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Цена свободная

Dear friends,

In this issue you will find:

The section Clinical studies opens with a study by a team of authors from Moscow and Tyumen (Belyak et al.), in which the authors conducted a comparative analysis of the methods of fully endoscopic decompression of the brachial plexus and minimally invasive techniques with endoscopic assistance in the treatment of patients with traumatic brachioplexopathy. Based on the results of treatment of 22 patients, the authors concluded that the method of endoscopic neurolysis of the brachial plexus in combination with arthroscopy of the shoulder joint is equally effective in the treatment of brachioplexopathies in comparison with isolated minimally invasive neurolysis of the brachial plexus under video endoscopic assistance.

Authors from St. Petersburg (Fedorova et al.) explored clinical and radiological features of the forearm in 92 children with congenital radioulnar synostosis. The authors identified statistically significant direct correlations between complaints and the position of the forearm; subluxation of the head of the ulna and the position of the forearm; arcuate deformity of the radius, position of the forearm and subluxation of the ulnar head, as well as between the length of the forearm bones and arcuate deformity of the radius. A statistically significant inverse correlation was revealed between complaints and scores reflecting the general state of health according to the PedsQL questionnaire. There was a statistically significant decrease in the lumen of the medullary canal in the middle third of the ulnar shaft with the radius lumen being unchanged. Dorsal subluxation of the ulnar head was detected in 30 % of cases. Based on the data obtained, the authors conclude that the dependence of the patient's predicted complaints on the position of the forearm must be taken into account in the classification and when determining indications for surgical treatment, distinguishing functional (< 45° pronation) and dysfunctional (⩾ 45° pronation) options.

Fedotov et al. (Cheboksary) assessed the long-term results of the proximal interphalangeal joint arthroplasty of the hand in 64 patients. Having analyzed the data obtained, the authors conclude that arthroplasty of the proximal interphalangeal joint of the hand with various types of implants provides increased mobility of the upper limb, pain relief and improvement in its functional state evaluated subjectively. The effectiveness of the operation was statistically confirmed for all types of implants. However, in all parameters, the reliability of changes is more pronounced in application of unconstrained implants.

Authors from Iraq (Jasim and Saeed) conducted a clinical study to identify non-obvious and obvious signs of pathology of the thoracic spine in a large cohort of patients (114 individuals) and note that non-local symptoms in the thoracic spine pathology are quite common. Complicated and multifocal low back pain is more frequent than isolated pain in the back or thoracic spine. Older age, female gender, obesity, and co-morbidities are predictive risk factors for developing low back pain. Paresthesias are the most common neurological manifestations, while kyphosis and scoliosis are the primary manifestations of thoracic pathology.

The effectiveness of ankle joint arthrodesis options was assessed by authors from Kazan, Ulan-Ude and China (Wang et al.). After analyzing the results of treatment in 82 patients, the authors concluded that despite the various complications that arise with ankle arthrodesis, it remains effective for most patients. The Ilizarov apparatus is more suitable for patients with compromised conditions in the surgical area. Each method of surgical fixation has its own advantages and disadvantages, but the difference in long-term effectiveness is small. The choice of surgical method is still subject to the principle of individualization.

The team of authors from the Pirogov Clinic for High Medical Technologies from St. Petersburg State University (Akulaev et al.) tested the Russian version of the SEFAS questionnaire for assessing the condition of the foot and ankle joint in surgical patients with pathology of the forefoot and noted that the study demonstrated reliability, validity and sensitivity of the Russian version of the SEFAS questionnaire. The questionnaire is an informative and clinically interpretable tool for assessing the condition of the foot in adult surgical patients with foot pathology. The SEFAS questionnaire can be recommended for use in domestic institutions of traumatology and orthopaedics to have the patient's opinion of assessing the condition.

The gait features of children with spastic hemiplegia were studied by authors from Kurgan (Mamedov et al.). The authors conclude that movement pathology is present in all three planes of measurement in gait types 2a, 3, 4 according to the Rodda et Graham classification. The most pronounced deviations were identified in gait type 3. Rotational turn of the pelvis is initially a compensatory mechanism due to intratorsional deformity of the femur. Isolated triceps lengthening operations performed at an early age lead to a decrease in plantar push force, an increase in compensatory work of the knee extensors, and most probably do not prevent the orthopaedic pathology that occurs in gait type 4 according to Rodda et Graham.

A series of clinical cases of impaction bone grafting (IBG) for filling acetabular defects in revision hip arthroplasty was presented by authors from Barnaul and Novosibirsk (Golnik et al.). The analysis of the results showed that the use of impaction bone grafting during revision arthroplasty can be especially effective for small acetabulum sizes. Combining IBG with trabecular metal augments significantly expands the application possibilities of this technology. The use of IBG improves the bone stock in the defect area, and creates more favorable conditions for inevitable repeated revision interventions.

Authors from India (Yadkikar et al.) presented a series of six cases of treatment of soft-tissue joint contractures of various etiologies using the Ilizarov method. In all cases, an acceptable functional result was obtained without deformity recurrence. All patients move independently. The authors conclude that the Ilizarov method can be used to treat joint contractures caused by traumatic and non-traumatic pathology.

Six review articles discuss the problems of using promising osteoplastic materials and surgical technologies in the reconstructive treatment of patients with pseudarthrosis and bone tissue defects (Borzunov et Gilmanov, Ekaterinburg), treatment of patients with contractures of the elbow joint, caused by ossification (Petlenko et al.; Sankt-Petersburg), diagnosis and treatment of transitional lumbosacral vertebrae in children and adolescents (Skryabin et al.; Tyumen), orthopaedic complications of hemiparetic cerebral palsy of lower extremities (Mamedov et al.; Kurgan), tactical approaches to length discrepancy correction of the lower extremities (Novikov et al.; Kurgan) and arthroplasty of the 1st metatarsophalangeal joint (Kotelnikov et al.; Samara).

We invite you to get acquainted with the materials presented in this issue and hope that they will interest you and will be useful in your practical and scientific work.

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/10.18019/1028-4427-2024-30-2-171-181

Comparative analysis of the methods of an all-endoscopic brachial plexus decompression and a mini-invasive endoscopically-assisted technique for management of patients with traumatic brachioplexopathy

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Abstract

Introduction As reported, brachioplexopathy is a relevant polyetiological disease with an annual incidence from 0.17 to 1.6 per 100,000. There are two basic endoscopic methods of brachial plexus decompression: an endoscopically-assisted mini-invasive transaxillary approach and fully endoscopic decompression in association with shoulder arthroscopy.

Purpose Compare the two main endoscopic methods of brachial plexus decompression.

Material and methods Twenty-two patients diagnosed with post-traumatic brachioplexopathy were included in the study. There were 8 patients in group 1 and 14 patients in group 2. All patients passed clinical and instrumental examination. Statistical analysis was performed with non-parametric U-criteria of Mann – Whitney. Differences were considered significant at $p < 0.05$. Patients of group 1 underwent shoulder joint arthroscopy and fully endoscopic brachial plexus decompression. Patients of group 2 had revision and transaxillary mini-invasive decompression of brachial plexus with video endoscopic assistance.

Results In the first group, upper limb dysfunction according to DASH scale decreased from 52.3 ± 2.2 to 28.8 ± 3.8 points ($p < 0.05$). In the second group, upper limb dysfunction according to DASH scale decreased from 47.9 ± 4.4 to 26.6 ± 4.3 points ($p < 0.05$). Discrepancy according to DASH scale before and after surgery in the first group was 23.5 ± 3.6 points and in the second group it was 19.4 ± 5.4 points; the difference between the groups was statistically insignificant ($p > 0.05$).

Discussion The results of our study are similar to the results of endoscopic brachial plexus decompression in the previously published studies.

Conclusion The methods of endoscopic brachial plexus decompression in association with shoulder joint arthroscopy and isoolated mini-invasive neurolysis and decompression of brachial plexus under videoendoscopic assistance are equally effective in the treatment of brachialplexopathy.

Keywords: brachioplexopathy, decompression, neurolysis, endoscopy, arthroscopy, shoulder joint, thoracic outlet syndrome

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INTRODUCTION

Brachioplexopathies (BPPs) are a group of conditions of various etiologies accompanied by damage to the brachial plexus at any level that leads to dysfunction of the upper limb due to the development of motor, sensory and autonomic disorders. According to recent studies and of different authors, the incidence of BPP varies from 0.17 to 1.6 per 100,000 per year [1–7]. Etiology includes both trauma, open and closed, as well as non-traumatic causes, including congenital anomalies, post-radiation plexitis, and idiopathic BPP. It is generally accepted that when symptoms of BPP develop, neuroimaging should be performed to verify the presence or absence of anatomical integrity break of the nervous structures. If there is an anatomical break in the nerve, its spontaneous recovery is considered impossible and requires immediate surgical treatment involving plastic surgery or neurotization of the damaged nerves [8–10]. If the break of anatomical integrity of the nerves is not reliably verified, it is believed that it is possible to restore conduction along the nerves with conservative treatment for 3–6 months, and if recovery does not occur within this period of time, surgical treatment should be performed [11–13]. One of the options for surgical treatment in such cases is neurolysis, the essence of which is to free the nerves from scars and adhesions. It can be carried out using low-invasive endoscopic techniques. Over the past two decades, this operation has developed, and two main approaches to its implementation have emerged:

- neurolysis of the brachial plexus under video-endoscopic assistance [14–16];
- completely endoscopic neurolysis of the brachial plexus, including robot-assisted [17–20].

A few published works prove the effectiveness of both methods, but their comparison has not been previously carried out, which determines the relevance of this study.

The purpose was to compare the two main currently used methods for performing neurolysis of the brachial plexus using an endoscope.

MATERIALS AND METHODS

Our study included 22 patients (18 men, 4 women) diagnosed with post-traumatic brachioplexopathy established on the basis of complaints, anamnesis, examination data and instrumental research methods. They underwent surgery at the Department of Traumatology and Orthopaedics of the Buyanov City Clinical Hospital (Moscow) and the Department of Neurosurgery No. 5 of the Federal Center for Neurosurgery (Tyumen) from 2015 to 2022. The study was retrospective in nature.

Criteria for inclusion of patients in the study:

1) verified diagnosis of post-traumatic brachioplexopathy based on complaints, anamnesis, and instrumental research data ;
2) absence of reliable signs of anatomical integrity break of the brachial plexus structures according to examination findings;
3) incomplete restoration of affected limb function after adequate conservative treatment for 6 months or more prior to hospitalization;
4) significant impairment of upper limb function, impairing the patient's quality of life;
5) patient's age 18 years and older.

Criteria for non-inclusion of patients into the study:

1) non-traumatic nature of the brachial plexus injury;
2) muscle paresis according to the British scale < 2 points;
3) patient's refusal to participate in the study.

Group 1 included 8 patients who underwent arthroscopy of the shoulder joint according to indications and all endoscopic decompression of the brachial plexus. Group 2 included 14 patients who underwent revision and neurolysis of the brachial plexus under video-endoscopic assistance.

All patients underwent examinations according to generally accepted standards prior to hospitalization. A neurological examination was carried out that determined muscle strength according to the British Medical Research Council Scale (BMRC, M5–M0). The following scales and questionnaires were used: the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire, the Numerical Pain Rating Scale (NRS) [21]. Stimulation ENMG and MRI of the brachial plexus were performed to exclude violations of the anatomical integrity of its structures.

Statistical data processing was carried out using the Microsoft Excel (Microsoft Office 365) and Stattech 2.0 software packages. For quantitative signs, the arithmetic mean (M) and standard error of the mean (SEM) were calculated. To assess the statistical significance of the results obtained, the Shapiro – Wilk test was used to assess the normality of the distribution of the parameter; the nonparametric Mann – Whitney U test was used in non-normal distribution. Differences were considered significant at $p < 0.05$. The resulting non-integer values were rounded to the nearest tenth.

Surgical technique

Surgical intervention in group 1

The operation was performed with the patient in the “beach chair” position under endotracheal anesthesia. The first stage included therapeutic and diagnostic arthroscopy of the shoulder joint with examination of intra-articular structures and identification of intra-articular pathology. If signs of chronic tenosynovitis of the long head of the biceps tendon (LHBT) were detected, tenotomy was performed. If degenerative changes in the fibrous labrum of the glenoid were detected, debridement of the changed areas of the fibrous labrum was performed. Areas of chondromalacia of the articular cartilage of the humeral head and glenoid were treated with a shaver and ablator. If degenerative changes in the rotator cuff tendons (RCT) were detected, debridement of the changed sections of the RC was performed. If a massive irreparable injury to the supraspinatus tendon was detected, a subacromial spacer was installed (Fig. 1).

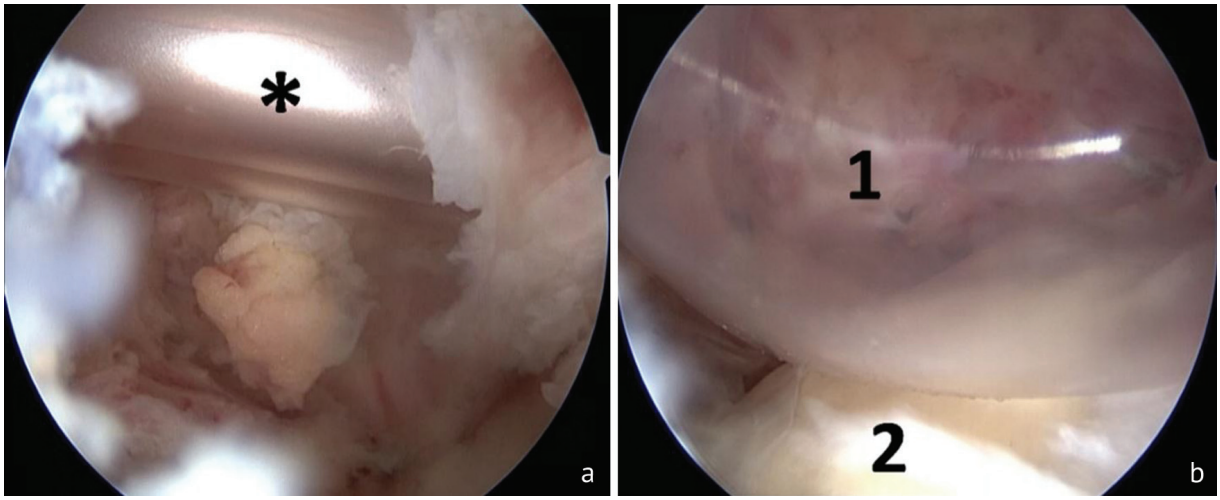

Fig. 1 Installation of a subacromial spacer in a massive injury to the rotator cuff: *a* spacer (*) inserted in a folded state; *b* spacer (1) straightened, head of the humerus (2)

Next, the tissues of the rotator interval were excised, the coracoid process of the scapula was visualized, and the tissues around the coracoid process were released, identifying the coracoacromial ligament, conjoint tendon, and pectoralis minor muscle. Further on, the pectoralis minor muscle was cut off from the coracoid process and displaced medially, which was a decompression component of the neurovascular bundle in the area of the pectoralis minor muscle. Through the “window” thus

formed, tissue dissection was carried out and the components of the brachial plexus and vessels were visualized. By cutting the scar-adhesive tissue in that area, neurolysis and decompression of the neurovascular bundle were performed (Fig. 2).

Next, tissue dissection was performed at the base of the coracoid process and medially from it. The subclavian muscle was visualized and the lateral portion of the muscle was cut off from the clavicle, forming a "window" to the thoracic outlet. Next, tissue dissection was performed in the area of the thoracic outlet, dissecting the scar-adhesive tissue around the plexus and between its components, and the BP components and the subclavian artery were visualized (Fig. 3).

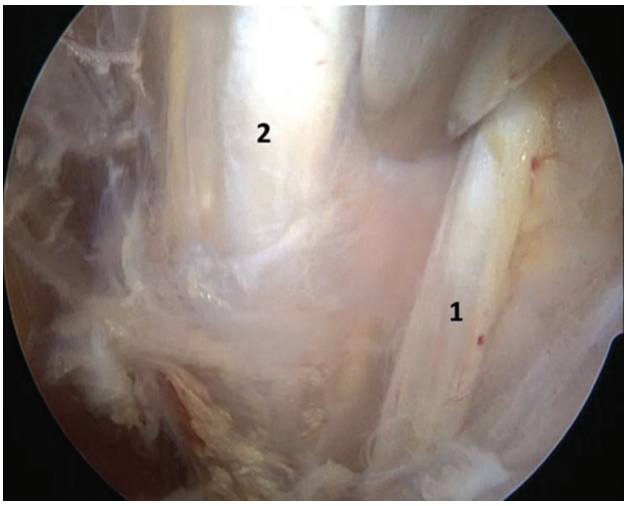

Fig. 2 Musculocutaneous nerve (1) and median nerve (2) in the area of the coracoid process after cutting off the pectoralis minor muscle

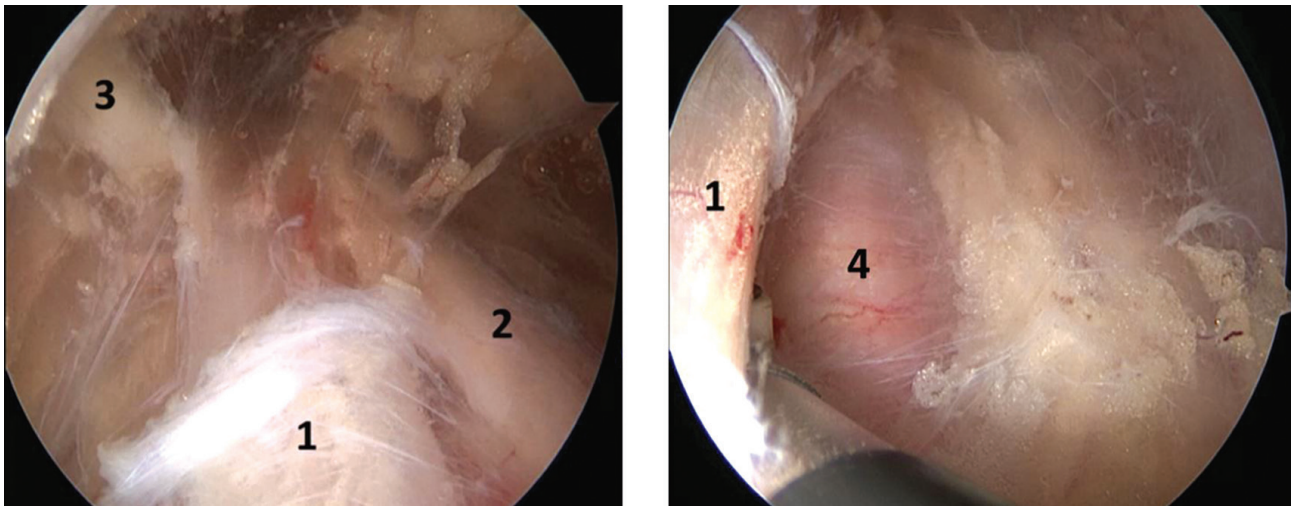

Fig. 3 Components of the brachial plexus (BP) in the area of the thoracic outlet after decompression: (1) is the upper BP trunk, (2) is the posterior division of the upper BP trunk, (3) is the suprascapular nerve, and (4) is the subclavian artery

Next, supraclavicular ports were formed, into which the arthroscope and working instrument were transferred (Fig. 7); tissue dissection was performed, and the interscalene space was accessed. The scar-adhesive tissues around the trunks of the brachial plexus and between them were dissected, thus achieving decompression and neurolysis. The upper, middle and lower BP trunks, the subclavian artery and the middle scalene muscle were visualized (Fig. 4, 5, 6).

