Caicedo JC, Guitterez MI, et al. The anatomic relationship of the brachial plexus and axillary artery to the glenoid. Implications for anterior shoulder surgery. *Am J Sports Med*. 2001;29(6):729-733. doi: 10.1177/03635465010290061001
26. Fu MC, Hendel MD, Chen X, et al. Surgical anatomy of the radial nerve in the deltopectoral approach for revision shoulder arthroplasty and periprosthetic fracture fixation: a cadaveric study. *J Shoulder Elbow Surg*. 2017;26(12):2173-2176. doi: 10.1016/j.jse.2017.07.021
27. Patel MS, Daher M, Fuller DA, Abboud JA. Incidence, Risk Factors, Prevention, and Management of Peripheral Nerve Injuries Following Shoulder Arthroplasty. *Orthop Clin North Am*. 2022;53(2):205-213. doi: 10.1016/j.ocl.2021.11.006
28. Provencher MT, Bhatia S, Ghodadra NS, et al. Recurrent shoulder instability: current concepts for evaluation and management of glenoid bone loss. *J Bone Joint Surg Am*. 2010;92 Suppl 2:133-151. doi: 10.2106/JBJS.J.00906
29. Hovelius L, Körner L, Lundberg B, et al. The coracoid transfer for recurrent dislocation of the shoulder. Technical aspects of the Bristow-Latarjet procedure. *J Bone Joint Surg Am*. 1983;65(7):926-934.
30. Lädermann A, Denard PJ, Burkhart SS. Injury of the suprascapular nerve during latarjet procedure: an anatomic study. *Arthroscopy*. 2012;28(3):316-321. doi: 10.1016/j.arthro.2011.08.307
31. Hoyen H, Papendrea R. Exposures of the shoulder and upper humerus. *Hand Clin*. 2014;30(4):391-399. doi: 10.1016/j.hcl.2014.08.003
32. Chawla H, Gamradt S. Reverse Total Shoulder Arthroplasty: Technique, Decision-Making and Exposure Tips. *Curr Rev Musculoskelet Med*. 2020;13(2):180-185. doi: 10.1007/s12178-020-09613-3
33. Knežević J, Mihalj M, Čukelj F, Ivanišević A. MIPO of proximal humerus fractures through an anterolateral acromial approach. Is the axillary nerve at risk? *Injury*. 2017;48 Suppl 5:S15-S20. doi: 10.1016/S0020-1383(17)30733-7
34. Yildirim C, Demirel M, Bayram E, et al. Acromion-axillary nerve distance and its relation to the arm length in the prediction of the axillary nerve position: a clinical study. *J Orthop Surg Res*. 2022;17(1):248. doi: 10.1186/s13018-022-03085-6
35. Cheung S, Fitzpatrick M, Lee TQ. Effects of shoulder position on axillary nerve positions during the split lateral deltoid approach. *J Shoulder Elbow Surg*. 2009;18(5):748-755. doi: 10.1016/j.jse.2008.12.001
36. Chuaychoosakoon C, Suwannaphisit S. The Relationship Between Arm Abduction Position and the Risk of Iatrogenic Anterior Branch of the Axillary Nerve Injuries: A Cadaveric Study. *Orthop J Sports Med*. 2021;9(5):23259671211008834. doi: 10.1177/23259671211008834
37. Wilkinson EB, Williams JF, Paul KD, et al. MRI evaluation of axillary neurovascular bundle: Implications for minimally invasive proximal humerus fracture fixation. *JSES Int*. 2021;5(2):205-211. doi: 10.1016/j.jseint.2020.11.002
38. Wirth MA, Butters KP, Rockwood CA Jr. The posterior deltoid-splitting approach to the shoulder. *Clin Orthop Relat Res*. 1993;(296):92-98.
39. Thomasson BG, Matzon JL, Pepe M, et al. Distal peripheral neuropathy after open and arthroscopic shoulder surgery: an under-recognized complication. *J Shoulder Elbow Surg*. 2015;24(1):60-66. doi: 10.1016/j.jse.2014.08.007
40. Walch G, Bacle G, Lädermann A, et al. Do the indications, results, and complications of reverse shoulder arthroplasty change with surgeon's experience? *J Shoulder Elbow Surg*. 2012;21(11):1470-1477. doi: 10.1016/j.jse.2011.11.010
41. Lenters TR, Davies J, Matsen FA 3rd. The types and severity of complications associated with interscalene brachial plexus block anesthesia: local and national evidence. *J Shoulder Elbow Surg*. 2007;16(4):379-387. doi: 10.1016/j.jse.2006.10.007
42. Hogan QH. Pathophysiology of peripheral nerve injury during regional anesthesia. *Reg Anesth Pain Med*. 2008;33(5):435-441. doi: 10.1016/j.rapm.2008.03.002
43. Anderson DM, White RA. Ischemic bandage injuries: a case series and review of the literature. *Vet Surg*. 2000;29(6):488-498. doi: 10.1053/jvet.2000.17847
44. Murphy EP, Fenelon C, Alexander M, Quinlan J. Anterior interosseous nerve palsy as a result of prolonged shoulder immobilisation. *BMJ Case Rep*. 2019;12(5):e229010. doi: 10.1136/bcr-2018-229010
45. Scully WF, Wilson DJ, Parada SA, Arrington ED. Iatrogenic nerve injuries in shoulder surgery. *J Am Acad Orthop Surg*. 2013;21(12):717-726. doi: 10.5435/JAAOS-21-12-717
46. Esmail AN, Getz CL, Schwartz DM, et al. Axillary nerve monitoring during arthroscopic shoulder stabilization. *Arthroscopy*. 2005;21(6):665-671. doi: 10.1016/j.arthro.2005.03.013
47. Nagda SH, Rogers KJ, Sestokas AK, et al. Neer Award 2005: Peripheral nerve function during shoulder arthroplasty using intraoperative nerve monitoring. *J Shoulder Elbow Surg*. 2007;16(3 Suppl):S2-S8. doi: 10.1016/j.jse.2006.01.016
48. Robinson LR. Traumatic injury to peripheral nerves. *Muscle Nerve*. 2022;66(6):661-670. doi: 10.1002/mus.27706
49. Pripotnev S, Bucelli RC, Patterson JMM, et al. Interpreting Electrodiagnostic Studies for the Management of Nerve Injury. *J Hand Surg Am*. 2022;47(9):881-889. doi: 10.1016/j.jhsa.2022.04.008
50. Gupta R, Patel NA, Mazzocca AD, Romeo A. Understanding and Treating Iatrogenic Nerve Injuries in Shoulder Surgery. *J Am Acad Orthop Surg*. 2020;28(5):e185-e192. doi: 10.5435/JAAOS-D-18-00608

51. Kamble N, Shukla D, Bhat D. Peripheral Nerve Injuries: Electrophysiology for the Neurosurgeon. *Neurol India*. 2019;67(6):1419-1422. doi: 10.4103/0028-3886.273626
52. Tuturov AO. The role of peripheral nerve surgery in a tissue reinnervation. *Chin Neurosurg J*. 2019;5:5. doi: 10.1186/s41016-019-0151-1
53. Petrosyan AS, Egiazaryan KA, Panin MA, Ratyev AA, Al-bawareed OA. Evolution of shoulder arthroplasty. *RUDN Journal of Medicine*. 2022;26(2):117-128. (In Russ.) doi: 10.22363/2313-0245-2022-26-2-117-128
54. Giyasova N., Alilov Kh., Sadullaev O. et al. Visualization of traumatic injuries of the shoulder girdle. *Innovation Scientific Journal*. 2022;1(11):59-75. (In Russ.)
55. Shershnev AM, Dokolin SY, Kuzmina VI, et al. Options in Tendon Transfers for Anterior-Superior Rotator Cuff Tears: Review. *Traumatology and Orthopedics of Russia*. 2023;29(1):135-142. doi: 10.17816/2311-2905-2017

The article was submitted 14.03.2023; approved after reviewing 19.01.2024; accepted for publication 18.06.2024.