The final stage of the operation was to suture the postoperative wounds, apply aseptic dressings, and immobilize the upper limb in a head scarf orthosis (Fig. 7).

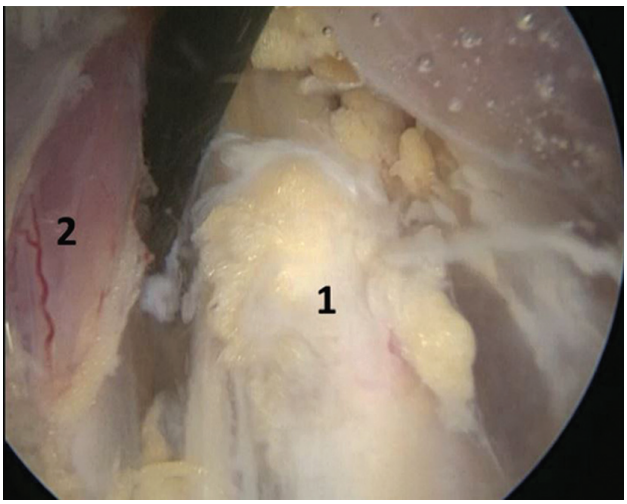

Fig. 4 Area of the interscalene space, upper trunk of the brachial plexus (1), middle scalene muscle (2)

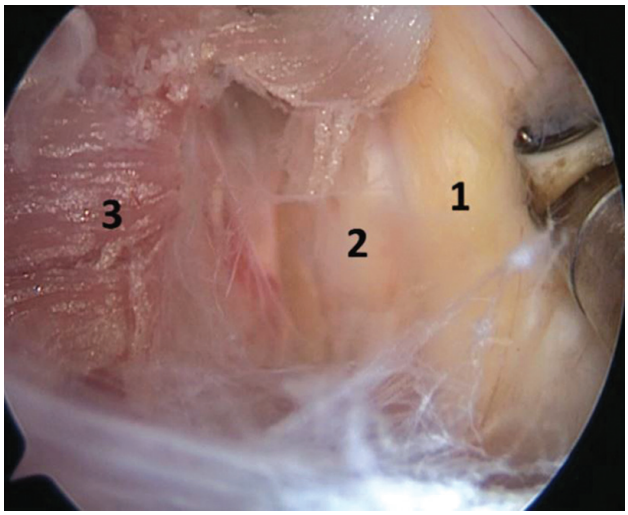

Fig. 5 Components of the brachial plexus (BP) after decompression: (1) is the middle BP trunk, (2) is the lower BP trunk, (3) is middle scalene muscle

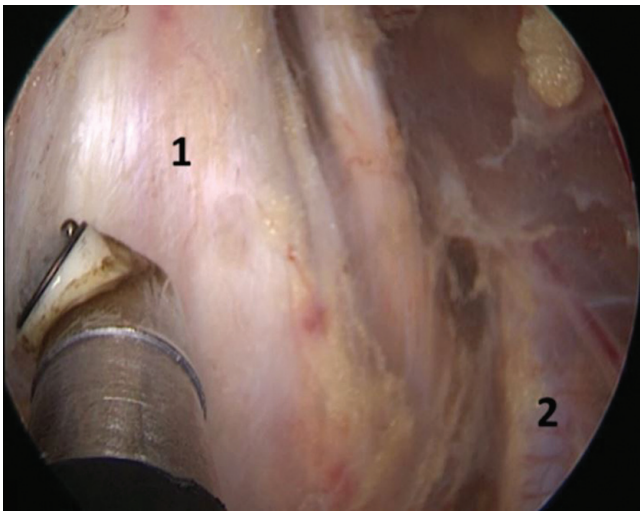

Fig. 6 Relative position of the superior trunk of the brachial plexus (1) and the subclavian artery (2) in the area of the interscalene space

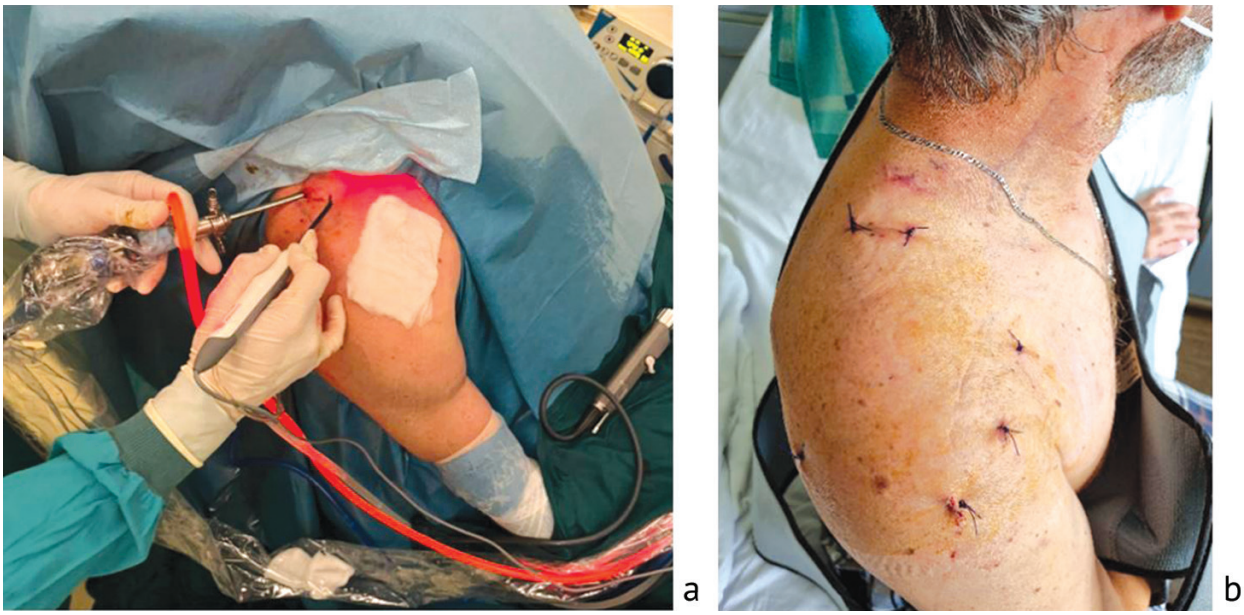

Fig. 7 View of intraoperative location of instruments (*a*); postoperative endoscopic approaches (*b*)

Surgical intervention in group 2

Under endotracheal anesthesia, with the patient lying on the back with the arm retracted to the side, an incision was made in the armpit in the skin fold so that the projection of the neurovascular bundle of the shoulder was located in the center of the incision (Fig. 8).

After opening the axillary fascia, the neurovascular bundle was exposed; nerves, arteries and veins were identified in it, and they were fixed on holders. Next, a retractor with optics was inserted into the wound parallel to the neurovascular bundle. Further actions were carried out under the control of endoscopic optics and with the help of the instruments for endoneurolysis.

Dissection of neurovascular structures was carried out in the proximal direction until the costoclavicular space was reached. Then the upper limb on the side under study was moved by the assistant upwards by the shoulder and held in this position (Fig. 9), which ensured protraction of the clavicle and expansion of the costoclavicular space (Fig. 10).

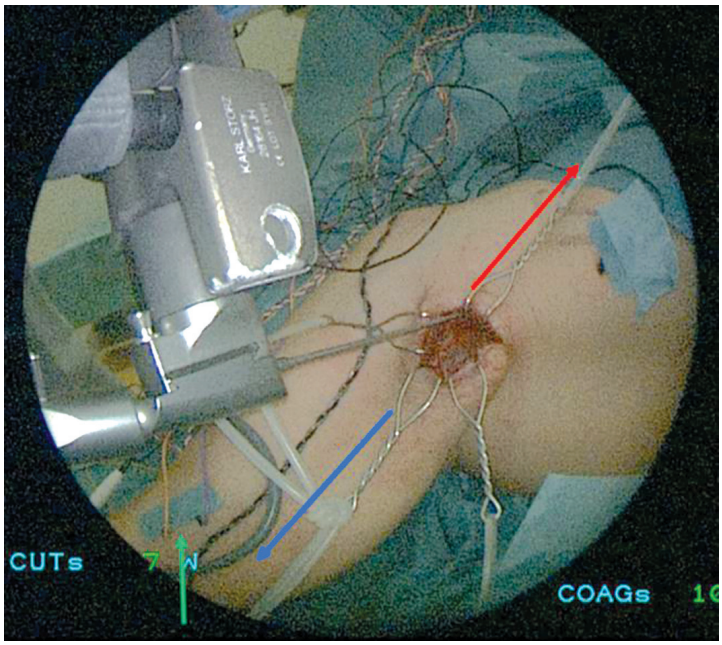

Fig. 8 View of the wound before inserting the endoscope into the endoscopic retractor. The red arrow indicates the proximal direction, the blue arrow indicates the distal direction. The green arrow indicates electrodes for neurophysiological monitoring

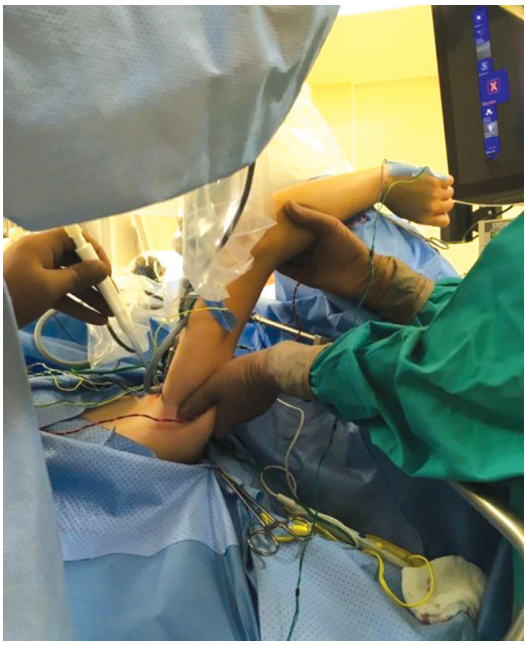

Fig. 9 Traction of the upper limb on the studied side upwards; the assistant holds the arm in the achieved position

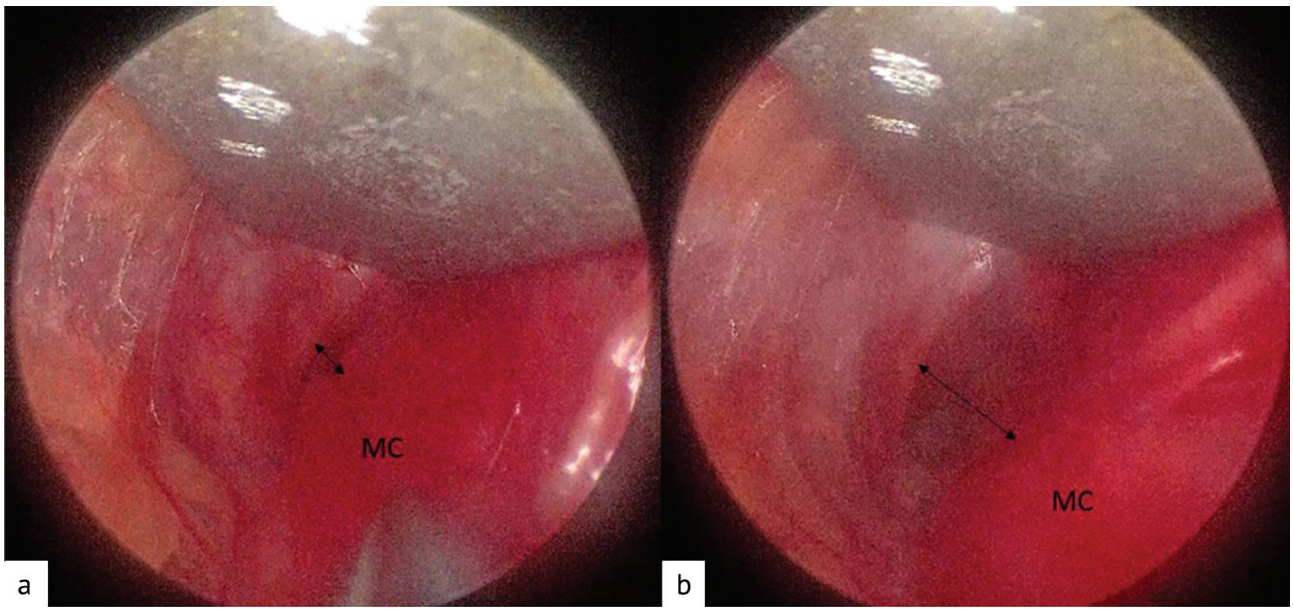

Fig. 10 Endoscopic view of the costoclavicular space before traction of the upper limb (*a*) and at the moment of traction (*b*). The black arrow indicates the costoclavicular space, MC — medial fascicle

An endoscopic retractor passed behind the clavicle followed by revision and neurolysis of the supraclavicular part of the brachial plexus which was carried out to the point where the roots entered the intervertebral foramina. Gradually moving the endoscopic retractor along the neurovascular structures, the adhesions were separated and the brachial plexus structures were freed from the surrounding tissues, starting distally at the level of the branch of the terminal branches and ending proximally, at the point where the roots entered the intervertebral foramina (Fig. 11). Neurophysiological monitoring conducted during the operation.

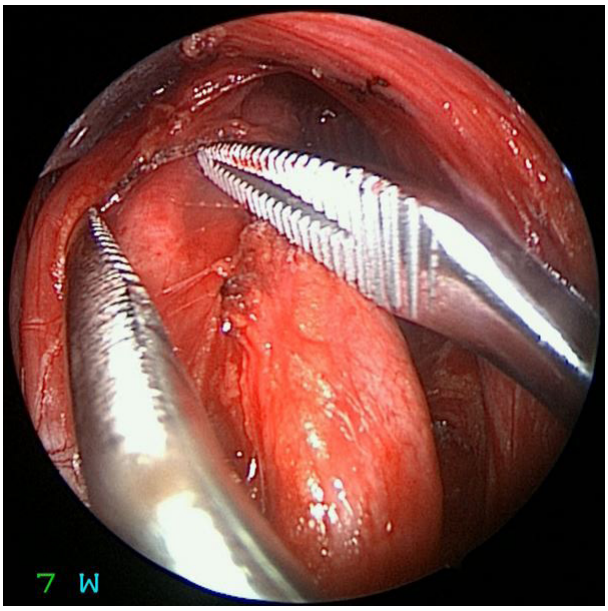

Fig. 11 Endoscopic view (diameter of the working part 4 mm, angle of direction of the optics 0 degrees) of the structures of the brachial plexus during the main stage of the operation

Interpretation of possible results

The results of treatment were assessed based on data from scales and questionnaires, a neurological examination, and were confirmed by functional diagnostic data (stimulation ENMG) 6 months after surgery. During the neurological examination, two parameters were assessed separately: strength and pain. An increase in strength in the affected muscles by 1 point or more was considered a positive result. Pain was assessed using the BMRC scale; a decrease in pain by 50 % or more was considered a positive result.

RESULTS

In group 1, positive treatment results were achieved in 87.5 % of cases (n = 7). In one case, a positive result was not achieved; no deterioration of the condition was observed after the operation. In group 2, positive treatment results were achieved in 92.9 % of cases (n = 13). In one case, a positive result was not achieved; no deterioration of the condition was observed after the operation. The results of patient treatment are presented in Table 1.

Table 1

Data of assessment before and after surgery

Scales of assessment	Before surgery (M ± SEM)		6 months after surgery (M ± SEM)		p-value	
	group 1	group 2	group 1	group 2	group 1	group 2
BMRC grade of paresis	3.1 ± 0.3	2.6 ± 0.7	4.4 ± 0.3	3.7 ± 1.0	< 0.05	< 0.05
NRS	6.8 ± 1.1	2.6 ± 1.0	1.9 ± 0.6	0.4 ± 0.3	< 0.05	< 0.05
DASH	52.3 ± 2.2	47.9 ± 4.4	28.8 ± 3.8	26.6 ± 4.3	< 0.05	< 0.05

Due to significant differences in surgical techniques, comparisons were made using the universal DASH scale. To do this, the difference in the indicator before and after surgery in each group was calculated, and then the arithmetic mean and standard error of the mean were calculated for the data obtained. In the first group, the value (M ± SEM) was 23.5 ± 3.6, in the second group — 19.4 ± 5.4, with $p > 0.05$.

According to stimulation ENMG data, patients noted a reduction in the latent period and an increase in the amplitude of the M-response (Fig. 12, 13).

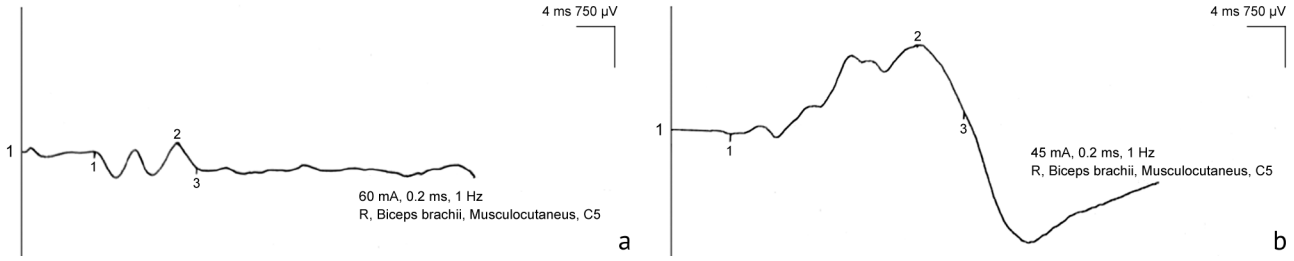

Fig. 12 Amplitude of the M-response upon stimulation of the musculocutaneous nerve in patient G. (male, 38 years old, endoscopic neurolysis group) before (*a*) and 6 months after surgery (*b*) (significant increase is noted)

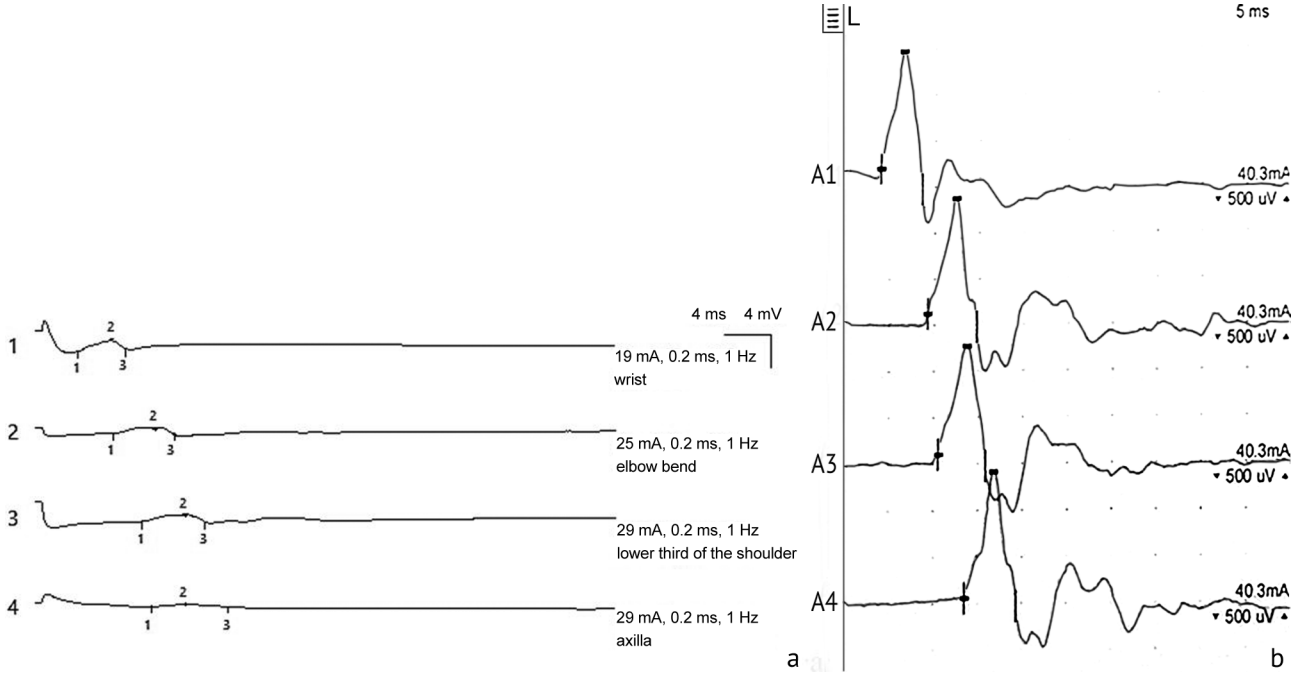

Fig. 13 Increase in the amplitude of the M-response during stimulation electroneuromyography of the brachial plexus in patient P. (male, 53 years old, group with endoscopic assistance) before (*a*) and after 6 months after surgery (*b*)

DISCUSSION

The current principles of surgery of peripheral nerves and the brachial plexus have established after the introduction of minimally invasive methods in peripheral nerve surgery in the 60s of the last century. Since then, the main directions in this area are:

- neurotization of the proximal parts of the brachial plexus with nerves passing near them, such as accessory, phrenic, intercostal, and other nerves;
- neurotization of the terminal and short branches of the brachial plexus with the nerves functioning nearby, and namely, neurotization of the median nerve by the radial nerve, neurotization of the musculocutaneous nerve by the ulnar nerve, etc.;
- muscle transposition.

The role of brachial plexus neurolysis as a self-sufficient method of surgical treatment has not been taken seriously for a long time. It was considered, rather, as one of the stages of plastic surgery or neurotization of nerves, allowing injury analysis, final diagnosis of the injury to the nerve structures and determination of their level [22].

In 1973, a literature review was published that provided information on the effectiveness of brachial plexus neurolysis and stated that neurolysis is an effective treatment for local fibrotic lesions, but is not considered a panacea [23].

The introduction of endoscopic technology into the arsenal of methods for the surgical treatment of peripheral neuropathies started not long ago, in the 80s of the 20th century, when it was proposed for the first time to decompress the median nerve at the level of the carpal tunnel under arthroscope control [24]. The use of an endoscope in surgery on the brachial plexus itself was proposed later, in the 90s, when an experiment was conducted for the first time to examine the roots of the brachial plexus under endoscopic assistance [14]. Later, Krishnan et al., having conducted studies on corpses, was one of the first to propose a revision of the brachial plexus as a diagnostic operation aimed at identifying the severity of brachial plexus injury and planning further treatment tactics. In addition, the main anatomical landmarks were identified when it is performed through the supraclavicular and subclavian approaches [14]. A similar study, but with the use of robotic technology, was carried out by Mantovani et al. in 2011 on two brachial plexuses on one fresh cadaver [17].

The first case of endoscopic revision of the brachial plexus on a living person was described in the literature in 2006. A patient with a closed brachial plexus injury due to an accident underwent this operation after which there was a complete restoration of strength and sensitivity in the affected arm 6 months later [15]. Subsequently in 2007, it was first proposed to perform resection of the first rib for upper outlet syndrome that was carried out since 1910 under video endoscopic assistance [26]. In 2017, Lafosse et al. offered an original method for performing neurolysis of all parts of the brachial plexus for upper thoracic outlet syndrome [18]. A little later, in 2020, the same group of scientists proved the effectiveness of this method in the treatment of brachioplexopathies in adults resulting from dislocation of the shoulder joint, and proposed an algorithm for the management of patients with this pathology [19]. In 2021, a group of scientists proposed a method of endoscopic revision and neurolysis of the brachial plexus, which allows, if necessary, to carry out interventions on the shoulder joint, which is relevant for patients with concomitant pathology [20]. In 2023, positive results were published in treated patients with brachioplexopathies of various etiologies using the method of neurolysis under video endoscopic assistance, which allows the operation to be performed through one transaxillary approach, especially when the technique for expanding the costoclavicular space [16, 27].

Despite the development of the endoscopic treatment of patients with brachioplexopathies, its widespread use is still limited. In the latest, most comprehensive, guidelines for the management and surgical treatment of patients with brachioplexopathies dated issued in 2021, brachial plexus neurolysis is shown only in a historical aspect, and its use with an endoscope is not described at all [21].

Based on the studies described above, it is currently possible to divide the methods of endoscopic neurolysis of the brachial plexus into several types:

• neurolysis of the brachial plexus under video endoscopic assistance;

• all-endoscopic neurolysis of the brachial plexus, including robot-assisted.

Due to the emergence of different options for performing brachial plexus neurolysis operations using an endoscope and positive results, we can conclude that there is no optimal generally accepted method of treatment and that this area of surgery is actively developing.

In general, based on the study, it follows that neurolysis using an endoscope is a low-traumatic method of treating post-traumatic brachioplexopathies in patients with not deep paresis in the affected muscle groups when conservative treatment appeared ineffective. In this study, the results of treatment of patients in group 1, in which, shoulder joint reconstruction was performed in combination with brachial plexus neurolysis, were not statistically different from the results in group 2 that underwent only brachial plexus neurolysis. This means that in case of isolated damage to the brachial plexus, both methods are effective and have approximately similar and expected treatment outcomes. However, in the association of plexopathy with the pathology of the shoulder joint, a one-stage combined intervention with correction of intra-articular

pathology and neurolysis is acceptable and contributes to a more complete and early restoration of upper limb function.

The team of the authors suggests a further study of the topic in order to create an optimal treatment and diagnostic algorithm for patients with brachioplexopathies.

CONCLUSION

The techniques of performing brachial plexus neurolysis with an endoscope are effective in the treatment of post-traumatic brachioplexopathies in adults if the strength in the affected muscles is two or more BMRC points. In this study, the methods of endoscopic neurolysis of the brachial plexus in combination with arthroscopy of the shoulder joint and isolated mini-invasive neurolysis of the brachial plexus under video-endoscopic assistance have resulted equally effective. Treatment of patients with post-traumatic brachioplexopathy is challenging and requires a multidisciplinary approach.

Competing interest *The authors declare that they have no competing interests.*
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Clinical and radiological aspects of the forearm in children with congenital radioulnar synostosis: a cohort study

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Abstract

Introduction The upper limb functional limitations in congenital radioulnar synostosis may significantly affect the daily activities of patients. Classifications of the condition are descriptive and have limited practical application.

Purpose Determine a functionally significant quantitative criterion for anatomical changes in the forearm.

Material and methods 92 children (136 forearms) with congenital radioulnar synostosis were examined for limitations in activities of daily living (ADL), health-related quality of life measured with PedsQL questionnaire; pronation of the forearm and radiographic parameters. A comparative and correlation analysis, ROC analysis were performed to determine the relationship between the forearm pronation and limitations of ADL.

Results Statistically significant correlations were revealed between symptoms and the forearm alignment ($p < 0.01$, $r_{xy} = 0.5$); subluxation of the ulnar head and forearm alignment ($p < 0.001$, $r_{xy} = 0.6$); bowing deformity of the radius, forearm alignment and subluxation of the ulnar head and between the length of the forearm bones and bowing deformity of the radius ($p < 0.05$, $r_{xy} = 0.4$ and $r_{xy} = 0.5$). A statistically significant inverse correlation was revealed between symptoms and PedsQL scores ($p = 0.038$, $r_{xy} = -0.4$). Pronation of 45° was the threshold value of the forearm alignment with a high risk of ADL limitation. The area under the ROC curve corresponding to the relationship between symptoms and the forearm alignment was 0.955 ± 0.021 (95 % CI: 0.915–0.995). There was a statistically significant ($p < 0.01$) decrease in the lumen of the medullary canal in the middle third of the ulnar shaft with the radius lumen being unchanged. Dorsal subluxation of the ulnar head was detected In 30 % of cases.

Discussion The characteristics identified demonstrated changes in the forearm bones with functional impairments being correlated with the forearm pronation.

Conclusion The correlation between the patient's symptoms and the forearm alignment must be taken into account in the classification and when determining indications for surgical treatment distinguishing between functional (< 45° pronation) and dysfunctional (⩾ 45° pronation) options.

Keywords: radioulnar synostosis, child, classification

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INTRODUCTION

Congenital radioulnar synostosis (CRUS) is a rare developmental condition of the upper limb caused by failure of differentiation that leads to the joint enchondral ossification in utero at the stage of embryogenesis [1, 2, 3]. Embryology-based Oberg-Manske-Tonkin (OMT) classification was accepted as the new classification system for all congenital upper extremity anomalies. CRUS is classified as disruption of radioulnar (antero-posterior) axial differentiation of tissues [4, 5]. Synostosis of bones occurs at the level of the proximal radioulnar joint, and can extend to the distal third of the forearm [6]. Idiopathic congenital synostosis of the distal forearm bones is an occasional case and can have a different genesis [7, 8]. Functional limitations in CRUS can affect daily activities, with pronounced pronation of the forearm and bilateral lesions, in particular [9, 10].

The current classifications of CRUS are descriptive and based on radiological manifestations seen at the level of the proximal forearm and have limited practical application.

The purpose of the work was to determine a functionally significant quantitative criterion for anatomical changes in the forearm.

MATERIAL AND METHODS

The review of 92 patients (136 forearms) aged 2.5 to 17 years was performed at the National Medical Turner Research Center for Pediatric Trauma and Orthopaedics between 2010 and 2022. The patients were examined and/or treated for congenital radioulnar synostosis (Table 1).

Table 1

Characteristics of children

Description		Total	Presented with complaints		No complaints reported	
			abs.	%	abs.	%
Number of patients		92	77	83.7	15	16.3
Involved side, No. of cases	left	33	28	84.8	5	15.2
	right	15	10	66.7	5	33.3
	both	44	39	88.6	5	11.4
Graded by Cleary – Omer, No. of forearms	I	7	4	57.1	3	42.9
	II	11	6	54.5	5	45.5
	III	104	97	93.3	7	6.7
	IV	14	9	64.3	5	35.7
Males		60	47	78.3	13	21.7
Females		32	30	93.8	2	6.2
Age, completed years, Me [Q1–Q3]		7 [4–10]	6 [4–9]		8 [7–13]	

The design is a single-center retrospective cohort study for the first part and a case-control study for the second part of the work. The study was performed in accordance with STROBE recommendations and was divided into two consecutive parts. The purpose of the first part was to assess the relationship between patient complaints, upper limb function and clinical presentation of padiatric forearm with CRUS. The purpose of the second part was to analyze the radiological parameters in patients with unilateral CRUS. The study design is presented in Figure 1.

Inclusion criteria included radiologically verified congenital radioulnar synostosis, patients under 18 years of age. The study did not include patients with incomplete data and those after surgical treatment.

Exclusion criteria for the second part of the work included bilateral involvement of the upper limbs and the absence of preoperative radiological findings. Pronation alignment of the forearm measured in degrees was assessed clinically using a goniometer at an elbow flexion of 90°. Subluxation of the ulnar head was identified using radiographs of the forearm in a strictly lateral projection (Fig. 2).

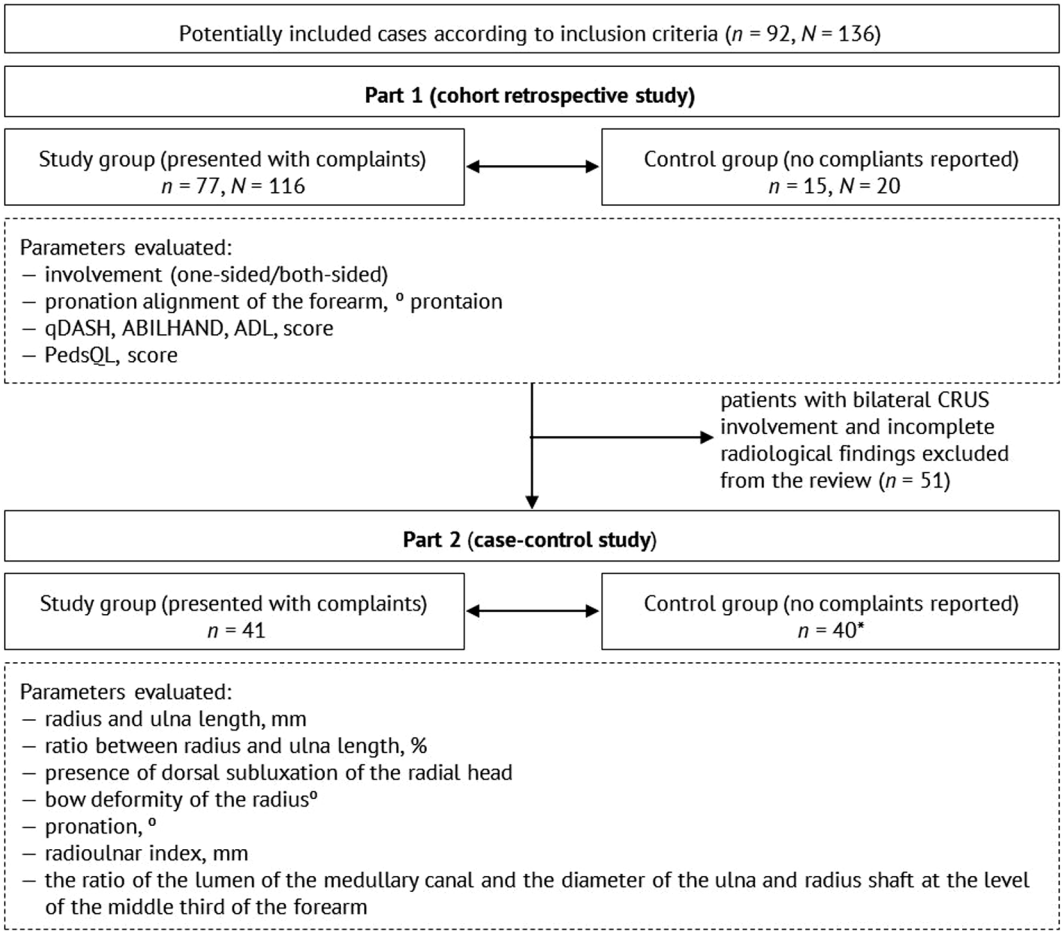

Fig. 1 Study Design Flowchart; * radiological findings of the contralateral healthy limb were unavailable in 1 case

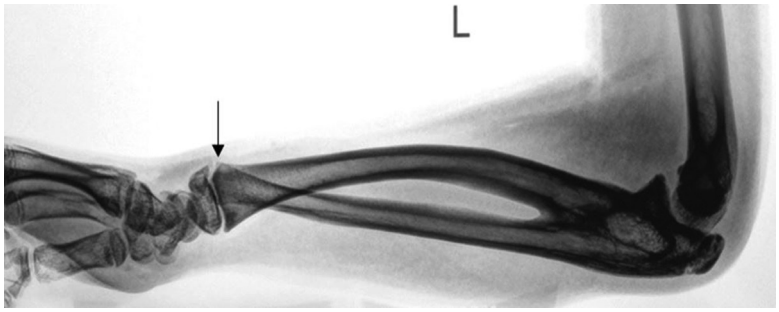

Fig. 2 Radiograph of the forearm of a patient with CRUS in a strictly lateral projection with the arrow indicating the dorsal subluxation of the ulnar head

The Hafner method was used for ulnar variance measurement in children under 11 years of age [11]. Ulnar variance measured in patients 12 years of age and older referred to the difference in height between the joint surfaces of the distal ulna and the distal edge of the radial sigmoid notch. Liu et al. reported measurements of the radius pronation angle using the special flexed posterior-anterior views of the X-ray image of the forearms [12]. Complaints about limitations in daily activity were assessed according to the 12-point ADL scale (activity of daily living) [13].

Subjective evaluation of the forearm function in children with CRUS consisted of a set of 12 questions regarding the basic activities of life [13]. The length of the forearm bones was measured using lateral radiographs. The ulna length was measured as the distance between the olecranon and the styloid process. Radial length was defined by the length measured between the tip of the radial styloid and the distal articular surface of the ulna. In younger children with radiological absence

of ossification nuclei of the distal and proximal parts of the forearm bones, the length was measured from the edges of the metaphyses, and from the most distal and proximal points of the secondary ossification centers in the presence of ossification nuclei.

Statistical analysis was performed using IBM SPSS Statistics 26. The distribution of quantitative data was primarily assessed using the Kolmogorov – Smirnov test with the Lilliefors correction for a sample size of more than 50 and using the Shapiro – Wilk test for a smaller sample size. The sample size was not calculated in advance. A comparative analysis of radiological parameters was performed using the nonparametric Mann – Whitney test after preliminary assessment of the data distribution. A correlation analysis was performed using the Spearman criterion to analyze the relationships between radiological, clinical and functional parameters. Strength of relationship was assessed using the Chaddock scale. ROC analysis was performed to determine the cut-off point for predicting complaints and creating a binary classification on the basis of the forearm pronation alignment and limitations in activities of daily living. The study was approved by the institutional ethics committee and was conducted in accordance with the ethical standards outlined in the Declaration of Helsinki.