Information about the authors:

Alexander O. Tuturov — orthopedic traumatologist, atneuro@yandex.ru;

Armenak S. Petrosyan — Candidate of Medical Sciences, orthopedic traumatologist, head of department, armenak.p@gmail.com;

Mikhail A. Panin — Candidate of Medical Sciences, orthopedic traumatologist, panin-mihil@yandex.ru;

Boris I. Zakharyan — resident, Zahorean98@mail.ru;

Omar Al-Bavarid — Candidate of Medical Sciences, orthopedic traumatologist, Alomar442@mail.ru.

Review article
https://doi.org/10.18019/1028-4427-2024-30-4-608-619

Impact of non-surgical factors on treatment results of patients with idiopathic scoliosis according to SRS-22 data (systematic review)

Yu.V. Molotkov[1]✉, A.V. Evsyukov[1], S.O. Ryabykh[2,3], D.M. Savin[1]

[1] Ilizarov National Medical Research Centre for Traumatology and Orthopedics, Kurgan, Russian Federation
[2] Veltischev Research and Clinical Institute for Pediatrics and Pediatric Surgery, Moscow, Russian Federation
[3] Pirogov Clinic of High Medical Technologies, St. Petersburg, Russian Federation

Corresponding author: Yury V. Molotkov, m.d.molotkov@gmail.com

Abstract

Introduction Idiopathic scoliosis is characterized by a multicomponent deformity of the axial skeleton, surgical correction of which is advisable to improve the quality of life of patients. The SRS-22 questionnaire is widely used for its evaluation.

The **purpose** of the work was to identify and evaluate, using a systematic review method, non-surgical, socio-economic and other factors not directly related to surgical intervention that influence the results of SRS-22.

Materials and methods The search was performed on the PubMed electronic platform in accordance with the PICOS protocol. Initially, 280 articles were selected for the period of 2003-2023. The authors carried out further selection manually. The review was based on the analysis of 15 articles containing data to determine the influence of various factors on the results of the SRS-22 questionnaire.

Results It was revealed that the results of SRS-22 depend on many factors that are not directly related to either the spinal pathology itself or its surgical treatment. Contemporary studies assessing quality of life in scoliosis emphasize the influence of ethnic and socioeconomic factors on the results of the SRS-22 survey. The results indicate differences in the assessment of the quality of life of patients with comparable pathologies depending on the geographical and social context. The role of three-way interaction between the doctor, parents and paediatric patient when assessing the results of the SRS-22 survey was considered. It was found that SRS-22 scores before and after the initial medical consultation did not have significant differences; and the assessment by parents did not differ from the assessment by the paediatric patient. A relationship was found between the use of "rigid" functional corrective braces and the results of SRS-22 — indicators of satisfaction with treatment, and, accordingly, the overall SRS-22 score in patients who received brace therapy were significantly higher. It was found that physical activity and endurance correlate with the quality of life of patients with idiopathic scoliosis.

Discussion The SRS-22 questionnaire is a key tool for assessing the quality of life of patients with scoliosis, taking into account their age and functional status. Over the years of using SRS questionnaires, various scientists have proposed several modifications to improve accuracy and ease of use, but only SRS-22 has become generally accepted. It is necessary to develop special additional algorithms that allow the results of various versions of SRS questionnaires to be interpreted into a single format for their analysis and comparison.

Conclusion The relationship and influence of the severity and structure of spinal deformity on the standard of living is an extremely heterogeneous and multicomponent issue. SRS-22 results are strongly influenced not only by medical factors, but also by age, ethnic, cultural, social and economic factors. There is a gradual change in SRS-22 scores in the postoperative period over decades since the moment of surgery. Parents are quite accurate in assessing their child's condition when using the SRS-22.

Keywords: scoliosis, quality of life, treatment, surgery, paediatrics, SRS-22; questionnaire

For citation: Molotkov YuV, Evsyukov AV, Ryabykh SO, Savin DM. Impact of non-surgical factors on treatment results of patients with idiopathic scoliosis according to SRS-22 (systematic review). *Genij Ortopedii*. 2024;30(4):608-619. doi: 10.18019/1028-4427-2024-30-4-608-619

© Molotkov Yu.V., Evsyukov A.V., Ryabykh S.O., Savin D.M., 2024
© Translator Tatyana A. Malkova, 2024

INTRODUCTION

Idiopathic scoliosis is a multicomponent three-dimensional deformity of the axial skeleton, which includes, in addition to the deformity of the spinal column, deformities of the ribs, chest and often the shoulder blades and pelvic distortions [1]. One of the most important goals of surgical correction is not the absolute correction of the magnitude of scoliotic deformity according to Cobb but the improvement of the balance of the trunk, the physical health of the patient and, as a result, an improvement in the quality of life. Thus, the goals of the operation, among other things, are an increase in respiratory volume, a decrease in back pain, the prevention of further progression of the deformity, and an increase in the motor activity of patients. One of the expectations of both the patients themselves and their relatives is an improvement in the appearance of the body (in the words of D.K. Tesakov, "... plastic anatomy of the trunk" [2]) by reducing visible deformations, which is also an important position among the indications for surgical treatment. For assessing the functional result, questioning patients is of key importance for determining the severity of the disease and the effectiveness of treatment. The Scoliosis Research Society questionnaire (SRS-22), created in 2003, has been currently the most widely used instrument [3] with high reliability for assessing the quality of life of patients with scoliosis of any etiology, considering age and functional status capabilities. The SRS-22 questionnaire is used to assess pain, emotion, level of daily life, improvement in appearance and patient satisfaction before, after surgery and at follow-up points. There are other methods for assessing treatment outcomes (PedsQL [4], EOSQL-24, SF-36 [5], KIDSCREEN-10 [6], etc.), but their specificity varies greatly depending on the age of the patient, the nosology of the spinal deformity and comorbidity.

This review presents an analysis of current scientific literature containing data on the use of the SRS-22 questionnaire to assess the quality of life and treatment effectiveness in patients with scoliosis in various nosological groups.

The **purpose** of the work was to identify and evaluate, using a systematic review method, non-surgical, socio-economic and other factors not directly related to surgical intervention that have an impact on the results of SRS-22 questionnaire.

MATERIALS AND METHODS

The selection was performed on the PubMed platform in accordance with the PICOS protocol using the logical operators AND or OR for the terms: SRS-22, quality of life, scoliosis, surgery (Table 1).