RESULTS

A higher prevalence of CRUS was found in male patients among individuals seeking surgical treatment (ratio 2:1). The mean age at the time of referral for surgery was 6 years. Morphotype III of Cleary and Omer classification was the most common (Table 1). Although an identical morphological type was observed in 70.5 % of cases of bilateral involvement, 13 patients out of 44 (29.5 %) with bilateral CRUS were diagnosed with different types as grouped by Cleary – Omer. Statistically significant differences in the forearm pronation alignment were identified between the group of patients who presented no limitations in activities of daily living, and those who did (Table 2). Radiological parameters of the second part of the study and quantification characteristics are presented in Table 3.

Table 2

Forearm bone alignment in the groups

Description	Total	Presented with complaints	No complaints reported	*p*
Pronation alignment of the left forearm, degrees, Me [Q1–Q3]	70 [30–90]	80 [50–90]	10 [10–20]	< 0.05*
Pronation alignment of the right forearm, degrees, Me [Q1–Q3]	85 [30–90]	90 [60–90]	10 [5–15]	< 0.05*

* statistically significant differences identified between the groups

Table 3

Radiological findings in patients with CRUS

Description		Unilateral CRUS involvement
Subluxated ulnar head, abs. (%)		19 / 48 (39.5 %)
Radius length, % relative to the normal limb, M ± SD		91.6 ± 5.4
Ulnar length, % relative to the normal limb, M ± SD		94.1 ± 6.2
Bow deformity of the radius, degrees, M ± SD		21.36 ± 6.05
Ulnar length, % relative to the radius, M ± SD	involved limb	103.4 ± 5.5
	normal limb	102.8 ± 4.2
The lumen of the medullary canal at the level of the middle third of the ulnar shaft, % of the diameter of the shaft at the level, M ± SD	involved limb	37.3 ± 8.1
	normal limb	45.9 ± 9.7
The lumen of the medullary canal at the level of the middle third of the radial shaft, % of the diameter of the shaft at the level, M ± SD	involved limb	41.9 ± 8.2
	normal limb	45.5 ± 9.5
Ulnar variance, mm, Me [Q1–Q3]	involved limb	0.74 [–1.48–1.52]
	normal limb	–0.84 [–2.56–0]
Pronation angle, degrees		11.06 ± 0.47

Dorsal subluxation of the ulnar head was seen in 30 % of all observations (41 out of 136 forearms) with greater proportion observed with Cleary-Omer type III CRUS noted in 37.5 % (39 out of 104 forearms). The length of the ulna and radius was 91.6 ± 5.4 % and 94.1 ± 6.2 % relative to the length of the intact bones of the contralateral forearm, respectively. There were no statistically significant differences in the ratios between the forearm bone lengths (ulna relative to radius) of the healthy and affected limbs. A statistically significant ($p < 0.01$) decrease in the lumen of the medullary canal and thinning of the ulna was revealed, with a relatively maintained diameter of the radius as compared with the healthy limb (Fig. 3).

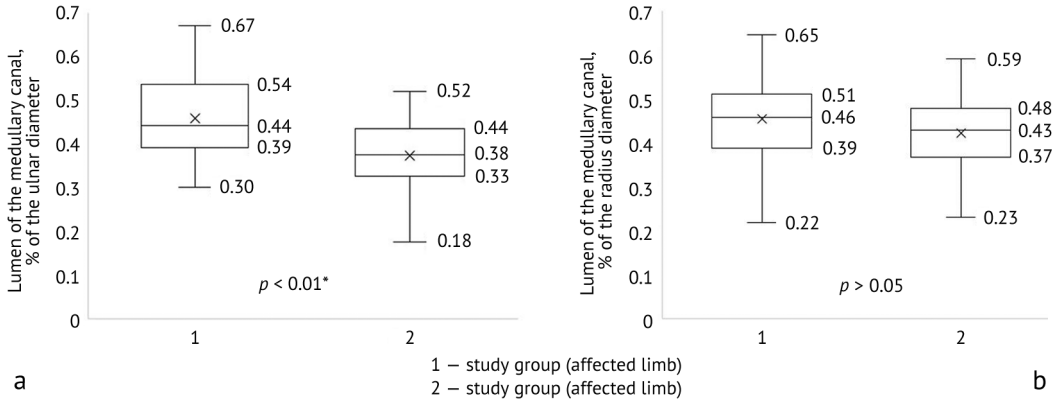

Fig 3 Comparison of the mean measurements of the lumen of the medullary canal at the level of the middle third of the forearm relative to the diameter of the ulna (a) and theradius (b): * statistically significant differences between the groups ($p < 0.01$)

Spearman's correlation coefficient showed statistically significant ($p < 0.01$, $r_{xy} = 0.5$) positive association between presentation of complaints and the forearm alignment measured with the Chaddock scale. An inverse correlation of moderate tightness ($p = 0.038$, $r_{xy} = -0.4$) measured with the Chaddock scale between complaints and PedsQL scores indicating general health. There were no statistically significant correlations between complaints and the affected side, gender, age, functional scales ADL, Failla, ABILHAND, qDASH and the total PedsQL score.

Statistically significant ($p < 0.05$) positive correlations of moderate tigntness ($r_{xy} = 0.4$ and $r_{xy} = 0.5$) measured with the Chaddock scale were identified between the bow deformity of the radius, the forearm pronation alignment and subluxated ulnar head, between the length of the radius and ulna and the bow deformity of the radius (Fig. 4). No statistically significant correlations were found between the forearm pronation alignment and the patient's age or ulnar variance.

A statistically significant ($p < 0.001$) positive correlation of noticeable tightness measured with the Chaddock scale ($r_{xy} = 0.6$) was revealed between dorsal subluxation of the ulnar head and severity of the forearm pronation alignment (Fig. 4).

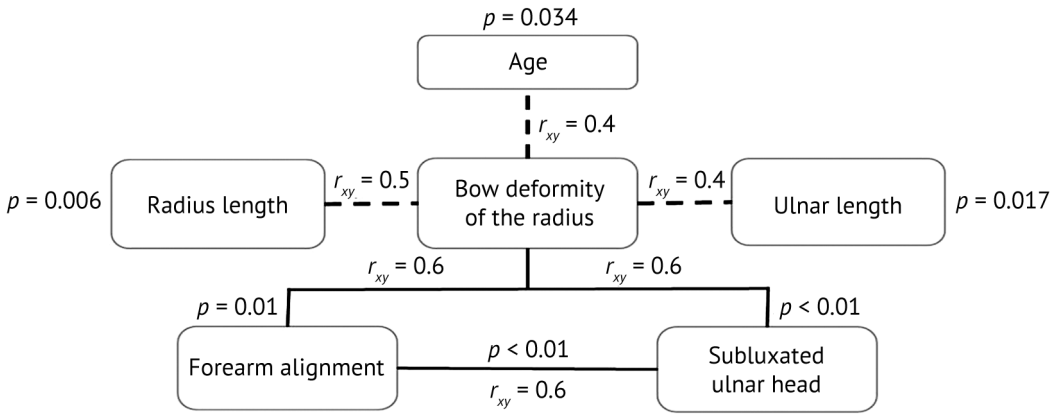

Fig. 4 Results of Spearman correlation analysis. Positive correlations are marked with solid lines, reverse correlations are marked with dotted lines

With a statistically significant correlation between limited activities of daily living and the forearm alignment an ROC analysis was performed to determine the minimum threshold value of the forearm alignment with higher values indicating the increased likelihood of having complaints. No correlations between the involvement side (unilateral or bilateral CRUS) and complaints about limited activities of daily living were identified at the previous stage of statistical data processing, the forearm with a greater pronation alignment was selected as more clinically significant for ROC analysis; the pronation alignment of one forearm was taken into account with the same forearm alignment. The area under the ROC curve corresponding to the relationship between the prediction of the complaints and the severity of pronation alignment of the right forearm measured 0.955 ± 0.021 degrees with 95 % CI: 0.915–0.995 (Fig. 5). The resulting model was statistically significant ($p < 0.001$). The threshold value of the forearm alignment at the cut-off point was 45° pronation. If the forearm alignment was equal to or greater than this value, the patient was predicted to have a higher risk of complains about limited activities of daily living. The sensitivity and specificity of the method were 91 % and 100 %, respectively.

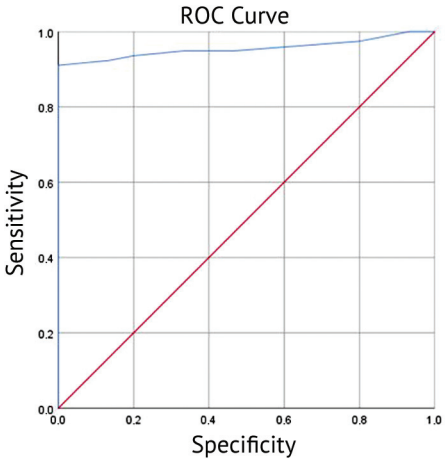

Fig. 5 Results of ROC analysis for binary classification of CRUS depending on the forearm pronation alignment in degrees

DISCUSSION

Most common classifications of patients with CRUS published in research works (Table 4) are based on radiological findings of the condition. The authors of the most popular classification [10] reported its limited use in evaluation of the limb function and making tactical decisions regarding treatment approaches [14, 15, 16].

Table 4

Classifications of CRUS

Authors, year, reference	Description
Tachdjian, 1990 [17]	Type I: “true” CRUS or type without radial head. radiographic radial head unobservable and osseous synostosis with the ulna. The radius is bowed, its thickness is greater than the thickness of the ulna Type II: with dislocated radial head. The malformed head of the radius is displaced posteriorly. Proximal bone fusion. Type III: There is no bony fusion, but there is a pronounced fibrous band attached to both bones limiting rotational movements. The rarest type
Cleary, Omer Jr, 1985 [14]	Type I: Fibrous ankylosis with normal radial head, without bone changes, but with limited movement and forearm shortening Type II: bony synostosis, radial head formed, centered Type III: bony synostosis, radial head displaced posteriorly Type IV: bony synostosis, the radial head displaced anteriorly
Wilkie, 1914 [18]	Type I: fusion of the medullary canals of the radius and ulna, the radius is larger and longer than the ulna Type II: anterior or posterior dislocation of the radial head, bony synostosis of the proximal shafts of the forearm bones

The morphological characteristics we identified indicated changes in the forearm bones including the proximal radioulnar joint. A decrease in the lumen of the medullary canal at the level of the middle third of the shaft and changes at the distal radioulnar joint, correlate with modern concepts, taking into account the stages of embryogenesis and the classification of malformations of the upper extremities graded by the OMT classification [4, 5].

In our series, subluxation of the ulnar head was observed in 30 % of cases. The subluxation was seen in the most common type III synostosis as graded by Cleary – Omer [19, 20, 21, 22]. It was noted that the more pronated the forearm was, the more common dorsal subluxation of the ulnar head observed (Fig. 4). We suggested that it might be caused by a more intense growth of the ulna and its relative "overlengthening." The proximal radial physis and the distal ulnar physis are responsible for 20 % of the forearm growth [23, 24]. "Mute" proximal radial physis in type III CRUS is likely to be responsible for a slowdown in growth rates leading to delayed bone growth and causing a bow deformity of the radius [25], progression of incongruity in the distal radioulnar joint and subluxation.

Then there is a question: is the discrepancy between the longitudinal dimensions of the radius and ulna bones truly anatomical or is it a projection distortion on the radiograph? Epner et al. [26] and Palmer et al. [27] reported the relative radial and ulnar variance being dependent on the position of the forearm. The pronation visually increases the ulnar variance, while the supination, on the contrary, reduces it. Jung et al. [28] studied radiographs of the wrists of 120 healthy volunteers and determined maximum ulnar variance when gripping in pronation and minimum ulnar variance when relaxed in supination. Standardization of study designs or computed tomography of the forearm in patients with CRUS can be a solution to interpretation of the findings.

Yeh et al. [29] recommended to standardize the measurement of ulnar variance with neutral rotation radiographs of the wrist. However, neutral rotation radiographs of the wrist cannot be anatomically produced in patients with radioulnar synostosis. Although the authors found a statistically significant difference in ulnar variance between the pronated and neutral positions, this difference may not be clinically significant [29]. The presence of radial bone deformity would not normally allow restoration of rotational movements even with the synostosis being separated and grafts implanted [30, 31, 32]. The absence of statistically significant differences in the forearm bone length ratios (ulna relative to the radius) indicates a proportional shortening of both bones of the affected forearm. This disproportion may indicate partial preservation of the function of the proximal physes of the radius having growth potential of 20–25 % [23, 24]. The absence of statistically significant correlations between the severity of the forearm pronation and the patient's age may indicate static changes that do not progress over time. Pathological changes in CRUS in children involve the whole forearm structures, and are not limited to changes at the level of the proximal radioulnar joint.

Limitations of the study A small sample size of patients with no active complaints for limited activities of daily living with CRUS being an incidental finding. If the forearm position is described as an average physiological one, patients may not seek consultation with a doctor or keep outpatient appointments at the place of residence. This would contribute to a representative sample.

CONCLUSION

We offer to give consideration to the dependence of the patient's presentation of complaints and the forearm position specified in the CRUS classification, and when determining the indications for surgical treatment of pediatric patients with this condition, distinguishing functional (< 45° pronation) and dysfunctional (⩾ 45° pronation) options.

Conflict of interest *The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.*

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Ethical review *The study was approved by the local ethics committee and was executed in compliance with the Declaration of Helsinki.*

Informed consent *All patients signed a voluntary informed consent form.*

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The long-term results of proximal interphalangeal joint arthroplasty of the hand

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Abstract

Introduction Small joints replacement is a valid treatment for deforming osteoarthritis and traumatic injuries to the phalangeal joints of the hand to restore motor hand functions. Various types of implants differing in shape, biomechanics and material composition have been developed.

The purpose of the study was to evaluate long-term results of the proximal interphalangeal joint arthroplasty of the hand using various implants and identify their advantages.

Material and methods We retrospectively reviewed 78 cases of proximal interphalangeal joint replacement in 64 patients. Outcomes were assessed at 6 months and at follow-up stages with preoperative and postoperative measurements of the range of motion in the joint evaluating pain, radiographs and outcomes measures using the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire.

Results The range of motion in the prosthetic joint increased significantly at different follow-up periods with all types of implants. The pain syndrome decreased. Radiographs revealed 10 cases of aseptic instability in the group of constrained prostheses. The DASH assessment showed high subjective satisfaction with the treatment.

Discussion We could not find papers reporting PIP joint arthroplasty using SBI D.G.T. implant system. A retrospective study of RM Finger arthroplasty of the PIP joint indicated restored joint stability with AROM improvement and with low pain, although it had a high rate of complications. We recorded no complications with this implant model. Some authors would not recommend the RM Finger implant (Mathys) for PIP joint replacement. Arthroplasty of small joints of the hand with MOJE kermik-implantate showed satisfactory outcomes for 82 % of patients at a long term

Conclusion Arthroplasty of the PIP joint of the hand using various implant designs resulted in greater mobility of the upper limbs, a lower pain due to subjective improvement in the functionality at a long term. Although the procedures were effective with all implant designs the reliability of changes in the parameters was more evident with nonconstrained implants.

Keywords: proximal interphalangeal joint, joint replacement of the hand, Moje ceramics, proximal interphalangeal joint arthroplasty

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INTRODUCTION

Fine motor skills of the hands create opportunities for learning and interactions. The hand is very important for any activity, and decreased functionality can lead to lower working capacity and physical capabilities and limitations. With present technologies, the hand function can be restored to ensure precise, strictly measured movements to control complex mechanisms [1]. The hand is a complex structure with many interconnected joints that allow versatile and very dexterous movements. The hand function is important for everyday activities. The activities such as writing, manipulating objects, grasping, opening and closing cans, turning a key would require stability and mobility at various joints of the upper limbs [2]. The normal flexion at the PIP joint ranges from 0 to 130°. In the absence of job-specific requirements for the hand the amplitude ranges between 16 and 93° in everyday life stratifying the results of treatment of arthrosis by a functional measure [3]. The treatment of deforming osteoarthritis and traumatic injuries of the phalangeal joints of the hand is aimed at maximal restoration of active movements within the functional amplitude. There is a lack of consensus regarding the optimal approach and surgical options for PIP joint disorders among the surgeons [4–6]. Maintaining or improving mobility in the joint and the grip strength is essential for the patients with an evident advantage of joint replacement over arthrodesis [7]. The decision on joint replacement or arthrodesis should be made jointly with the patient considering the patient's goals and a greater risk of complications associated with arthroplasty [8–11]. Various types of implants differing in shape, biomechanics and material composition have been developed [12–15]. The purpose was to evaluate outcomes of PIP joint replacement using various types of implants and identify the advantages.

MATERIAL AND METHODS

A retrospective continuous study was performed at the Federal Center for Traumatology, Orthopaedics and Joint Replacement in Cheboksary (hereinafter referred to as the Center).

The study was performed in accordance with ethical principles for medical research involving human subjects stated in the 2013 Declaration of Helsinki developed by the World Medical Association, Order of the Ministry of Health of the RF dtd 19th June 2003 No. 266 on Clinical Practice Guidelines in the Russian Federation and approved by the local ethical committee of the Center (protocol No. 7 dated June 20, 2023). Eighty PIP replacement procedures were performed at the Center between 2009 and 2022 (Table 1).

Table 1

PIP replacement procedures performed with different implants as reported in 2009–2022

Year	Implant modification			Total
	SBI D.G.T. PIP joint implant	RM Finger (Mathys)	Moje ACAMO PIP	
2009	2			2
2010	6			6
2011	12			12
2012	8			8
2013	7			7
2014	14	3		17
2015	1	2		3
2016		2		2
2017		3	5	8
2018			2	2
2019			4	4
2020			3	3
2021			4	4
2022			2	2
Total	50	10	20	80

Different modifications of implants used at different periods were associated with the changed range on the medical market. A total of 66 patients underwent the p;rocedure with 31 female (47 %) and 35 male (53 %) patients. The mean age of patients was 47.1 years (CI = 95 %; SD = 12.7, range, 25 to 83). Inclusion criteria included idiopathic and post-traumatic arthrosis; post-traumatic defects of the digital joints; degenerative and post-infectious arthrosis; bone ankylosis; initial stages of rheumatoid arthritis and psoriasis. The endoprostheses were implanted through the dorsal median transtendon surgical approach. Flexion and extension with active and passive amplitude could be performed at 2 to 3 weeks. More than half of the PIP joint replacements were performed on the right side on the third finger (Table 2).

Table 2

Location of PIP joint implants

Hand	Finger				
	I	II	III	IV	V
Right-sided	—	12	25	10	—
Left-sided	—	6	9	16	2
Total	—	18	34	26	2

The following types of implants were used for joint replacements:

– constrained implants with the lateral stability being ensured by the design of the implant – SBI D.G.T. PIP joint implant (Fig. 1) and RM Finger (Mathys) (Fig. 2); 50 and 10 implants were used, respectively;

– Moje ACAMO PIP implants, an unconstrained endoprosthesis made of zirconium ceramics (Fig. 3); A total of 20 implants were used.

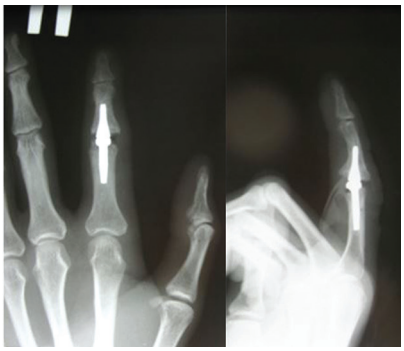
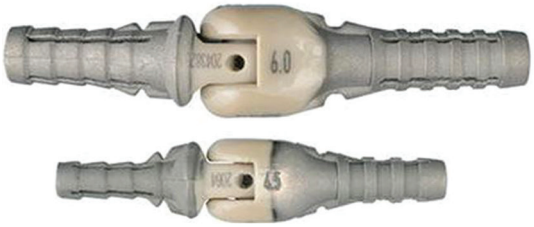


Fig. 1 Constrained SBI D.G.T. PIP joint implant



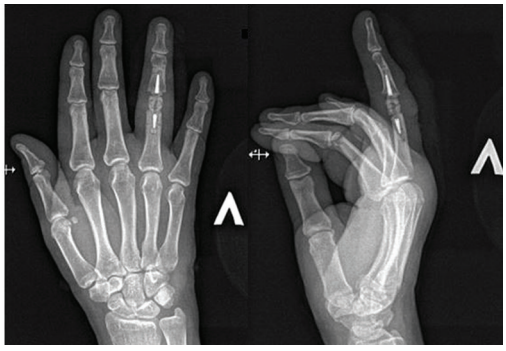
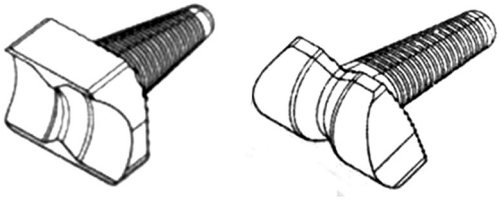


Fig. 2 Constrained RM Finger implants (Mathys)



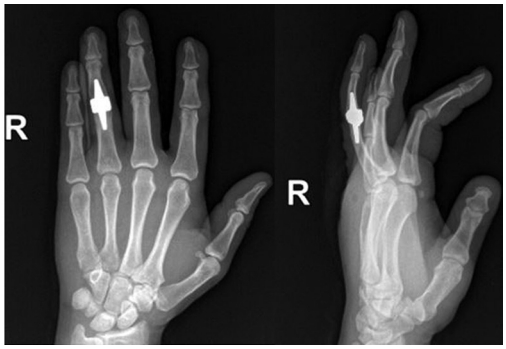


Fig. 3 Non-constrained Moje ACAMO PIP implant

Short- (at 6 months of surgery) and long-term results (at the follow-up stage, 1 year or more after surgery) were assessed using objective criteria (preoperative and postoperative measurement of ROM with a protractor, assessment of pain on the VAS scale and radiological examination), and subjective criteria using DASH score, to assess the extent of disability of the arm, shoulder and hand from 0 meaning no disability and a good function to 100 points indicating severe disability.

Statistical analysis was produced using the package of the Microsoft Excel 2007 program. Normal distribution of the variables was confirmed graphically in MS Excel with the data represented in the form of the arithmetic mean (M) and standard error (m). The minimum, maximum, median, mode were identified in the absence of normality. The Fisher's exact test was used to assess the statistical significance of differences in the groups calculated with the Graf Pad program. Differences were considered statistically significant at $p<0.05$.

RESULTS

Long-term results of 78 cases of replaced PIP joints using constrained and unconstrained implants were retrospectively reviewed in 64 patients. Two patients (two arthroplasty cases) with replaced PIP joint using SBI D.G.T. implant were unavailable for the follow-up due to changed contact information. Follow-up period for patients with the SBI D.G.T PIP joint implant was 8–14 years, 6–9 years for RM Finger (Mathys), 6-month-to-6-year period for Moje ACAMO PIP. Assessment of the range of motion in the prosthetic joint at various periods of observation showed a statistically significant increase in the parameter for the three types of implants ($0.00001 \leqslant p \geqslant 0.04475$) (Table 3).

Table 3

ROM in the PIP joint at stages of treatment, °

Type of implant	ROM at stages of treatment, °			
		pre-op	at 6 mo	at the follow-up stage
SBI D.G.T. PIP joint implant	*M* ± *m*	9.6 ± 14.0	16.3 ± 18.7	17.2 ± 19.9
	p	–	0.04475*	0.02944*
RM Finger (Mathys)	*M* ± *m*	16.5 ± 14.2	44.0 ± 30.3	46.5 ± 31.5
	p	–	0.02214*	0.01651*
Moje ACAMO PIP	*M* ± *m*	7.8 ± 9.2	42.8 ± 26.6	48.0 ± 30.0
	p	–	0.00001*	0.00001*

* as compared to pre-op value

There was no optimistic increase in ROM as compared to preoperative measurements. Postoperative ROM either remained at the same level or increased with no maximum ROM to be achieved at the follow-up stage. In our series, the unconstrained Moje ACAMO PIP ceramic implant showed restored the best ROM regained in the joint postoperatively (up to an average of 48°). All patients reported a decrease in pain after surgery (Table 4).

Table 4

Pain assessed with VAS, scores

Type of implant	VAS score		
		pre-op	at the follow-up stage
SBI D.G.T. PIP joint implant	*M* ± *m*	6.0 ± 1.9	0.4 ± 0.6
	p	–	0.00000*
RM Finger (Mathys)	*M* ± *m*	6.5 ± 2.2	0.4 ± 0.5
	p	–	0.00001*
Moje ACAMO PIP	*M* ± *m*	4.9 ± 1.9	0.6 ± 0.8
	p	–	0.00000*

* as compared to pre-op value

Radiological assessment of endoprosthetic results showed no evidence of lateral instability with the Moje ACAMO PIP ceramic non-constrained implant (Fig. 4).

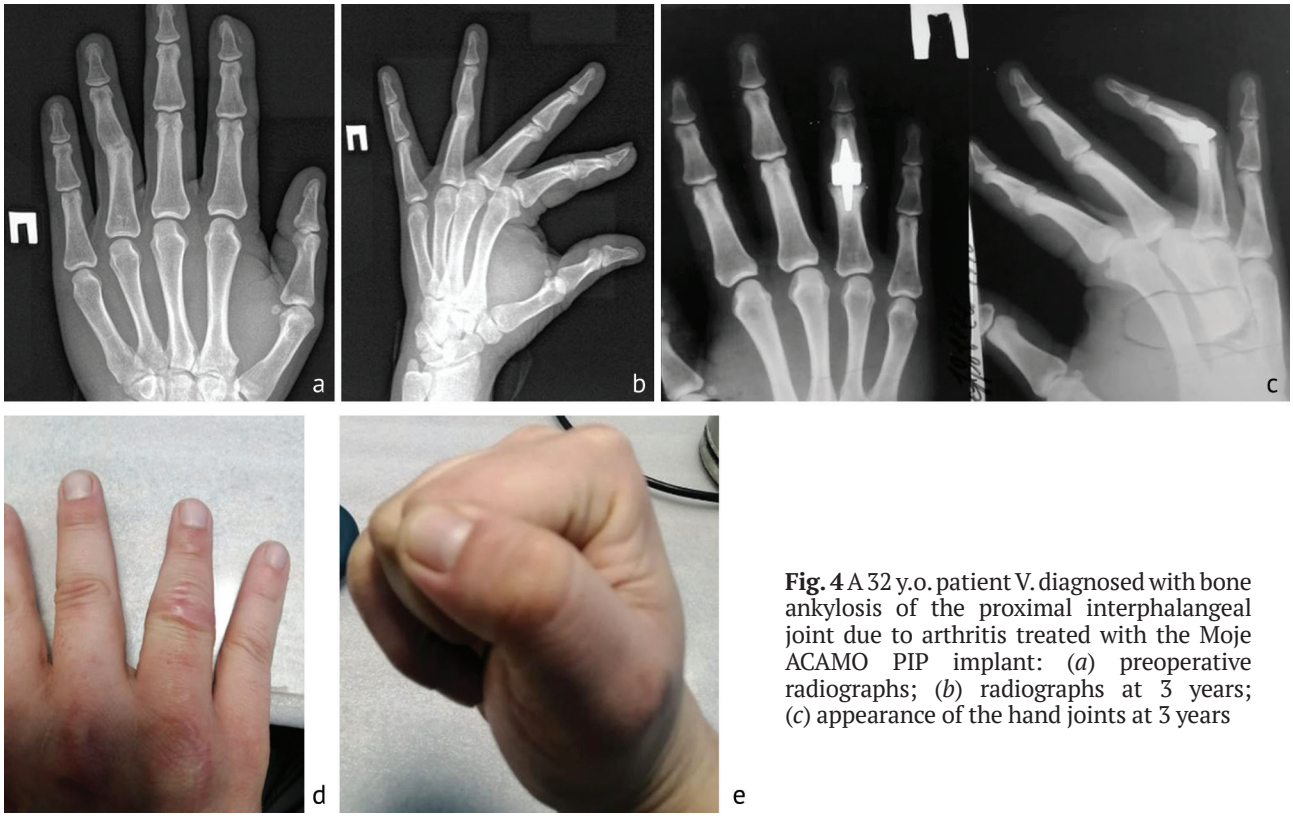


Fig. 4 A 32 y.o. patient V. diagnosed with bone ankylosis of the proximal interphalangeal joint due to arthritis treated with the Moje ACAMO PIP implant: (*a*) preoperative radiographs; (*b*) radiographs at 3 years; (*c*) appearance of the hand joints at 3 years

Radiological examination demonstrated 10 cases of aseptic instability of the SBI D.G.T. PIP joint implant, including 5 cases of unstable implant at 3 years with 2 due to periprosthetic joint fracture (Fig. 5).

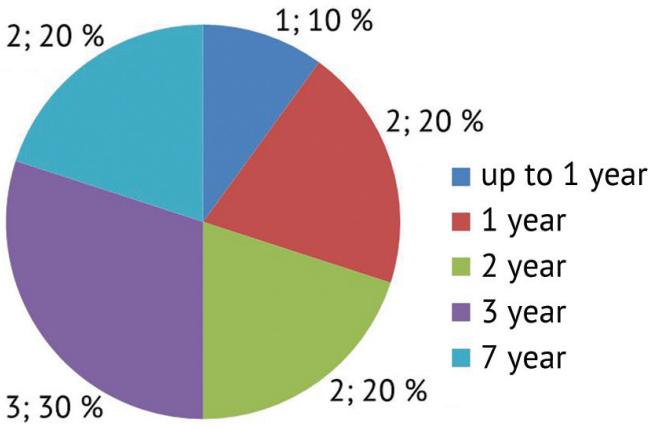


Fig. 5 Cases of aseptic instability of SBI D.G.T. PIP joint implant developed at various follow-up periods

No infectious complications were noted in the three groups throughout the observation period. The DASH score was measure in 64 patients at a long term (Table 5). Two patients with the SBI D.G.T. PIP joint implant were unavailable follow-up due to changed contact details. Patients with unconstrained Moje ACAMO PIP ceramic implant demonstrated the best score of 14.2. The maximum ROM achieved (on average 48°) at the follow-up stage was also observed in patients with unconstrained implantation.

Table 5

Outcomes of PIP joint replacement assessed on the DASH (The Disabilities of the Arm, Shoulder and Hand) scale

Type of implant	Postoperative DASH score		
		pre-op	at the follow-up stage
SBI D.G.T. PIP joint implant	*M* ± *m*	29.7 ± 1.3	19.5 ± 3.7
	p	–	0.00000*
RM Finger (Mathys)	*M* ± *m*	29.6 ± 1.7	17.4 ± 6.2
	p	–	0.00015*
Moje ACAMO PIP	*M* ± *m*	30.3 ± 1.3	14.2 ± 5.0
	p	–	0.00000*

* as compared to pre-op value

The effectiveness of the operation was statistically confirmed ($p < 0.05$) for all types of implants. The changes in the three parameters (p value) was more evident in the group of Moje ACAMO PIP implants as compared to other implant models with a greater ROM and subjective criteria measured with the DASH score.

DISCUSSION

Normal biomechanics of the joint is essential for a full functional range of motion. The implant is aimed at restoring the center of rotation of the joint maintaining the anatomical distances between the muscles and tendons of the finger [16–18]. Understanding the anatomy, biomechanics, physiology of the hand and its components is the key to success in the comprehensive restoration of the function and improvement of the quality of life [3, 19, 20]. Despite advances in materials and new implant designs proximal interphalangeal joint replacement remains an unsolved biomechanical problem, [21, 22]. The goals of the operation are to reduce pain, increase range of motion, restore the biological axis of the fingers and improve the function [23, 24]. Various surgical approaches depending on the needs and experience of the surgeon are used to replace the proximal interphalangeal joint of the hand, [25, 26]. We normally use dorsal access in our practice. Literature review showed no statistical differences in postoperative range of motion, complication rates, or the number of revision surgeries between palmar and dorsal approaches in proximal interphalangeal joint arthroplasty [27, 28]. The operations were performed under general anesthesia with use of a tourniquet. Advantages of local anesthesia with the procedures have been reported in recent publications without the use of a tourniquet and can be used in the future [29–32]. No scientific papers describing the results of clinical use of the SBI D.G.T. PIP joint implant could be found. The search was performed with use of GoogleScholar, PubMed, eLIBRARY, PubMedCentral in Russian and English using the keywords “replacement of the proximal interphalangeal joint”, “arthrodesis of the proximal interphalangeal joint”, “osteoarthritis of the proximal interphalangeal joint”. There were no papers reporting SBI D.G.T. PIP joint implant. In our series, patients reported an improvement from preoperative 29.7 ± 1.3 DASH score to postoperative 19.5 ± 3.7 DASH score. Radiological examination indicated to 10 cases of aseptic instability of the implant of the 50 identified with poor outcomes registered in 20 %.

J.P. Rijnja et al. performed a retrospective study of the RM Finger arthroplasty (Mathys) and concluded that proximal interphalangeal joint arthroplasty could restore joint stability, improve range of motion and pain with a high complication rate [33]. There were no complications in our

series with the use of this model of implant. A. Middleton et al. did not recommend the RM Finger implant (Mathys) for replacement of the proximal interphalangeal joint, in cases of rheumatoid arthritis, in particular [34]. M.I. Muradov et al. reported 82 % of satisfactory long-term results with replacmeent of small joints of the hand using MOJE kermik-implantate were with the range of motion increased in the prosthetic joint from preoperative 16º to 59º at 6 months and 73º at 1 year [35]. The best results in our series were obtained with ceramic implants with the range of motion restored in the joint to 48.0 ± 30.0º at the follow-up. The advantages of the study include comparative assessment of the replacements depending on the type of implant used. A limitation of the study included a small number of observations, which requires further study of the problem with the possibility of applying the results in clinical practice.

CONCLUSION

Long-term results of replacement of the proximal interphalangeal joint of the hand using various types of implants showed improvement in the mobility of the upper limb, pain and the appearance of the segment due to subjective functional improvement. Non-constrained implants anatomically imitate the articular surfaces of the finger joints with the loading provided by the finger's ligamentous apparatus. Non-constrained ceramic implants having optimal biocompatibility with the bone facilitated maintaining or increasing the range of motion in the interphalangeal joint. No case of joint instability was identified with their use. Although effective procedure was statistically confirmed with all types of implants ($p < 0.05$) the reliability of changes (p) was more pronounced for all parameters with use of non-constrained Moje ACAMO PIP implants as compared to constrained types.

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Original article

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Non-obvious and obvious signs of the thoracic spine pathology: a clinical study

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Abstract

Background The thoracic spine pathology can lead to severe disability and discomfort.

This study aims to identify determinant characteristics in patients with thoracic spine pathologies who present with non-regional complaints such as lumbar/cervical pain and others.

Methods A prospective observational descriptive study was conducted at Basrah Teaching Hospital from March 2020 to December 2021, enrolling 114 patients categorized into two groups. Group A included patients with thoracic spine pathology and thoracic pain, while Group B consisted of patients with thoracic spine pathology and non-local symptoms (such as lower lumbar pain, pain in extremities, etc.). Comprehensive clinical evaluations were performed using a specially designed questionnaire.

Results The majority of patients were in the 60-79 age group, with females comprising 55 % in Group A and 60 % in Group B. Smoking was observed in 28.98 % of Group A and 26.66 % of Group B. Symptomatic patients with solitary back pain commonly exhibited dorsal root compression symptoms (49.27 %), lower limb weakness (18.84 %), and sphincter dysfunction (7.24 %). Patients with thoracic plus lower and/or neck pain frequently reported paraesthesia (42.22 %) and cervical root symptoms (48.38 %). Kyphotic deformity was present in 20.28 % of Group A and 11.11 % of Group B, while tenderness was observed in 23.18 % of Group A and 13.33 % of Group B. Plain radiograph changes, including disk space narrowing (44.44 %), subchondral sclerosis (29.63 %), curve alterations (29.63 %), and facet arthropathy (25.9 %), were more prevalent in those with symptomatic thoracic back pain (Group A).

Conclusion Non-local symptoms in thoracic spine pathologies are common, with complicated and multi-site low back pain being more prevalent than isolated back or thoracic pain. Elderly individuals, females, obesity, and comorbidities appear to be predictive risk factors for low back pain development. Paraesthesia emerges as the most common neurological manifestation, while kyphosis and scoliosis are primary presentations of thoracic pathologies. Multi-modalities of imaging, including plain radiographs, MRI, CT scan, and DEXA scan, can aid in detecting back pathologies. The mainstay of managing symptomatic thoracic pathologies is surgical intervention.

Keywords: spinal pathology, thoracic spine, symptomatic thoracic pathology, spinal deformity

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INTRODUCTION

The thoracic spine, while often overlooked, plays a crucial role in the vertebral column. Afflictions of the thoracic spine can lead to significant disability and pain, exacerbated by its inherent stiffness due to structural disparities when compared to the cervical and lumbar spine [1]. This region is susceptible to a spectrum of conditions, including inflammatory, degenerative, metabolic, infective, and neoplastic, all of which contribute to pain and disability [2]. The concept of 'regional interdependence' elucidates the interrelation wherein seemingly unrelated impairments in one anatomical region can influence the development or persistence of pain in another [3].

Although thoracic intervertebral discs and facet joints can act as pain generators, thoracic radicular pain is uncommon. Similar to the lumbar spine, degenerative changes visualized in thoracic spine imaging may not necessarily correlate with pain, highlighting the prevalence of non-specific thoracic spine pathology [4]. Therefore, it is imperative to scrutinize the reliability of clinical methods for thoracic spine evaluation.