Table 1

Criteria for inclusion/exclusion and selection of publications in accordance with the principles PICOS [7]

PICOS elements	Inclusion	Exclusion
Participants	Patients with spinal pathology who completed the study using the SRS-22 questionnaire, as well as healthy people who completed the study using the SRS-22 questionnaire	Patients who did not complete the SRS-22 questionnaire
Intervention	Assessment of quality of life with the SRS-22 questionnaire	Unavailable data on quality of life with the SRS-22
Comparison	Studied groups in the selected articles	
Result	Results of the SRS-22 questionnaire, assessment of correlation with non-surgical factors	
Study design	Non-randomized, retrospective, prospective	Randomized
Publication	In Russian, English, full text articles	Any other language; full text unavailable

Initially, 280 articles published between 2003 and 2023 were selected (Fig. 1). Then, based on the titles and abstracts of the articles, further selection was carried out manually by the authors: a neurosurgeon with 20 years of experience, an orthopaedic surgeon with 10 years of experience, and an orthopaedic surgeon with 2 years of experience. All specialists are proficient in medical

English and worked with the original texts of publications without the assistance of translators. First of all, the authors evaluated the publications with detailed statistically processed numerical data on the results of assessing the quality of life using the SRS-22 questionnaires in patients with scoliosis. Publications that examined the correlations of the SRS-22 results with various socio-economic aspects of patients' lives were analyzed. The review included also the articles whose study groups consisted of both adolescents and adult patients.

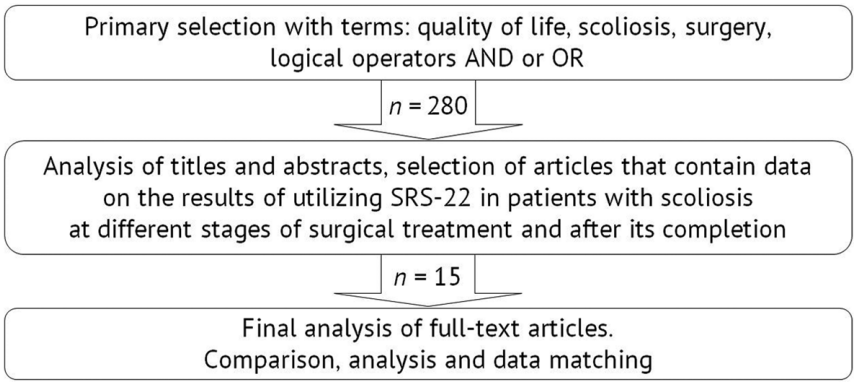

Fig. 1 Diagram of material selection for literature review

As a result, 15 articles were selected containing the necessary data on the use of SRS-22 questionnaires to assess the quality of life in cohorts of patients with scoliosis (Table 2). The data were summarized and analyzed according to the most relevant aspects concerning the validity of the questionnaire and the influence of various factors on it.

Table 2

Summary data on selected literary sources

N	Author, reference list number	Year of publication	Country	Number of patients	Follow-up (years)
1	Yagi et al. [8]	2020	USA+Japan	186	2
2	Ohashi et al. [9]	2020	USA+Japan	405	2
3	Bastrom et al. [10]	2015	USA	829	2
4	Daubs et al. [11]	2014	USA	3052	–
5	Verma et.al. [12]	2014	USA+ Ghana	160	–
6	Alzayed et al. [13]	2022	Saudi Arabia	115	9.4
7	Cheung et al. [14]	2020	China	233	–
8	Chau et al. [15]	2020	China	254	1–2
9	Cong et al. [16]	2021	China	63	–
10	Li et al. [17]	2021	China	259	–
11	Gardner et al. [18]	2021	UK	3481	1
12	Meng et al. [19]	2017	Multinational	640	–
13	Brewer et al. [20]	2014	UK	52	–
14	Yu et al. [21]	2016	China	211	–
15	Gem et al. [22]	2021	Turkey	30	–

RESULTS

Validity of SRS-22 questionnaire in the interaction “doctor-parent-patient”

Considering that scoliotic spinal deformities occur mainly in childhood/adolescence, an important criterion in assessing the patient’s quality of life is the factors of the three-way interaction “doctor – patient’s parent – paediatric patient”.

Brewer et al. studied the influence of these factors on the results of the SRS-22 questionnaire. The SRS-22 questionnaire was distributed to 52 children (13 boys and 39 girls) with adolescent

idiopathic scoliosis and their parents at the first consultation, before and after the meeting with the doctor. Parents and patients filled out the questionnaires separately [20]. No statistical differences were found in the SRS-22 results for both patients and parents when comparing the indicators before and after the consultation in most sections. Significant differences were found in several cases. Thus, there were differences in the patient group before and after the consultation in the "functions" section, the patient and parent groups before and after the consultation in the "pain" section, the patient and parent group after the consultation in the "self-image" section, and the parent group before and after the consultation in the "mental health" section. However, the differences in all these cases were low and were not considered clinically significant.

Based on this, it is noted that the SRS-22 questionnaire reliably reflects the patients' assessment of their symptoms, which is not influenced by the information provided by the doctor during the initial consultation. The parent's assessment of the child's condition using the SRS-22 questionnaire does not statistically differ from the child's self-assessment. The time of filling out the SRS-22 questionnaire during the initial consultation does not have an effect on the overall result of the questionnaire.

The influence of age, ethnicity and socio-economic factors

It was found that the results of the SRS-22 questionnaire are influenced by many factors that are not directly related to either the spinal pathology itself or its treatment. In fact, the initial characteristics of the patient are considered, his/her lifestyle and environment that potentially influence the results of the SRS-22 (Table 3).

Table 3

Results of the SRS-22 questionnaire

Studies			Number of patiens (m/f)	Mean age	Follow-up (years)	SRS-22					
						Function	Pain	Self-image	Mental health	Satisfaction	Score
Yagi et al. [8]	(Japan)		93 (11/82)	65.2	2	3.6	3.8	3.7	3.8	4.0	3.8
	(USA)		93 (10/83)	65.8	2	3.6	3.6	3.7	4	4.3	3.8
Ohashi et al. [9] (USA + Japan)			405	14,4	14.4	–	4.2	3.9	3.3	4	–
Bastrom et al. [10] (USA)			829 (158/671)	–	–	2	4.6	4.4	4.4	4.2	4.6
Daubs et al. [11] (USA)			3052 (1480/1536)	14,6	14.6	–	4.31	4.44	4.41	3.96	–
Verma et.al. [12]	(USA)	healthy	14.8	–	4.4	4.6	4.4	4.1	–	4.4	4.4
		Idiopathic scoliosis	14.8	–	4.2	4.2	3.6	4.1	–	4.1	4.1
	(Ghana)	healthy	14.2	–	4.5	4.3	4.1	3.5	N/A	4.1	4.1
		Idiopathic scoliosis	14.4	–	3.7	3.9	2.9	3.7	N/A	3.6	3.6
Alzayed et al. [13] (Saudi Aravia)			115 (12/103)	24.5	9.4	3.98	4.09	3.98	3.68	4.18	3.98
Cheung et al. [14] (China)			233	–	–	4	4.77	4.72	4.35	3.93	4.45
Chau et al. [15] (China)#			254 (64/190)	15.7	1–2	4.1	4.2	3.9	3.9	4.2	4
Cong et al. [16] (China)			63 (54/9)	14.1	–	2.7	2.32	2.39	2.85	–	2.56
Li et al. [17] (China)			259 (0/259)	14.6	–	4.13	4.38	3.36	4.14	–	4
Gardner et al. [18] (Great |Britain)*			3481	–	1	~4.2	~4.4	~4.2	~4.25	–	~4.25
Meng et al. [19]&			640	–	–	4.3	4.2	3.5	4.8	3.7	4.2
Gem et al. [22] (Turkey)			30	15.8	–	4.5	4.2	4	4	4.7	4.1