Pathological afflictions impacting the thoracic spine encompass osteoporotic fractures (most prevalent), spinal tumors, thoracic spinal canal stenosis, vertebral osteomyelitis, tuberculosis, lateral recess stenosis, and arthritis [5–11]. Radiological imaging, including X-ray (revealing disc space narrowing, subchondral sclerosis, curve changes, and facet arthropathy), MRI (detecting disc abnormalities, bony changes, dura, or other anomalies), and CT scans (evaluating disc condition, canal size, osteophytes, and other factors), along with electrical impulse testing such as EMG to assess nerve function, provide comprehensive insights [12].

This study endeavours to uncover potential determinants and characteristics of thoracic spine pathologies, exploring patient and pathology specifications along with their outcomes. By delving into these aspects, we aim to enhance our understanding of this often-neglected region, paving the way for more effective clinical evaluation and management strategies.

METHODS

Study Design: A prospective observational descriptive study was conducted at Basrah Teaching Hospital from March 2020 to December 2021. A total of 114 patients were enrolled and categorized into two groups.

Study Population and Sampling:

Group A: Comprising 69 patients with chronic thoracic pain attributed to thoracic spine pathologies, confirmed through clinical and radiological examinations, irrespective of complaint duration.

Group B: Consisting of 45 patients presenting non-regional extra-thoracic symptoms (lumbar, cervical, etc.) subsequently diagnosed with thoracic spine pathologies.

Exclusion Criteria:

- Patients with acute traumatic back pain were excluded from the study (They were insignificant findings).
- Patients with organic pathology of the lumbar and cervical spine visible on MRI or CT or RG were also excluded.
- Patients with chronic medical conditions that may cause pain or numbness, such as anaemia, vitamin B deficiency or neuromuscular disease, should also be excluded.

Ethical Committee:

Approval from the Basrah Health Directorate and the scientific research ethical committee of the scientific council of the Arabic Board of Orthopaedics was obtained prior to data collection.

Clinical Evaluation:

Each patient underwent a comprehensive clinical assessment, including a medical history, comorbidity evaluation, and BMI calculation using the formula (kg/m^2).

Follow-up of Patients:

Selected cases requiring surgery underwent monitoring during hospitalization, detailing procedures, surgeries, and treatments. Monthly visits over six months included updated history, examinations, and investigations.

Data Collection:

Information was gathered using a meticulously designed questionnaire with three essential sections:

1. Socio-demographical characteristics (name, age, gender, BMI, occupation, and address).

2. Patient history and examination related to the complaint.

3. Subsequent investigations and applied managements.

History:

Patient complaints were thoroughly analyzed, considering pain characteristics (site, onset, radiation, aggravating and relieving factors). Full medical and surgical histories covered chronic illnesses, social history, and relevant habits (smoking, alcohol and sports).

By employing this comprehensive approach, the study aimed to not only identify determinant characteristics but also establish a robust foundation for understanding and managing thoracic spine pathologies.

Investigations

Laboratory tests included hematological tests (Complete Blood Count), biochemical tests (glycosylated hemoglobin (HbA1c), estimated sedimentation rate (ESR), and C-reactive protein (CRP)).

Imaging studies included **X-rays** (narrowing of the disc space, subchondral sclerosis, curve changes, and facet arthropathy), **MRI** (disc abnormality, bony changes, dura, and cord, or others), **CT-scan** (disc, size of the canal, osteophytes, and others), and **DEXA-scan**.

Statistical analysis

Statistical calculations were done using Statistical Package for the Social Sciences version 25 (SPSS Inc.) in which categorical data were expressed as numbers and percentages, the differences between the groups were analyzed using the Chi-square test (X^2). Adjusted standardized residuals were used to explore which variable is considered a contributor to the chi-square results (> 3 adjusted standardized residuals). Continuous data expressed as mean ± SD and the differences between the groups were analysed by non-parametric Kruskal – Wallis H test for abnormally distributed data and ANOVA test for normally distributed data. Shapiro – Wilk test was used to test the normality of the data, and outliers were detected using Boxplot methods. Confidence intervals of 95 % were applied as the dependent interval in statistics and *P*-values < 0.05 were accepted as statistically significant.

RESULTS

Among sixty-nine patients in Group A (60.52 %), 27 (39.13. %) had isolated thoracic back pain and 42 (60.86 %) presented with thoracic plus other symptoms (lower back pain and/or neck pain). Group B consisted of 45 (39.47 %) of the enrolled patients and 31 subjects (68.88 %) presented with lower back pain and/or neck pain. Most of the patients in both groups were in the age group of 60–79 years. Females were predominant in both groups. Besides, most of the patients from groups A and B were recorded as overweight or obese. In addition, in both groups, there were slightly more unemployed than employed. Regarding the medical, surgical, and social characteristics, both groups shared close results in the incidence of diabetes, hypertension, hyperlipidemia, Sickler cell disease, and renal disease. There was a significant difference in diabetes cases between group A and group B ($p = 0.047$) (Table 1).

Table 1

Comparison between group A and group B regarding the demographical parameters

Variables		Group A (*n* = 69)		Group B (*n* = 45)		*P* value
		Thoracic back pain (*n* = 27)	Thoracic + Lower back pain and/or Neck pain (*n* = 42)	Lower back pain and/or Neck pain (*n* = 31)	Other symptoms (*n* = 14)	
		No.				
Age (years)	< 20 years	2	1	1	0	0.245
	20–39	3	4	2	3	0.35
	40–59	7	12	9	4	0.124
	60–79	10	17	15	4	0.75
	⩾ 80	5	8	4	3	0.057
Gender	Male	11	20	13	5	0.68
	Female	16	22	18	9	
BMI (kg/m^2)	Normal weight	7	12	8	2	0.87
	Overweight	12	19	13	5	0.23
	Obese	8	11	10	7	0.48
Occupation	Employee	12	15	13	6	0.17
	Non-employee	15	27	17	8	0.59
Medical history	Diabetes mellitus	10	18	14	4	0.047
	Sickle cell anemia	2	1	3	1	0.24
	Renal disease	2	1	3	0	0.421
	Hypertension	11	10	9	2	0.64
	Hyperlipidemia	9	11	9	2	0.15
Surgical history	Previous surgery	3	5	3	1	0.78
	Previous trauma	0	7	2	1	0.98
Social history	Smoking	8	12	9	3	0.365
	Alcohol	1	0	1	0	0.27
	Active sport habit	2	4	3	1	0.25

Neurological evaluation Group A patients mostly presented with paraesthesia along the distribution of radicular nerve 34 (49.27 %), and dorsal root symptoms 17 (56.34 %). Nineteen out of 45 (42.22 %) of group B had paraesthesia which was significantly lower than that found in the group A ($p = 0.009$). Cervical root pain found in 8 (19.04 %) cases of group A and 6 (23.27 %) cases of group B. Weakness of the lower limb was reported by 13 (18.84 %) in group A and 5 (11.11 %) in group B. The urinary and stool sphincters uncontrolled reported by 5 subjects (7.24 %) of group A and 3 (6.66 %) of group B (Table 2).

Table 2

Comparison between group A and group B regarding the neurological evaluation

Neurological evaluation	Group A (*n* = 69)		Group B (*n* = 45)		*P* value
	Thoracic back pain (*n* = 27)	Thoracic + Lower back pain and/or Neck pain (*n* = 42)	Lower back pain and/or Neck pain (*n* = 31)	Other symptoms (*n* = 14)	
	No.				
Paresthesia	12	22	15	4	0.009
Cervical root	0	8	5	1	0.078
Dorsal root	12	5	3	0	0.82
Lumbosacral root	0	9	7	3	0.091
Lower limb weakness	6	7	4	1	0.26
Sphincter uncontrolled	2	3	2	1	0.054

The examination results of patients with thoracic pathologies reveal that group A presented mostly with kyphosis in 14 (20.28 %) and scoliosis in 5 (7.24 %) while group B in 5 (11.11 %) and 1 (2.22 %), respectively.

We felt tenderness in 16 subjects (23.18 %) of group A and 6 (13.33 %) of group B. There were 30 (43.47 %) of group A with a limited range of motion of the thoracic spine and 19 (42.22 %) of group B.

Hyperreflexia of the upper limb was found in 1 (1.44 %) in group A and 1 (2.22 %) in group B. Hyperreflexia of lower limbs was found in 12 (17.39 %) of group A and 6 (8.88 %) of group B. There were 3 (4.34 %) cases of spastic gait in group A and one case (2.22 %) in group B. (Table 3).

Table 3

Comparison between group A and group B regarding the examination parameters of the thoracic spine

Variables		Group A (*n* = 69)		Group B (*n* = 45)		*P* value
		Thoracic back pain (*n* = 27)	Thoracic + Lower back pain and/ or Neck pain (*n* = 42)	Lower back pain and/ or Neck pain (*n* = 31)	Other symptoms (*n* = 14)	
		No.				
Look	Kyphosis	6	8	4	1	0.078
	Scoliosis	2	3	1	0	0.68
	Mass	0	1	1	0	0.58
	Ulcer skin lesion	0	1	1	0	0.245
	Rash skin lesion	0	1	0	0	0.35
Feel	Tenderness	9	7	5	1	0.18
Move	Limited range of spine motion	10	20	13	6	0.65
Reflexes	Lower limb Hyperreflexia	5	7	4	2	0.65
Spastic gait		1	2	1	0	0.14

Complete blood count, HbA1c, and ESR were recorded higher values among group B compared to others, while CRP recorded higher results mostly among group A, which was statistically non-significant ($p > 0.05$) (Table 4).

Table 4

Comparison between group A and group B regarding the laboratory parameters

Parameters	Group A (*n* = 69)		Group B (*n* = 45)		*P* value
	Thoracic back pain (*n* = 27)	Thoracic + Lower back pain and/or Neck pain (*n* = 42)	Lower back pain and/ or Neck pain (*n* = 31)	Other symptoms (*n* = 14)	
	Mean ± SD				
CBC	10.32 ± 1.47	9.84 ± 1.21	10.87 ± 0.92	10.2 ± 1.13	0.541
HbA1c	8.56 ± 2.7	7.53 ± 1.62	9.82 ± 2.96	7.89 ± 1.8	0.068
ESR	37.68 ± 7.42	42.28 ± 5.36	46.52 ± 7.9	35.34 ± 6.8	0.059
C-reactive protein	8.72 ± 3.7	9.59 ± 3.45	8.98 ± 3.18	8.56 ± 2.61	0.47
Hypercholesterolemia	270.29 ± 50.67	279.67 ± 54.98	260.72 ± 42.31	254.39 ± 70.21	0.098
Hypertriglyceridemia	280.7 ± 40.36	285.3 ± 65.47	290.74 ± 62.15	289.47 ± 36.25	0.074

Plain radiograph changes including narrowing of disk space in 28 (40.5 %), subchondral sclerosis in 19 (27.5 %), curve change in 19 (27.5 %), and facet arthropathy in 17 (24.6 %) were registered in group A. In group B, the narrowing of disk space was found in 14 (31.11 %), subchondral sclerosis in 9 (20 %), curve change in 6 (13.33 %), and facet arthropathy in 7 (15.6 %).

MRI changes in group A included disc abnormality in 20 cases and bony changes in 16 cases. Cord and dural pathology were found in two patients and primary bone tumor in one patient. Additionally, there was metastasis in 3 (4.3 %) cases and Pott's disease in 4 (5.7 %) cases. In group B, there were 2 (4.44 %) metastatic cases and 2 cases (4.44 %) of Pott's disease.

In CT scans, the canal stenosis was found in 3 patients for each group. Primary thoracic bone tumors were reported in one patient in group B (giant cell tumor) and one case in group A (osteoid osteoma). The osteophytes were recorded in 19 patients in group A and 9 patients in group B. Osteomyelitis and discitis were recorded in 2 (4.34 %) cases in group A. Spine TB was found in 3 patients in group A and 2 patients in group B.

DEXA scans were performed in 25 cases in group A and 24 patients in group B, revealing that osteopenia presented in group A in 12 (17.4 %), whereas in group B, there were 7 (15.5 %) cases. Osteoporosis was recorded mostly in group A in 15 cases (21.7 %) and only 6 subjects of group B (13.3 %), but the findings were statistically not significant ($p > 0.05$) (Table 5).

Table 5

Comparison between group A and group B regarding the radiological parameters

Parameters		Group A (*n* = 69)		Group B (*n* = 45)		*P* value
		Thoracic back pain (*n* = 27)	Thoracic + Lower back pain and/or Neck pain (*n* = 42)	Lower back pain and/or Neck pain (*n* = 31)	Other symptoms (*n* = 14)	
		No.				
Plain X-ray	Narrowing of disk space	12	16	9	5	0.25
	Subchondral sclerosis	8	11	6	3	0.64
	Curve change	8	11	5	1	0.09
	Facet arthropathy	7	10	5	2	0.07
MRI	Disc abnormality	8	12	9	2	0.21
	Bony changes	7	9	8	1	0.2
	Cord and Dural pathology	1	1	0	2	0.35
	Primary bone tumor	0	1	0	1	0.08
	Metastatic disease	1	2	1	1	0.056
	Spinal TB	1	3	1	1	0.59
CT	Canal Stenosis	1	2	2	1	0.08
	Osteophyte	7	12	6	3	0.12
	Dural calcification	2	1	1	0	0.21
	Osteomyelitis and discitis	1	1	0	0	0.23
	TB spine	1	2	1	1	0.45
	Primary thoracic bone tumor	0	1	0	1	0.87
	Metastatic disease	1	2	1	1	0.61
DEXA	Osteopenia	5	7	5	2	0.058
	Osteoporosis	7	8	4	2	0.08

The metastasis was found in 3 cases of group A and 2 cases in group B. Intradural extramedullary tumor percentage was (2.22 %) in group B (meningioma). Intradural intramedullary tumor percentage was (2.89 %) in group A and (2.22 %) in group B. Spine TB recorded in 3 cases in group A and 2 cases in group B. Discitis and osteomyelitis were found in 2 (2.89 %) of group A. Degenerative changes were reported in 59 (85.5 %) cases of group A and 38 (84.4 %) cases of group B (Table 6).

Regarding surgical versus nonoperative management, all metastasis cases were treated by chemotherapy and radiation. One case underwent spine decompression. In intradural mass, all cases underwent laminectomy. Three patients with TB underwent surgery (two in group A and one in group B). Two cases of osteomyelitis and discitis in group A underwent drainage operation. Two patients with primary bone tumors underwent laminectomy. All degenerative cases were managed conservatively (Table 7).

Table 6

Comparison between Group A and Group B regarding the pathology diagnosis

Variables		Group A (*n* = 69)		Group B (*n* = 45)		*P* value
		Thoracic back pain (*n* = 27)	Thoracic + Lower back pain and/or Neck pain (*n* = 42)	Lower back pain and/or Neck pain (*n* = 31)	Other symptoms (*n* = 14)	
		No.				
Metastasis		1	2	1	1	0.59
Intradural extramedullary		0	0	0	1	0.098
Intradural intramedullary		1	1	0	1	0.08
TB, spine		1	2	1	1	0.12
Diskitis and osteomyelitis		1	1	0	0	0.23
Primary bone tumor		0	1	0	1	0.45
Degenerative changes	Degenerative disk disease	2	2	2	4	0.87
	Facet joint disease	10	14	11	3	0.61
	Spinal stenosis	2	1	0	1	0.45
	Spondylosis	9	19	16	1	0.59

Table 7

Comparison between Group A and Group B regarding the management non operative vs. surgery

Surgery	Group A (*n* = 69)		Group B (*n* = 45)		*P* value
	Thoracic back pain (n = 27)	Thoracic + Lower back pain and/or Neck pain (*n* = 42)	Lower back pain and/or Neck pain (*n* = 31)	Other symptoms (*n* = 14)	
	n (%)				
Metastasis	0	1	0	0	0.062
Intradural extramedullary	0	0	0	1	0.08
Intradural intramedullary	1	1	0	1	0.59
Spinal TB	1	1	0	1	0.074
Discitis and osteomyelitis	1	1	0	0	0.059
Herniated disk	None				
Primary bone tumor	0	1	0	1	0.098
Bulging disk	None				
Facet joint disease	None				
Spinal stenosis	None				

DISCUSSION

The clinical and epidemiologic exploration of the thoracic spine has been comparatively neglected when juxtaposed with the lumbar and cervical spine. However, our study underscores the substantial impact of thoracic spine pathology on individuals, with pain in this region proving equally disabling and burdensome.

Goh et al. delved into the influence of age and gender on thoracic spine degenerative disease, revealing an age-related increase in abnormal findings, particularly in the mid- and lower thoracic discs [13]. In our study, age and gender significantly affected the prevalence of thoracic spine pain in Group A, aligning with the trend of lesions presenting more commonly in the elderly. Conversely, a meta-analysis reported a higher prevalence of thoracic pain in young ages and children, attributing it to factors like school bag usage and workstations [14]. This is explained by risen the abnormal annuli, nuclei and disc margins in elderly age group, particularly in the mid and lower thoracic discs [13].

Briggs et al. [14] found thoracic spine pain was significantly related to concurrent musculoskeletal pain; backpack; postural; lifestyle and social; psychological and environmental and growth and physical factors. Besides, the risk factors identified in adolescents included age (being older) and poorer mental health [14].

Our findings indicate a higher prevalence of thoracic pain among females in group A, consistent with general reports on musculoskeletal pain across different age groups [15, 16]. Exploring the reasons behind these gender-based disparities, including factors like physical activity, musculoskeletal maturity, posture, endocrine and psychosocial characteristics, warrants further investigation [17]. There are no significant differences between the groups according to your statistical analysis.

While the study suggests a higher prevalence of thoracic pain among females, attributing it to various factors like hormonal changes, pregnancy, menarche, menopauses, hormonal therapy and contraceptive pills and devices, the nuances of gender-based differences in the experience of thoracic pain might be more complex and require further exploration.

Roquelaure et al. [23] found that the incidence of thoracic spine pain (TSP) was 5.2 / 100 men and 10.0 / 100 women. TSP in men was associated with age, being tall, frequent/sustained trunk bending, lack of recovery period or change in the task and driving vehicles. Being overweight or obese was associated with lower risk (OR = 0.5). TSP in women was associated with high perceived physical workload. They concluded the TSP risk model combined personal and work-related organizational and physical factors. Trunk bending appeared to be a strong independent predictor of pain.

Smoking emerged as a potential risk factor, influencing vertebral cellular changes and exacerbating degenerative alterations. The study data align with previous findings highlighting the injurious effects of nicotine on nucleus pulposus cells and osteoblasts [18, 19]. Smoking habits were notably more prevalent in patients with dorsal back pain (group A) and lower neck pain (group B). There are no significant differences between the groups according to our analysis and we suggest further studies at cell levels to prove the relationship between smoking and spine injuries. We suggest a non-significant association between smoking and thoracic spine pathologies, citing influences on cell changes. Meanwhile, there is evidence linking smoking to general health issues.