— The article by Chau et al. presents data for a period of 1 to 30 years after surgery; this table presents data only 1 year after surgery. More detailed data from this article are presented in the form of a graph further in the text.
* — The article by Gardner et al. presents the data on the SRS-22 results exclusively in the form of graphs, therefore the average values in the table are approximate, for informational purposes only.
& —Meng et al. meta-analysis is a multinational review that compares groups of patients that were brace-treated and not brace-treated before the surgery. Mean data are presented in the table for the total group.

In an analysis of a group of 186 patients, Yagi et al. noted that spinal deformity correction with posterior instrumentation in adults was equally effective for patients in the United States and Japan. However, despite similar deformity correction rates and fusion rates, two-year SRS-22 satisfaction scores were lower in Japanese patients: (4.0 ± 0.8) versus (4.3 ± 0.9) in US patients. Differences in lifestyle and cultural background may have an impact on patient's satisfaction. [8].

In Saudi Arabia, the SRS-22 score in a group of 115 adolescents who underwent surgical treatment for scoliotic deformity was (4.18 ± 1.0). The difference in this indicator may depend on both cultural and sociological characteristics and the age of the patients: in the group from Saudi Arabia, the average age at the time of the survey was 24.5 years versus 65.8 and 65.2 years in the groups from the USA and Japan, respectively [13].

In 2014, Verma et al. conducted a large study comparing the quality of life assessment with the SRS-22 questionnaire in groups of adolescents with scoliosis and their healthy peers from the USA and Ghana [12]. Patients were selected into 4 groups of 40 subjects, in each group the ratio of boys and girls was 15/25. The average age was 14.5 years. The average primary deformity curve according to Cobb in the group of patients from Ghana was higher than in patients from the USA. For all SRS-22 parameters, except for mental health, the group of patients with scoliosis from Ghana showed significantly lower indices than in the other three groups. Patients with scoliosis from Ghana demonstrated significantly lower activity levels than patients with scoliosis from the USA and both groups of healthy adolescents (3.7 vs. 4.2, 4.5, 4.4, respectively). There were no significant differences in activity levels between healthy US adolescents, Ghanaians, and US scoliosis patients. Ghanaian scoliosis patients reported more pain than healthy U.S. individuals (3.9 vs. 4.6), but the difference was less pronounced with healthy Ghanaian adolescents (3.9 vs. 4.3). US scoliosis patients also reported more pain than healthy US adolescents (4.2 vs. 4.6). There were no significant differences in pain scores between healthy Ghanaians and US adolescents (4.3 vs. 4.6), healthy Ghanaians and US scoliosis patients (4.3 vs. 4.6), or Ghanaian scoliosis patients and US patients (3.9 vs. 4.2). Ghanaian scoliosis patients scored significantly lower in the self-image section than US scoliosis patients, healthy Ghanaian and US adolescents (2.9 vs. 4.2, 4.1, 4.5, respectively). Healthy US and Ghanaian adolescents did not differ significantly in the self-image section (4.4 vs. 4.1). Ghanaian scoliosis patients showed significantly lower mental health section scores than US scoliosis patients (3.7 vs. 4.1), but higher than healthy Ghanaian adolescents (3.7 vs. 3.5). It should be noted that the scores of healthy Ghanaian adolescents were significantly lower than healthy US adolescents and even than US scoliosis patients (3.5 vs. 4.1 and 4.1, respectively). The results for healthy US adolescents and US scoliosis patients were similar. Adolescents with scoliosis and without it that lived in Manhattan reported better mental health scores than their Ghanaian peers. Given the significant differences in the standard of living, social and economic well-being, and access to health care between the US and Ghanaian populations, it is clear that all of these factors significantly influence the SRS-22 scores, independent of scoliosis and its treatment.

A group of 233 patients from China, according to the study by Cheung et al. [14], had high scores in the sections of function (4), pain (4.77), self-image (4.72) and mental health (4.35), but had low assessment scores of treatment satisfaction (3.93). The overall SRS-22 score in these patients was also high (4.45).

According to Daubs et al., such factors as age, gender and race have a significant impact on the results of the SRS-22 in healthy adolescents [11]. A large study was conducted among 3,052 healthy volunteers aged 10 to 19 years (Fig. 2, 3, 4).

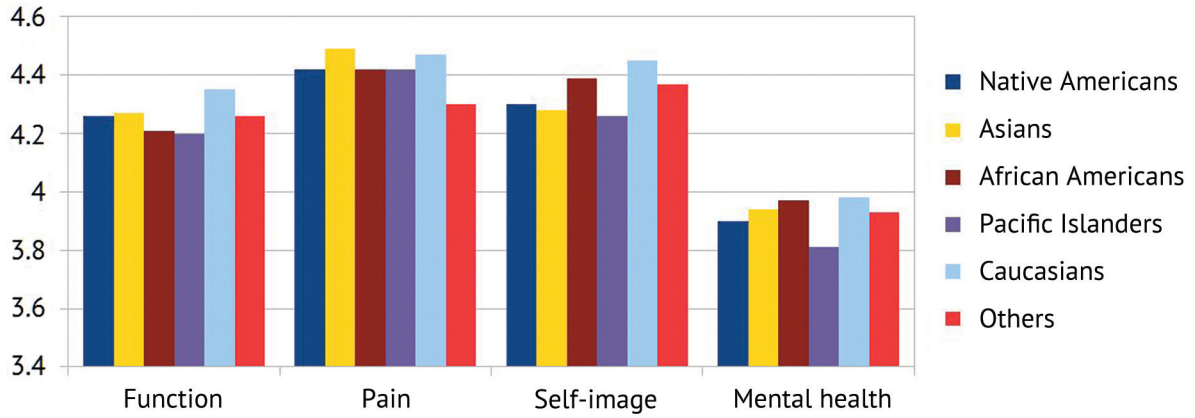

Fig. 2 Distribution of SRS-22 results by nationality [11]