Neurological manifestations in the thoracic spine present a unique challenge due to the multifaceted nature of thoracic myelopathy. Our study corroborates the association between back pain and neurological symptoms, with dorsal root compression symptoms, limb weakness, and sphincter dysfunction observed in group A, and paraesthesia and cervical root symptoms more prevalent in group B. There are statistical significant differences between the groups according the frequency of paraesthesias ($P = 0.009$).

The incidence of thoracic disc herniation, though rare, was higher in group B than in group A. Conservative management was predominantly employed, aligning with literature suggesting comparable outcomes to surgical interventions in mid-term and long-term follow-up [42]. The treatment approach for thoracic disc herniation may vary, and the decision between conservative and surgical management should be based on the individual case and its specific characteristics.

Other pathologies like tumors, infections and degenerative lesions have no significant differences between groups of the present study. Pathological conditions like spinal tumors, infections, and degenerative diseases were diverse, demonstrating the complexity of thoracic spine pathologies. Surgical interventions emerged as the primary management approach for symptomatic cases, consistent with studies emphasizing the efficacy of surgery in specific conditions such as spinal tuberculosis [34].

CONCLUSION

Non-local symptoms in thoracic spine pathologies are common, with complicated and multi-site low back pain being more prevalent than isolated back or thoracic pain. Elderly individuals, females, obesity, and comorbidities appear to be predictive risk factors for low back pain development. Paraesthesia emerges as the most common neurological manifestation, while kyphosis and scoliosis are primary presentations of thoracic pathologies. Multi-modalities of imaging, including plain radiographs, MRI, CT scan, and DEXA scan, can aid in detecting spine pathologies. The mainstay of managing symptomatic thoracic pathologies is surgical intervention.

Conflict of interests None.

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Evaluation of the effectiveness of ankle arthrodesis options

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Abstract

Introduction Treatment methods for late stages of ankle osteoarthritis are varied, but the issue of assessing the long-term results of various fixation methods has not yet been studied, and this issue is of great importance in clinical practice.

Purpose To compare the effectiveness of the fixation methods commonly used for ankle arthrodesis in patients with advanced ankle osteoarthritis.

Materials and methods Eighty-two patients with advanced ankle osteoarthritis were treated with ankle fusion between 2019 and 2023 at three major medical institutions. All patients underwent 12-month follow-ups. The patients were divided into four groups depending on the method of surgical fixation of bone fragments.

Results Most patients showed a significant improvement in the function and a decrease in pain intensity after the arthrodesis operation. The comparison of the effectiveness of various surgical fixation methods found that external apparatus screw fixation is characterized by lower blood loss and a relatively short duration of the operation. Plate and screw fixation resulted in higher AOFAS and VAS scores at 3 months postoperatively. However, by the 12th month after surgery, the differences in these two indicators were insignificant.

Discussion Despite the various complications that occur in ankle arthrodesis, it remains effective for most patients. Among them, the Ilizarov apparatus is more suitable for patients with compromised conditions in the surgical area. Each method of surgical fixation has its own advantages and shortcomings, but the difference in long-term effectiveness is small.

Conclusion Ankle arthrodesis is an effective treatment for advanced ankle osteoarthritis. The choice of surgical method is still subject to the principle of individual approach.

Keywords: ankle arthrodesis, apparatus of external fixation, screw, plate, intramedullary nail, osteoarthritis

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INTRODUCTION

Osteoarthritis (OA) affects 7 % of the world population that is more than 500 million people [1, 2]. In turn, ankle joint OA accounts for up to 1 % [3–5], and it can be classified into primary and secondary, depending on the etiology of the primary pathology. The causes of secondary osteoarthritis of the ankle joint (SOA) include trauma, rheumatoid arthritis, osteonecrosis of the talus, failed surgical interventions, anatomical deformity, and others [6, 7], and post-traumatic osteoarthritis is the most common cause of the development of pathology. It constitutes up to 78 % [8, 9].

The main treatments of late stage osteoarthritis are mainly arthroplasty or arthrodesis of the joint [5, 10–12].

Ankle arthroplasty has not become widespread yet [13], although its use in numbers has been growing over the years [13, 14]. In contrast, ankle arthrodesis has been considered the "gold standard" for the treatment of late OA stages since its development in 1879 to the present day [9, 11, 12, 15, 16].

Despite ankle arthrodesis is quite well established scientists and clinicians still face numerous problems in their practical work. Thus, the optimal fixation method for this type of surgery is controversial [3, 11, 16, 17, 18].

To date, more than 40 surgical methods for performing arthrodesis have been developed [11, 15, 16]. The most common of them are classified according to the type of surgical fixation, which includes external and internal (screws, pins, plates or intramedullary pins) means [8–11, 16, 17, 19].

The team of authors had the opportunity and need to compare the effectiveness of the four most common fixation methods using a multicenter open prospective cohort study.

Purpose To compare the effectiveness of the fixation methods commonly used for ankle arthrodesis in patients with advanced ankle osteoarthritis.

MATERIALS AND METHODS

The study was approved by the regional ethics committee, and informed consent was obtained from all participating patients.

The study included 82 patients (34 men and 48 women, mean age 55.57 ± 11.85 years) with late stages of osteoarthritis of the ankle joint, who underwent arthrodesis in three large medical institutions in Wuhan (China) and Kazan (Russia) from 2019 to 2023

The patients were divided into four groups according to the method of fone fragment fixation during the ankle joint arthrodesis procedure:

— External fixation (EF) group: 21 patients (9 men and 12 women, mean age 59.05 ± 5.93 years), arthrodesis of the joint joint was performed with the Ilizarov apparatus (IA);

— Screw fixation (SF) group: 23 patients (8 men and 15 women, mean age 54.22 ± 10.30 years), arthrodesis of the joint was performed with screws;

— Plate fixation (PF) group: 20 patients (9 men and 11 women, mean age 55.10 ± 15.76 years), arthrodesis of the ankle joint was performed with plates;

— Intramedullary fixation group (IMF): 18 patients (8 men and 10 women, mean age 53.78 ± 13.83 years), joint arthrodesis was performed using IM pins.

It should be especially noted that in the AEF group, there were 11 patients with rheumatoid arthritis, three with gouty arthritis and one with post-infectious osteoarthritis. These categories are often considered unsuitable for fixation types other than AEF due to compromised skin or bone in the surgical site [4, 11, 17].

The comparison of the basic data of the patient groups (gender, target limb, age, BMI, stage of osteoarthritis) found that the differences were insignificant (Table 1).

Table 1

Basic patients' information

Parameter		AEF group (n = 21)	SF group (n = 23)	PF group (n = 20)	IMF group (n = 18)	p
Age		59.05 ± 5.93	54.22 ± 10.30	55.10 ± 15.76	53.78 ± 13.83	0.47
BMI		26.73 ± 3.05	24.77 ± 3.61	25.68 ± 3.10	26.09 ± 4.76	0.35
Males	n	9	8	9	8	0.89
	%	43	35	45	44	
Females	n	12	15	11	10	
	%	57	65	55	56	
Involved limb, left	n	8	11	11	8	0.75
	%	38	48	55	44	
Involved limb, right	n	13	12	9	10	
	%	62	52	45	56	
OA stage IIIb	n	9	14	14	11	0.35
	%	43	61	70	61	
OA stage IV	n	12	9	6	7	
	%	57	39	30	39	

Surgical technologies

The choice of surgical approach and fixation method depends on the stage of ankle OA stage, deformity, as well as on the personal preferences of the surgeon.

In cases with the lesion in the tibiotalar joint, the medial malleolus was not involved in the pathological process or the lesion was mild, and the condition of the skin on the lateral malleolus and the overall alignment of the ankle joint were assessed as satisfactory, a lateral approach was used. A longitudinal incision of 10–15 cm was made along the projection of the lateral malleolus, its apex, 2 cm lower.

The anterior approach was used in cases if surgical treatment required approach to both the medial and lateral malleolus. It passed between the tibialis anterior tendon and the extensor of the great toe.

If the skin condition of the anterior joint surface was compromised, a paired approach was chosen: lateral approach + small medial incision. The first incision was between the extensor longus of the great toe and the tibialis anterior tendon, and the second was between the peroneus tendons or the extensor digitorum longus.

Osteotomy of the fibula was used in a lateral approach and in cases with difficult reduction of the talus is difficult; the fibula was cut 6–7 cm above the ankle joint to expose its lateral surface and prepare for bone grafting.

During the operation, periarticular scars, ossifications, and remnants of cartilage were removed from the articular surfaces. Corrective osteotomies were also performed on the articular surfaces of the distal tibia and the upper part of the talus. The surfaces were leveled and filled with bone chips. Next, the ankle joint was fixed with an appropriate means chosen: Ilizarov AEF, 2–3 cannulated 3.5-mm screws, an anterior or lateral fixation plate, or a retrograde HAN nail.

The most important element in achieving ankle arthrodesis in the compromised condition of the skin and bone tissue, or signs of infection was the use of the Ilizarov AEF. The ability of extrafocal effect on the fusion of bone fragments with AEF is a great uncontested advantage, but also significantly impacts the outcome of stabilizing surgery in the area of the joint, what we observed from results of the study.

In the postoperative period, patients were treated with a short plaster cast on the lower leg and foot to immobilize the joint.

All patients are advised to use crutches and avoid weight-bearing on the target limb for 5 weeks after the operation. Limited weight-bearing began at 6 weeks and gradually progressed to full one after 3 to 6 months. During this period, the cast was changed every 3 months.

Examination of patients

All patients underwent a pre- and postoperative specialized examination, the function of the affected limb and pain were assessed using the American Society of Foot and Ankle Surgeons Scoring System (AOFAS) and Visual Analogue Pain Score (VAS) [20]. X-ray studies were used to assess the degree of preoperative state of the ankle joint and postoperative bone fusion. Postoperative complications were also recorded.

Statistical methods of processing the findings

Study data were analyzed using SPSS 26.0. Measurement parameters were presented as ($X \pm S$), and a paired t-test was used for comparison between the groups. Calculation data were expressed as rates or percentage, and the χ^2 test was used. Analysis of variance was performed with repeated measures for continuous variables. The results were considered statistically significant at $p < 0.05$.

RESULTS

The results of four different fixation methods at different time-point after surgery are presented in Figures 1 to 4.

Clinical case 1 A 60-year-old patient was admitted to the department with stage IV rheumatoid arthritis of the left ankle joint. Arthrodesis of the left ankle joint was performed with the Ilizarov AEF. Radiographs before surgery, during fixation and 3 months after surgery are presented in Figure 1.

Clinical case 2 A 58-year-old patient with stage IV post-traumatic OA of the left ankle joint underwent arthrodesis with screw fixation. Radiographs before surgery, during treatment and after 3 months post-surgery are shown in Figure 2.

Clinical case 3 A 45-year-old patient was admitted to the department with stage IIIb post-traumatic OA of the right ankle. Ankle arthrodesis with plate fixation was performed. Radiographs before surgery, 6 months and 12 months after surgery are presented in Figure 3.

Clinical case 4 A 58-year-old patient was admitted with stage IV post-traumatic right ankle OA. Arthrodesis of the ankle joint was performed with IMF nail. Radiographs before surgery, three days and 3 months after surgery are presented in Figure 4.

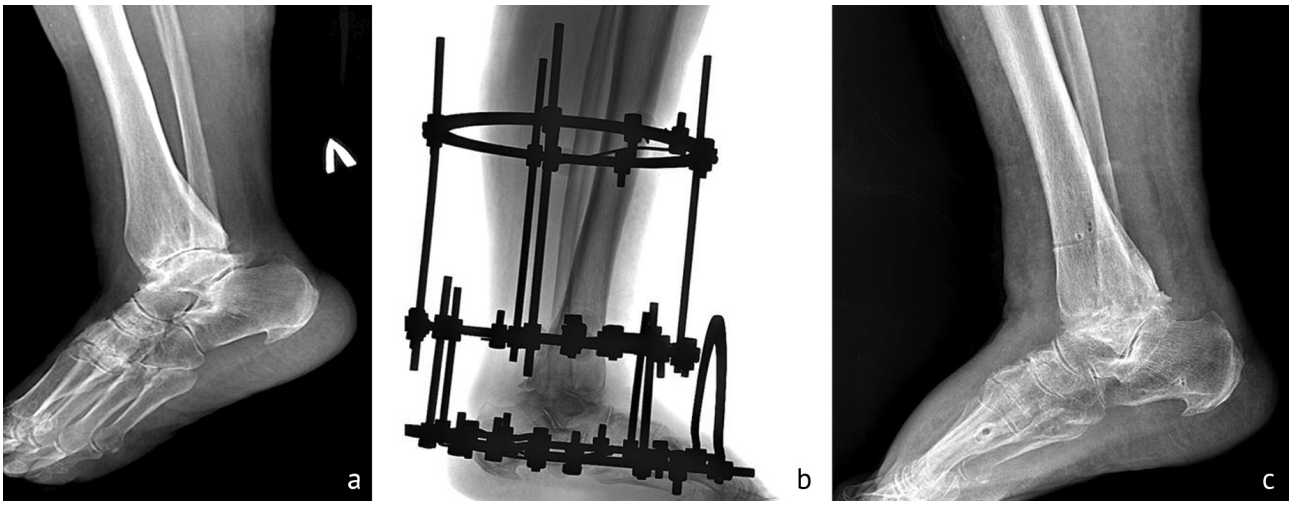

Fig. 1 Radiographs of the left ankle of a 60-year-old patient (lateral views): dynamics of the arthrodesis process with Ilizarov external fixation before surgery (*a*), 1st day after surgery (*b*), 3rd month after surgery (*c*)

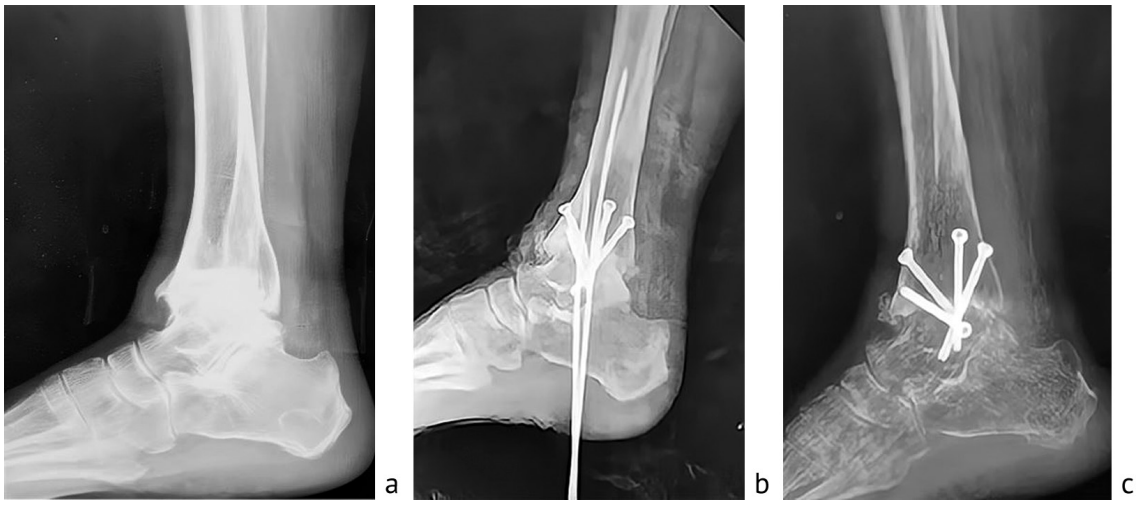

Fig. 2 Radiographs of the left ankle joint of a 58-year-old patient (lateral views); dynamics of the arthrodesis process with intraosseous cannulated screws fixation: before surgery (*a*), 1st day after surgery (*b*), 3rd month after surgery (*c*)

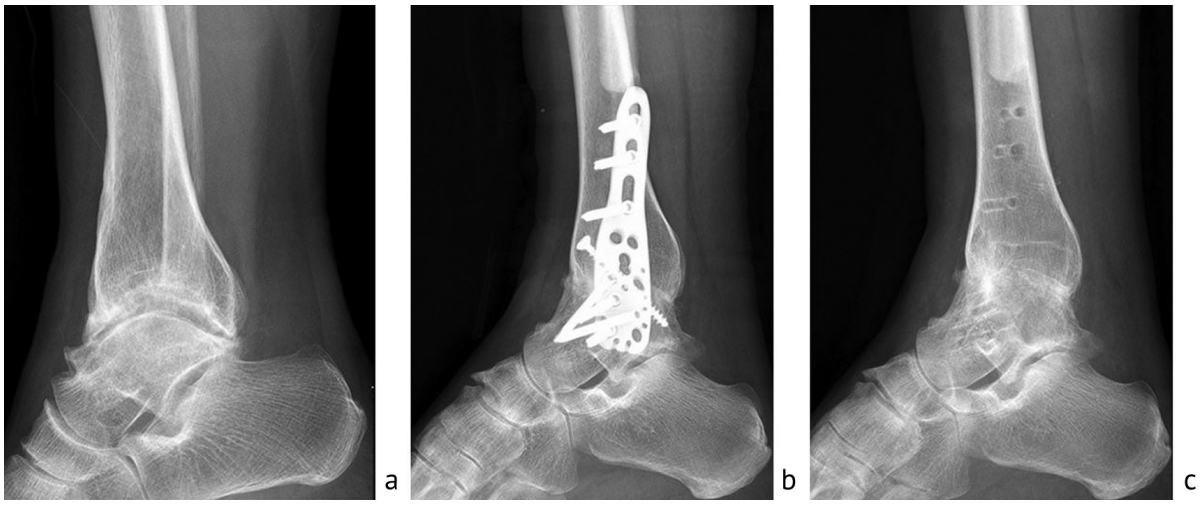

Fig. 3 Lateral radiographs of the right ankle joint in a 45-year-old patient: dynamics of the arthrodesis process with bone plate fixation and screws: before surgery (*a*);6th month after surgery (*b*); 12th month after surgery (*c*)

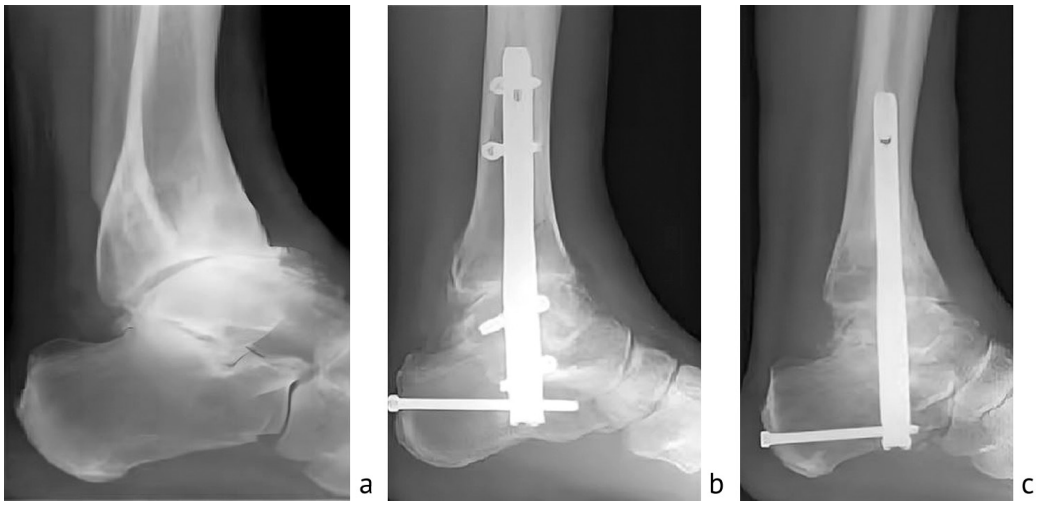

Fig. 4 Lateral radiographs of the right ankle joint in a 58-year-old patient; dynamics of the arthrodesis process with internal fixation and a retrograde locking screw: before surgery (*a*); 3rd day after surgery (*b*); 3rd month after surgery (*c*)

As a result, it was found that there was no significant difference in the volume of intraoperative blood loss between the AEF and IMF groups. Similarly, there was no significant difference in this parameter between the SF and PF groups. However, intraoperative blood loss with the first two fixation methods was significantly less than with the last two (Table 2; Fig. 5).