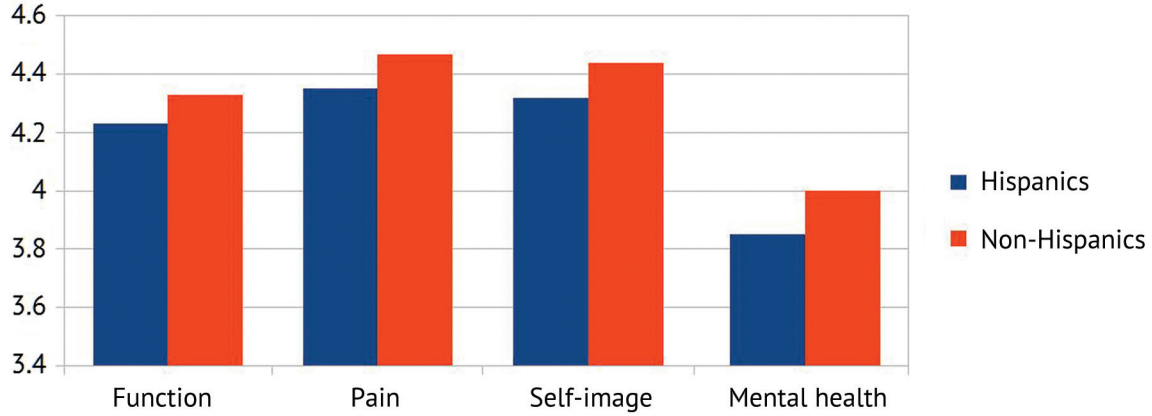

Fig. 3 Distribution of SRS-22 results in Hispanic and Non-Hispanics [11]

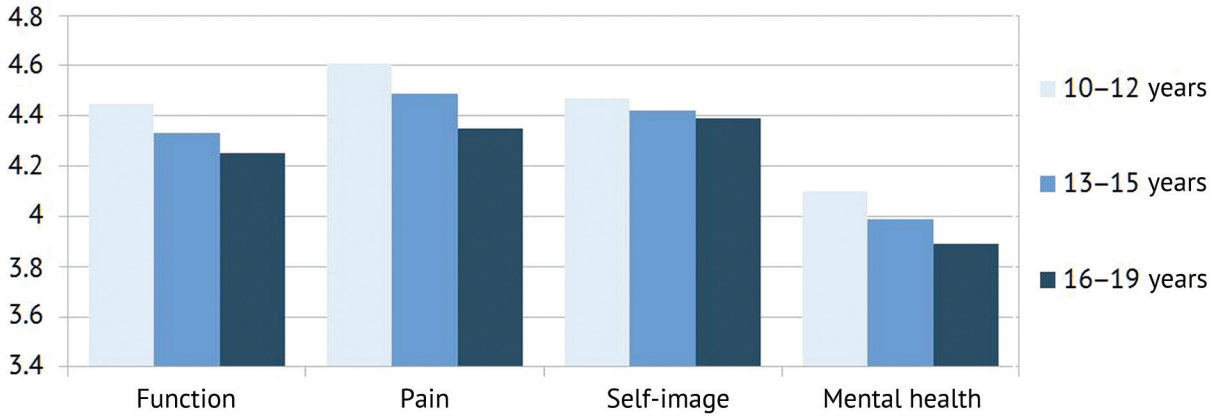

Fig. 4 Distribution of SRS-22 results in regard to age [11]

In general, scores lowered as age increased from 10 to 19 years, Caucasians scored higher in function, pain, and image than other racial groups, and Hispanics scored lower than non-Hispanics in all domains. These factors should be considered when evaluating SRS-22 scores. This suggests that even without any association with spinal pathology and/or its treatment, age and race/ethnicity may influence SRS-22 scores.

Dynamics of indicators at different observation periods

Posterior instrumented spinal fixation surgery is an irreversible intervention that impacts the patient's life once and for all. A study by Gardner et al., conducted in the UK, demonstrated that patient's follow-up data for more than two years after surgery do not differ from the data one year after

surgery [18]. However, Chau et al. [15] conducted a large study that assessed patient's parameters for 30 years after surgery. Long-term follow-up revealed unclear dynamics in postoperative changes in SRS-22. A total of 254 patients were examined, 57 % had surgery 5 years prior to the study, 23 % from 5 to 10 years prior, 13 % from 10 to 20 years prior, and the rest had it more than 20 years ago. Annually, 90 % of patients visited the clinic within 10 years after surgery, 83 % of patients within 10–20 years, and 71 % more than 20 years since surgery. Overall, the scores for the six SRS-22 items were relatively stable from year 5 postoperatively onwards. The Mental Health and Satisfaction sections were significantly better than the Self-image score in the first 5 years postoperatively. Self-image scores were consistently lower than the scores for the other parameters at all time points postoperatively. All scores gradually decreased from year 9 to 30 years and more postoperatively. Pain was also noted to improve after 15–20 years (Fig. 5).

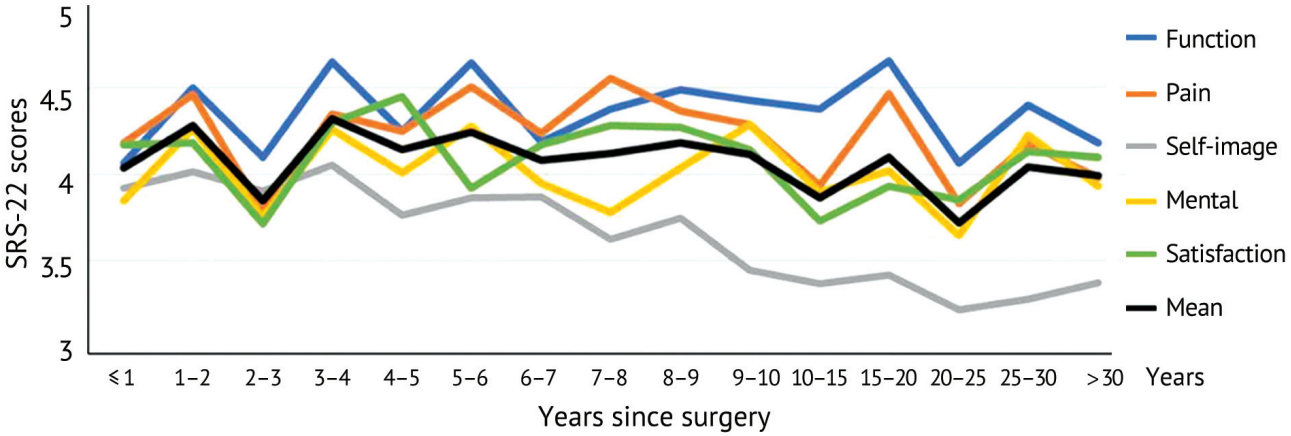

Fig. 5 Distribution of SRS-22 scores in regard to time since the surgery [15]

It is important to note that patients who underwent surgery 30 years ago were in perimenopausal age (> 40 years) at the time of assessment, which might have a significant impact on their mental state and, accordingly, on the SRS-22 results.

Impact of additional methods and treatment option

Apart from surgery, the SRS-22 results are also influenced by other, non-surgical methods used in the treatment of scoliosis. According to Meng et al., there is a relationship between the use of "rigid" functionally corrective braces and the SRS-22 results [19]. A systematic review of the literature was conducted, in which, based on seven publications that passed the inclusion/exclusion criteria, the SRS-22 indicators were determined in the sections of pain, self-imag / appearance, mental health, and function / activity in patients with idiopathic scoliosis. The results in individuals who underwent surgery and did not receive treatment with rigid bracing were similar to the assessments of patients wearing braces. However, the satisfaction rates with treatment, and accordingly the total SRS-22 score in patients receiving brace therapy were significantly higher.

Of interest are the data of the study by Bin et al., which retrospectively analyzed the SRS-22 and SF-36 questionnaires of 211 patients with idiopathic scoliosis who underwent posterior instrumented fixation surgery [21]. The average age of the patients was 14.4 years (range from 11 to 18 years), the patients were divided into 2 groups: with preoperative brace treatment (group BS — 32 cases, 5 men and 27 women) and without preoperative brace treatment (group S — 179 cases, 23 men and 156 women). A comparison of radiographic data and mental health indicators according to the SRS-22 and SF-36 questionnaires was conducted between the patients of the two groups. There were no significant differences between the BS and S groups in the parameters of costal gibbus, mean

preoperative Cobb angle of the primary curve or apical translation of the primary curve, thoracic kyphosis, or coronal trunk balance. The mean mental health scores according to the SRS-22 in the BS and S groups were (3.6 ± 0.7) and (3.7 ± 0.5); the total score was (18.1 ± 3.5) and (18.3 ± 2.6), respectively. The total mental health scores according to the SF-36 of the BS and S groups were (71.1 ± 8.7) and (68.7 ± 11.5), respectively.

Based on these data, it can be concluded that rigid bracing during treatment influences the SRS-22 results only in the issue of satisfaction with treatment.

Another important factor that has an effect on the quality of life is the patient's physical activity. The study by Cong et al. found that physical performance, the ability to exercise intensively and endurance correlate with the quality of life of patients with adolescent idiopathic scoliosis [16]. The study included 54 female patients (mean age 14.1, range 10–19 years) and 9 male patients (mean age 15.9, range 14–19 years) with idiopathic scoliosis (Cobb angle of the primary deformity curve was 28–86°). Significant correlations were found between peak oxygen consumption normalized by body weight and indices of function, pain, mental health and the overall SRS-22 score. Significant correlations were also found between oxygen consumption at the anaerobic threshold normalized by body weight and the indices of function, pain, and total SRS-22 scores. In addition, the respiratory exchange ratio also influenced the total SRS-22 scores.

DISCUSSION

Quality of life is a key issue in medicine and healthcare. Research into the impact of medical care on changes in quality of life includes many scientific projects around the world. According to the PubMed database, more than half a million scientific papers related to HRQoL (Health-Related Quality of Life) have been published over a period of more than 100 years. This is a very large and complex issue, in which there is no unified concept and methodology [23]. Even in such a narrow and "young" issue relative to all of the medicine as the evaluation of the results of surgical treatment of spinal pathology, there is a wide range of concepts and methods for assessing the quality of life of patients.

Over the years of utilizing the SRS questionnaires, several modifications have been proposed by various scientists to improve their accuracy and ease of use. One of the most common options is the SRS-22 and SRS-24 questionnaires (the older version, which was used in many earlier studies). After the shortened modification of the SRS-22 had appeared and become generally accepted, the problem of correlation of the results of these questionnaires arose. In the study by Bastrom et al., 829 patients were surveyed using the SRS-22 and SRS-24 questionnaires [10]. The SRS-22 scores in the pain and general functioning sections were significantly higher than the SRS-24 scores, whereas in the self-image sections, the SRS-22 scores were significantly lower than the SRS-24. The preoperative threshold effect was noted only in one domain. Both versions distinguish between large (> 80°) and small (< 45°) preoperative curves in all sections and total scores. Postoperatively, the SRS-22 scores for all common sections and the total score were significantly higher than the SRS-24 scores. A threshold effect was observed in all five sections postoperatively for the SRS-22 and in 4 of the 7 sections for the SRS-24. At a smaller range of postoperative deformities, only the self-image section of the SRS-22 was able to differentiate between large (> 29°) and small (< 11°) residual deformity curves. In conclusion it was noted that the results obtained with the SRS-22 and SRS-24 are not comparable despite the common sections.

Later, a shortened Rasch-compatible questionnaire SRS-7 was developed based on the SRS-22. According to the study by Caronni et al., the SRS-22 does not meet the fundamental measurement requirements, i.e. additivity, generalizability, and unidimensionality [24]. Moreover, a strong

threshold effect occurs by using the SRS-22 in adolescents with idiopathic scoliosis at their first examination. The SRS-7, a short seven-item questionnaire, provides an HRQL measure that is better adapted to such patients.

In addition, a version of the SRS-18 questionnaire has been proposed, which recommends deleting the most suitable items in each of the four sections of the SRS-22 (items 3, 14, 15, 17), as well as adapting and standardizing other items in different language versions in order to form an improved version of the SRS questionnaire. It is expected that over time, that the SRS-18, if proven to be effective and accurate, would become a common choice for quality of life assessment in patients with idiopathic scoliosis.

In addition to the SRS-22, other questionnaires for assessing the quality of life in patients with spinal pathology have been described in current scientific literature. One of these questionnaires is the EOSQL-24, developed specifically for patients with early scoliosis. Its special feature is that, unlike the SRS-22 questionnaire, the EOSQL-24 is filled out only by the parent or guardian caring for the patient. The study by Li et al. compared these questionnaires [25]. The researchers compared the sections of the questionnaires to identify correlations (Fig. 6).

Fig. 6 Correlation of the corresponding sections of SRS-22 and EOSQ-24 [25]

EOSQ-24	SRS-22
General Health	Function
Pulmonary Function	Function
Transfer	Function
Physical Function	Function
Daily Living	Function
Fatigue	Function
Financial Impact*	Function
Pain	Pain
Emotion	Mental health
Child Satisfaction	Satisfaction
Parent Satisfaction	Satisfaction

*The SRS-22 question that addresses financial impact is in the function domain.
EOSQ-24 indicates 24-item Early-Onset Scoliosis Questionnaire; SRS-22, 22-item Scoliosis Research Society Questionnaire.

A group of 98 patients was examined. The average age at the time of filling in the questionnaires was 9.5 years. Strong correlations were found for all domains except for Satisfaction, when the patient or caregiver filled in both questionnaires. The analysis demonstrated the strongest relationship between domains in the age group from 0 to 5 years. In patients with developmental retardation, weak correlations were noted for all parameters except for pain, which showed a strong correlation. In all subgroups, a strong correlation was observed with pain domains and a weak correlation with satisfaction domains. Based on this study, it was concluded that the SRS-22 may be suitable for children with congenital scoliosis who do not have a diagnosis of developmental retardation. And although the results of the SRS-22 and EOSQL-24 were found to be correlated, it remains unclear which questionnaire is more suitable for patients with developmental delays.

Another popular questionnaire for assessing the quality of life of children and adolescents with various pathologies is the PedSQL-24. However, this questionnaire has not been widely used in patients with scoliosis. The query with key-words PedSQL, scoliosis in the PubMed database found only 13 results,

what excluded a more detailed analysis within the framework of the present review. However, despite the obvious small amount of data, the study of Cheungi et al. found that the total psychosocial health score, the total physical health score, and the total PedsQL score correlated with the total SRS-22r score for all patients with scoliosis [14]. In adolescent patients with scoliosis (13 to 18 years old), both the total PedsQL scores and the total score significantly correlated with each of the SRS-22r domain indicators, with the exception of the "Satisfaction with Treatment" domain.

The current scientific literature contains a fairly large amount of data on the use of SRS questionnaires to assess the quality of life in various groups of patients. Thanks to the ability to compare the results obtained by researchers from different countries, it becomes clear what a pronounced effect on the SRS-22 results ethnic and socioeconomic factors have. In addition to the fact that the indicators change with the patient's age, his ethnic origin, lifestyle and level of financial well-being also have a significant impact on the quality of life. Due to a large number of social, cultural, individual, economic characteristics of life in a particular geographic region and social group, two patients with comparable spinal pathologies and similar surgical treatment outcomes may have significantly different results in assessing the quality of life using the SRS-22 questionnaire. The living environment, rural or urban, may influence the postoperative quality of life in spinal deformities. Self-image indicators are significantly lower in the urban group, but we did not note any other significant differences in activity, pain or mental health indicators compared to the rural group.

The key factor that has an impact on the quality of life of a patient with scoliosis is the extent and structure of spinal deformity. Scoliotic spinal deformity is a clear and severe syndrome that significantly affects almost all aspects of a person's life. Body deformities cause both cosmetic defects and clinical manifestations (pain, fatigue), which, in turn, restrict the patient's physical activity. At the same time, treatment and medical procedures that continue for many years can also affect a person's psychological state, self-perception and quality of life. However, the correlation of SRS-22 results for various indicators with the type, location, severity of the deformity and the extent of its correction was not as obvious and direct as expected.

To what extent do radiographic parameters and their changes during scoliosis treatment may influence the SRS-22 results? The current scientific literature presents rather heterogeneous and contradictory data on this issue. The displacement (translation) of the apical vertebra of the primary curve of deformity has a more significant effect on the patient's self-image than the volume of the primary curve of deformity (Cobb angle) itself [16, 25]. At the same time, the magnitude of the deformity correction resulting from treatment does not directly correlate with the improvement of the SRS-22 indicators after surgical treatment [21]. The structure of the spinal deformity itself is also important, since patients with a triple structural curve have a greater magnitude of deformity and lower scores in the self-image and function sections. All these details indicate that the effect of the volume and structure of scoliotic deformity on the quality of life is a complex multifactorial issue. Posterior instrumental fixation of the spine is a serious surgical intervention that has an impact on the patient's quality of life both immediately after it and decades later. Patients who have undergone such surgery show stable moderately negative dynamics in quality of life indicators [15]. These data are undoubtedly of interest, however, given such a long observation period, it is impossible to say with certainty that the gradual decrease in SRS-22 indicators is associated with surgical treatment.

In addition to the surgical intervention itself, other treatment procedures, such as a course of rigid bracing, may have an impact on the patient's quality of life [18]. However, it is worth noting that such an effect was not that significant and was manifested only in the section of satisfaction

with the treatment. This effect can presumably be explained by the patient's greater personal involvement in the treatment process. Continuous bracing causes some discomfort, inconvenience in everyday life and requires a certain amount of volitional effort. Overcoming these difficulties through personal involvement and by applying patient's own efforts produces a psychological effect that makes him/her more satisfied with the treatment results, despite the fact that from the point of view of radiological indications, such an approach does not have a pronounced positive effect.

Due to the fact that scoliosis usually develops in children/adolescents, it is impossible not to consider the role of parents in the treatment process and their impact on quality of life. It was found that parent's assessment of the child's condition using the SRS-22 questionnaire is not statistically different from the child's self-assessment [19].

CONCLUSION

There are several key points to consider in utilizing the SRS-22 questionnaire in patients with scoliosis:

— The SRS-22 questionnaire is currently the most widely used instrument, as it has high reliability for assessing the quality of life of patients with scoliosis of any etiology, considering age and functional status;

— The relationship and impact of the severity and structure of spinal deformity on the standard of living is an extremely heterogeneous and multi-component issue. The results of the SRS-22 are significantly influenced not only by medical factors, but also by a large number of age-relared, ethnic, cultural, social and economic factors. An attempt to consider the impact of these factors within the framework of the presented questionnaires seems dubious due to their heterogeneity and non-obviousness. This explains the large number of variants and modifications of questionnaires;

— Gradual changes in SRS-22 scores are observed in the postoperative period over decades from the time of surgery. These changes may be caused by factors unrelated to the surgery. Additional medical procedures and conservative treatments, including those associated with other diseases and conditions, may have an impact on patient's quality of life;

— In paediatric patients, the parents assess their child's condition quite accurately with SRS-22;

— Over the many years of using SRS questionnaires, many modifications have been proposed to simplify the work of assessing the quality of life of patients, but none of them, except SRS-22, has become generally accepted. For this reason, it is necessary to develop special additional algorithms that allow interpreting the results of SRS-7, SRS-18, SRS-22, SRS-24, etc. in a single format for their analysis and comparison with each other.

Conflict of interest *Not declared.*

Funding *Not declared.*

REFERENCES

1. Mimura T, Ikegami S, Kuraishi S, et al. Residual thoracolumbar/lumbar curve is related to self-image after posterior spinal fusion for Lenke 1 and 2 curves in adolescent idiopathic scoliosis patients. *J Neurosurg Pediatr*. 2020;26(2):211-216. doi: 10.3171/2020.2.PEDS19656
2. Tesakov DK, Tesakova DD. Changes in plastic anatomy of the trunk in patients with severe progressive scoliosis. *Russian Journal of Spine Surgery*. 2008;(4):013-019. (In Russ.) doi: 10.14531/ss2008.4.13-19
3. Monticone M, Nava C, Leggero V, et al. Measurement properties of translated versions of the Scoliosis Research Society-22 Patient Questionnaire, SRS-22: a systematic review. *Qual Life Res*. 2015;24(8):1981-1998. doi: 10.1007/s11136-015-0935-5
4. Varni JW, Seid M, Kurtin PS. PedsQL 4.0: reliability and validity of the Pediatric Quality of Life Inventory version 4.0 generic core scales in healthy and patient populations. *Med Care*. 2001;39(8):800-812. doi: 10.1097/00005650-200108000-00006

5. Laucis NC, Hays RD, Bhattacharyya T. Scoring the SF-36 in Orthopaedics: A Brief Guide. *J Bone Joint Surg Am*. 2015;97(19):1628-1634. doi: 10.2106/JBJS.O.00030
6. Befus EG, Helseth S, Mølland E, et al. Use of KIDSCREEN health-related quality of life instruments in the general population of children and adolescents: a scoping review. *Health Qual Life Outcomes*. 2023;21(1):6. doi: 10.1186/s12955-023-02088-z
7. Methley AM, Campbell S, Chew-Graham C, et al. PICO, PICOS and SPIDER: a comparison study of specificity and sensitivity in three search tools for qualitative systematic reviews. *BMC Health Serv Res*. 2014;14:579. doi: 10.1186/s12913-014-0579-0
8. Yagi M, Ames CP, Hosogane N, et al. Lower Satisfaction After Adult Spinal Deformity Surgery in Japan Than in the United States Despite Similar SRS-22 Pain and Function Scores: A Propensity-Score Matched Analysis. *Spine* (Phila Pa 1976). 2020;45(17):E1097-E1104. doi: 10.1097/BRS.0000000000003483
9. Ohashi M, Bastrom TP, Bartley CE, et al. Associations between three-dimensional measurements of the spinal deformity and preoperative SRS-22 scores in patients undergoing surgery for major thoracic adolescent idiopathic scoliosis. *Spine Deform*. 2020;8(6):1253-1260. doi: 10.1007/s43390-020-00150-0
10. Bastrom TP, Bartley C, Marks MC, et al. Postoperative Perfection: Ceiling Effects and Lack of Discrimination With Both SRS-22 and -24 Outcomes Instruments in Patients With Adolescent Idiopathic Scoliosis. *Spine* (Phila Pa 1976). 2015;40(24):E1323-E13239. doi: 10.1097/BRS.0000000000001082
11. Daubs MD, Hung M, Neese A, et al. Scoliosis research society-22 results in 3052 healthy adolescents aged 10 to 19 years. *Spine* (Phila Pa 1976). 2014;39(10):826-832. doi: 10.1097/BRS.0000000000000280
12. Verma K, Lonner B, Toombs CS, et al. International utilization of the SRS-22 instrument to assess outcomes in adolescent idiopathic scoliosis: what can we learn from a medical outreach group in Ghana? *J Pediatr Orthop*. 2014;34(5):503-508. doi: 10.1097/BPO.0000000000000137
13. Alzayed ZS, Majid OB, Alqahtani SA, et al. Young Patients' Satisfaction Following the Correction of Adolescent Idiopathic Scoliosis in Saudi Arabia: A Cross-Sectional Study. *Cureus*. 2022;14(10):e30058. doi: 10.7759/cureus.30058
14. Cheung PWH, Wong CKH, Cheung JPY. Comparative study of the use of Paediatric Quality Of Life Inventory 4.0 generic core scales in paediatric patients with spine and limb pathologies. *Bone Joint J*. 2020;102-B(7):890-898. doi: 10.1302/0301-620X.102B7.BJJ-2019-1766.R2
15. Chau WW, Ng BK, Hung AL. Health-related quality of life (HRQOL) of adolescent idiopathic scoliosis (AIS) patients from surgery to after 30 years using SRS-22 questionnaire. *Spine Deform*. 2020;8(5):951-956. doi: 10.1007/s43390-020-00132-2
16. Cong H, Chen L, Shen J, et al. Is physical capacity correlated with health-related quality of life in patients with adolescent idiopathic scoliosis? *Ann Palliat Med*. 2021;10(6):6220-6227. doi: 10.21037/apm-20-2624
17. Li J, Tseng C, Yuan Y, et al. Determining the association between the radiographic parameters and the SRS-22 scores in Chinese female patients with adolescent idiopathic scoliosis: does curve pattern matter? *Br J Neurosurg*. 2024;38(2):349-355. doi: 10.1080/02688697.2021.1875396
18. Gardner A, Cole A, Harding I. What does the SRS-22 outcome measure tell us about spinal deformity surgery for Adolescent Idiopathic Scoliosis in the UK? *Ann R Coll Surg Engl*. 2021;103(7):530-535. doi: 10.1308/rcsann.2021.0005
19. Meng ZD, Li TP, Xie XH, et al. Quality of life in adolescent patients with idiopathic scoliosis after brace treatment: A meta-analysis. *Medicine* (Baltimore). 2017;96(19):e6828. doi: 10.1097/MD.0000000000006828
20. Brewer P, Berryman F, Baker D, et al. Analysis of the Scoliosis Research Society-22 Questionnaire Scores: Is There a Difference Between a Child and Parent and Does Physician Review Change That? *Spine Deform*. 2014;2(1):34-39. doi: 10.1016/j.jspd.2013.08.006
21. Yu B, Wang Y, Qiu G, et al. Effect of Preoperative Brace Treatment on the Mental Health Scores of SRS-22 and SF-36 Questionnaire in Surgically Treated Adolescent Idiopathic Scoliosis Patients. *Clin Spine Surg*. 2016;29(5):E233-E2339. doi: 10.1097/BSD.0000000000000057
22. Gem K, Hancioglu S, Bilgiç A, Erkan S. Comparison of Changes in SRS-22 Values with Improvement in Cobb Angles after Posterior Fusion Surgery in Adolescent Idiopathic Scoliosis. *Z Orthop Unfall*. 2022;160(5):532-538. doi: 10.1055/a-1401-0477
23. Haraldstad K, Wahl A, Andenæs R, et al. A systematic review of quality of life research in medicine and health sciences. *Qual Life Res*. 2019;28(10):2641-2650. doi: 10.1007/s11136-019-02214-9
24. Caronni A, Zaina F, Negrini S. Improving the measurement of health-related quality of life in adolescent with idiopathic scoliosis: the SRS-7, a Rasch-developed short form of the SRS-22 questionnaire. *Res Dev Disabil*. 2014;35(4):784-799. doi: 10.1016/j.ridd.2014.01.020
25. Li Y, Burke MC, Gagnier J, et al. Comparison of EOSQ-24 and SRS-22 Scores in Congenital Scoliosis: A Preliminary Study. *J Pediatr Orthop*. 2020;40(3):e182-e185. doi: 10.1097/BPO.0000000000001412

The article was submitted 17.04.2024; approved after reviewing 24.04.2024; accepted for publication 18.06.2024.

Information about the authors:

Yury V. Molotkov — post-graduate student, orthopaedic surgeon, m.d.molotkov@gmail.com, https://orcid.org/0000-0003-3615-2527;

Alexey V. Evsyukov — Candidate of Medical Sciences, neurosurgeon, Head of the Clinic for spine pathology and rare diseases, alexevsukov@mail.ru, https://orcid.org/0000-0001-8583-0270;

Sergey O. Ryabykh — Doctor of Medical Sciences, orthopedic traumatologist, Deputy Director for Scientific Work, Head of Department, rso_@mail.ru, https://orcid.org/0000-0002-8293-0521;

Dmitry M. Savin — Candidate of Medical Sciences, orthopaedic surgeon, Head of Department, savindm81@mail.ru.

Главный редактор А.В. Бурцев

Компьютерная верстка М.А. Беляева

Журнал зарегистрирован Федеральной службой по надзору в сфере связи,
информационных технологий и массовых коммуникаций
ПИ № ФС77-68207 от 30 декабря 2016 года

Территория распространения: Российская Федерация, зарубежные страны

Подписано в печать 18.06.2024. Дата выхода 28.06.2024
Формат 60 × 84 1/8. Усл. печ. л. 16,3
Тираж 75 экз. Заказ № 11829. Свободная цена

Адрес издателя, редакции журнала «Гений ортопедии»
640014, Россия, г. Курган, ул. М. Ульяновой, 6
http://ilizarov-journal.com

Отпечатано в Типографии «Эталон». 198097, г. Санкт-Петербург, ул. Трефолева, 2 литера БН, помещение 3-Н, офис 1