Table 2

Assessment of differences in the volume of intraoperative blood loss in the groups of patients with different fixation arthrodesis for arthrodesis

Method of surgical fixation	Blood loss (ml)	
EF group (*n* = 21)	118.81 ± 10.36	
SF group (*n* = 23)		125.65 ± 5.90
PF group (*n* = 20)		130.50 ± 10.38
IMF group (*n* = 18)	115.56 ± 8.73	
p	0.25	0.09

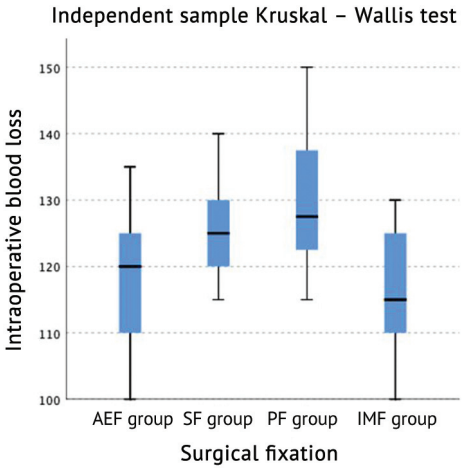

Fig. 5 Differences in the volume of intraoperative blood loss in groups of patients with different fixation options for arthrodesis

A comparative analysis of the operation duration revealed no differences between the AEF and IMF groups. Likewise, there was no significant difference in the operative time between the SF and PF groups. However, the duration of the operation was significantly less with the first two types of fixation than with the last two (Table 3; Fig. 6).

Table 3

Assessment of differences in the duration of surgery in groups of patients with different fixation options for arthrodesis

Method of surgical fixation	Duration of intervention (min)	
EF group (*n* = 21)	145.24 ± 9.15	
SF group (*n* = 23)		153.26 ± 11.04
PF group (*n* = 20)		154.25 ± 13.89
IMF group (*n* = 18)	142.50 ± 9.59	
p	0.43	0.78

Note: the significance of differences between groups was assessed using the Student – Newman – Keuls test

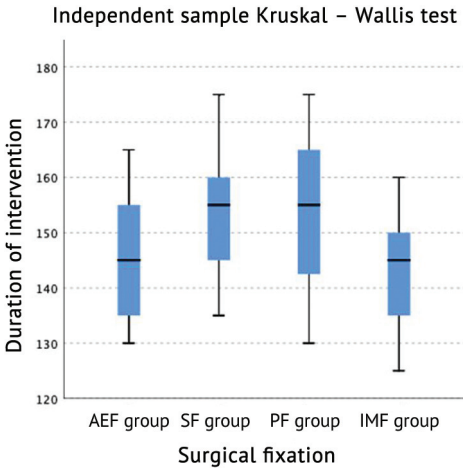

Fig. 6 Differences in the duration of the operation in groups of patients with different fixation options for arthrodesis

A comparative analysis of the dynamics of the functional state of the affected limb in groups of patients after arthrodesis revealed that 3 months after surgery, a significant difference between AOFAS scores was observed. At the same time, the maximum score was recorded in the PF group (68.95 ± 3.44 points), the minimum in Ilizarov apparatus EF group (62.67 ± 1.32 points) (Table 4).

Table 4

Comparison of the average AOFAS score in groups of patients after arthrodesis surgery

Method of surgical fixation	Average AOFAS score post-surgery			
	3 months	6 months		12 months
EF group (*n* = 21)	62.67 ± 1.32	73.48 ± 5.48		77.62 ± 6.74
SF group (*n* = 23)	66.57 ± 2.43		76.35 ± 3.42	79.91 ± 5.08
PF group (*n* = 20)	68.95 ± 3.44		77.30 ± 3.51	80.60 ± 3.73
IMF group (*n* = 18)	64.72 ± 1.32	72.94 ± 3.08		80.50 ± 3.26
p	1.00	0.67	0.45	0.23

Note: the significance of differences between groups was assessed using the Student – Newman – Keuls test

After 6 months, there was no significant difference between the mean AOFAS score in the AFF and IMF groups ($p = 0.67$). Similarly, AOFAS scores were not significantly different between the SF and PF groups ($p = 0.45$). However, the average AOFAS score in the SF and PF groups was significantly higher than in the AEF and IMF groups ($p < 0.05$) (Table 4).

Analysis of the average AOFAS score at the follow-ups did not reveal differences between the groups (Table 4). The dynamics of this parameter in all groups was unidirectional, an increase in the average score and improvement in the function of the affected limb (Fig. 7).

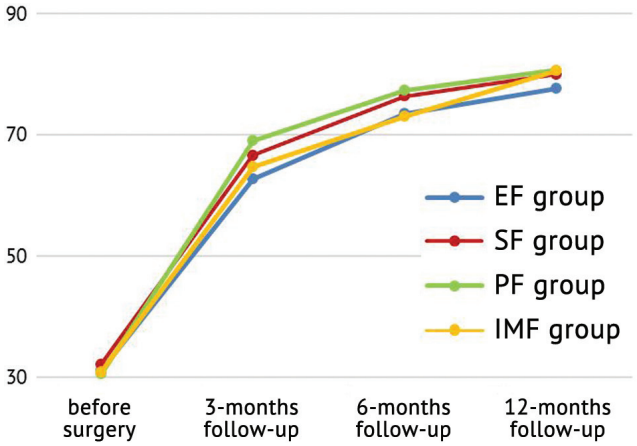

Fig. 7 Comparison of the dynamics of the average AOFAS score in groups of patients with different fixation options after arthrodesis procedure

Comparison of pain intensity in the affected joint 3 months after the intervention revealed no significant differences between the average VAS scores in the SF, PF and IMF groups. However, the AEF group had a significantly higher mean score than the other three fixation methods (Table 5).

Similar results were obtained upon re-evaluating the intensity of pain 6 months after (Table 5).

However, a comparative analysis of the final assessment of pain according to VAS one year after surgery revealed no differences between the groups (Table 5; Fig. 8).

Table 5

Comparison of the average VAS score in groups of patients after arthrodesis surgery

Method of surgical fixation	Average VAS score post-surgery				
	3 months		6 months		12 months
EF group ($n = 21$)	4.24 ± 0.83		3.43 ± 0.93		2.81 ± 1.08
SF group ($n = 23$)		3.57 ± 0.66		2.78 ± 0.85	2.61 ± 0.78
PF group ($n = 20$)		3.50 ± 0.76		2.65 ± 0.59	2.25 ± 0.55
IMF group ($n = 18$)		3.67 ± 0.91		2.78 ± 0.88	2.61 ± 0.85
p	1.00	0.78	1.00	0.87	0.15

Note: significance of differences between the groups was assessed using the Student – Newman – Keuls test

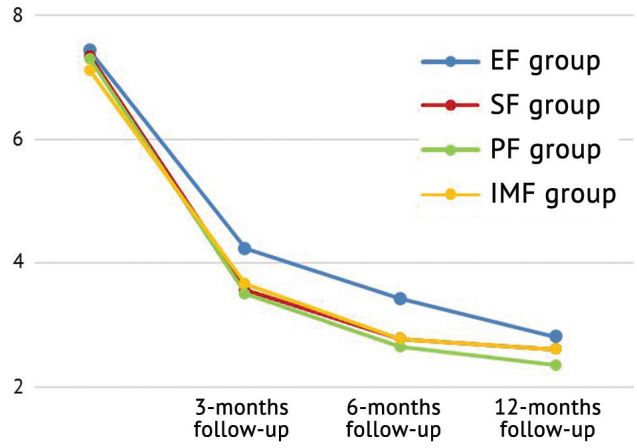

Fig. 8 Comparison of the dynamics of the average VAS score in groups with regard to fixation options

The postoperative period was uneventful in most cases. The diagram shows that the maximum of complications in the postoperative period was recorded in the IMF group, and the minimum in PF group (Fig. 9). However, these differences were not statistically significant ($p > 0.05$).

Fusion was achieved in most patients postoperatively, regardless of the method of fixation (Fig. 10).

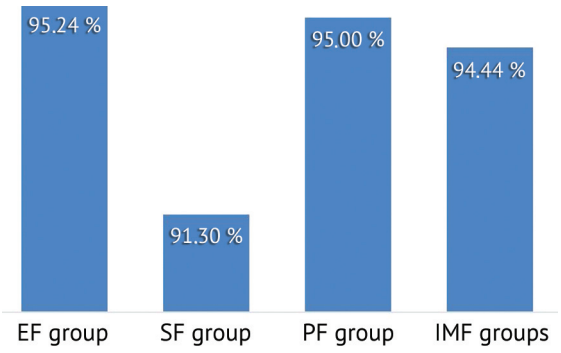

Fig. 9 Comparison of the incidence of complications with regard to the method of fixation

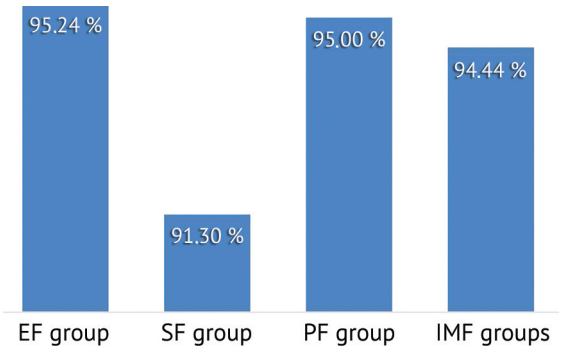

Fig. 10 Comparison of fusion rates in regard to the method of fixation

As follows from the diagram above, postoperative fusion was the highest in the AFF group, and the lowest rate was in cases of fixation with screws. However, the differences between the groups did not reach the level of statistical significance.

DISCUSSION

Ankle joint arthrodesis is a reliable method for treating advanced stages of ankle OA, which effectively reduces pain intensity and improves the function of the affected limb [4]. The success of arthrodesis the joint lies in the observance of several key principles, including adequate bone contact, interosseous compression and stability at the bone contact site [8, 13]. The success rate is 85–100 % [9, 15].

A study by Morasiewicz et al. [17] revealed that the intensity of pain assessed using the VAS scale in arthrodesis of the ankle joint with Ilizarov apparatus fixation is lower than with screw fixation. However, Teramoto et al. [21] reported that intraoperative bleeding and operative time were lower with screw-fixed arthrodesis of the anklet joint than with the Ilizarov fixation.

Nonunion is the most common among postoperative complications. Historical data report that the incidence of nonunion reached 40 % [22], but in the current literature the reported incidence of nonunion approaches 10 % [15, 23].

SF is traditionally considered a more preferable technique due to its easy performance and high fusion rate [24]. More recent studies have shown SF fusion rates ranging from 91 to 100 % [8]. However, there is no guarantee of its reliability in patients with osteoporosis [25].

On the other hand, some authors note that PF has high stability and rigidity [26]. In one of the latest studies, the rate of arthrodesis fusion with PF application was observed to be up to 97.6 % [19, 27]. However, another study did not find a significant difference in the results between the use of screws and plates in arthrodesis of the joint [28].

In contrast, IM fixation has a low technical threshold and can be quickly mastered by surgeons, and its union rate is 71–95 % [6].

In this study, the overall fusion rate was 93.90 % (77 cases). Although there was a difference in fusion rates between the groups, it was not statistically significant.

Besides nonunion, other complications of ankle arthrodesis include aseptic loosening, malposition, infectious complications, and nerve damage [12, 15].

The study by Slivkova et al. showed that 28 % of patients start experiencing complications within three weeks after surgery [29]. Several authors have argued that treatment with intramedullary locking nails is more effective than screws and plates, with the advantage of high fusion rates and low complication rates. However, the technique requires reaming and may increase the likelihood of infection, pulmonary embolism, and systemic inflammation [6].

In our study, the overall complication rate was 12.20 % (10 cases).

Postoperative infections of the postoperative wound area or the exit sites of the pins predominated — 4 (4.88 %) cases. Two of these cases occurred in the AVF group. Changing the antiseptic, piercing the exit points of the needles with an antibiotic, and ultraviolet irradiation made it possible to stop complications without consequences for the final result of treatment in one patient. However, in another patient, arthrodesis did not occur as a result.

In the case of fixation with a blocked retrograde IM after deep infection, loosening of the implant occurred with the subsequent development of postoperative nonunion. One of the patients, after fixation with cannulated screws, underwent multiple debridement operations with antibiotic therapy. Attempts at revisions did not lead to relief of the infectious process, and arthrodesis did not take place.

The main cause of the two nonunion cases was fracture of the implants in the groups SF (one case) and PF (one case). Two relatively rare cases (2.4 %) of postoperative refracture that occurred after IM fixation were judged as associated with stress concentration.

We considered venous thromboembolism to be the most serious complication, since it could be fatal for the patient [30]. In this study, two cases (2.4 %) of this complication were observed in AEF and SF groups.

It should be noted that patients in the AEF group had more compromised conditions compared with other groups, and among them were patients with etiologies causing bone damage or infection. However, postoperative results, both in terms of the rate of union and the rate of complications, did not differ significantly from other groups. This confirms the position that EF has significant advantages in overcoming the above difficulties.

Thus, the majority of patients initially reported unsatisfactory ankle function and chronic pain of moderate and high intensity. After the arthrodesis operation, the majority of patients reported a significant improvement in function and a decrease in pain intensity, which indicates the effectiveness of this approach to the treatment of ankle OA.

The comparison of the effectiveness of the four surgical fixation methods found that they have both advantages and disadvantages. External fixation and nailing are characterized by lower volumes of blood loss and a relatively short duration of the operation. If plates and screws are used, functional recovery occurs faster and pain intensity is reduced more effectively. Overall, there was little difference in postoperative outcomes at long-term follow-up, and the effectiveness of the techniques used was similar. Based on this, we believe that the most appropriate surgical treatment plan should be developed considering the patient's condition, including his age, life history, patient compliance, and other factors and should be based on the principle of individual approach in combination with clinical examination and imaging [4, 10].

CONCLUSION

The effectiveness of ankle joint arthrodesis in the treatment of advanced OA is quite high and can significantly improve the function of the affected limb and reduce the intensity of pain in the joint.

Each fixation method has its own advantages and shortcomings, but there is no significant difference in long-term outcomes. The choice of the optimal surgical method to achieve the effective result should be based on the principle of an individual approach.

Conflict of interest *The authors declare that there are no obvious or potential conflicts of interest related to the publication of this article.*

Financing *The study was not sponsored.*

Ethical review *The study was reviewed and approved by the local ethics committee of the Federal State Budgetary Educational Institution of Higher Education Kazan State Medical University of the Ministry of Health of Russia (protocol No. 1 of 02.03.2021) and the Local Ethics Committee of the Central Hospital of Wuhan (protocol No. 2835 of 15.01.2019).*

Informed consent *All patients signed an informed consent.*

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Validation and evaluation of the Russian version of the SEFAS questionnaire for assessing foot and ankle in surgically treated patients with forefoot disorders

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Abstract

Introduction The Self-reported Foot and Ankle Score (SEFAS) is one of the foot health assessment tools in Sweden. Validation procedures, reliability, validity, sensitivity, approval are essential for the Russian version of the questionnaire with a new language environment.

The objective was to validate the Russian version of the SEFAS questionnaire and approve the tool in the Russian surgical patients with foot disorders.

Material and methods The questionnaires the patients completed preoperatively included SEFAS, SF-36, a general health survey questionnaire, and the Lower Extremity Functional Scale (LEFS). Patients were requested to complete the SEFAS questionnaire at 2 months of surgery to assess the sensitivity of the instrument. Based on the case histories clinical researcher recorded general and physical parameters of the patients to include gender, age, socio-demographic data, nature of the foot disorder, a dorsiflexion angle of the first metatarsophalangeal joint. To assess the reproducibility of the Russian version of the questionnaire, some patients were requested to complete the SEFAS questionnaire twice preoperatively with an interval of one day.

Results The questionnaire was characterized by good internal consistency and reproducibility indicating acceptable reliability of the Russian version of SEFAS. Statistically significant correlations of varying strength were seen between the SF-36 scores and nearly all the selected questions of the SEFAS Russian version. Statistically significant correlations (moderate to weak) were observed between the LEFS total score and the selected SEFAS questions. Minimal clinically significant changes in MCID scored 3 in the assessment of clinical interpretability of the Russian version of SEFAS.

Discussion The study demonstrated the reliability, validity and sensitivity of the Russian version of the SEFAS questionnaire. The questionnaire appeared to be an informative and clinically interpretable instrument for assessing foot in surgical adult patients with foot disorders.

Conclusion The SEFAS questionnaire can be recommended for Russian trauma and orthopaedic practice to learn the patient's opinion of the condition.

Keywords: foot and ankle function assessment, questionnaire, validation, testing, quality of life

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INTRODUCTION

The foot performs the most important functions of support and locomotion and can be more susceptible to pathological changes associated with external and internal causes as compared to other musculoskeletal components [1–5]. Surgery is an effective treatment option for patients with a foot pathology [6–8]. In addition to clinical and radiological examination the patient's opinion regarding the effect of orthopaedic condition and the treatment on daily activities and various aspects of life is essential for management of patients with musculoskeletal disorders at the decision-making stage in accordance with modern international recommendations determining the effectiveness of surgical treatment and rehabilitation [9–11]. Self-reported Foot and Ankle Score (SEFAS) is one of the tools recommended by the international orthopedic community to assess foot and/or ankle joint in various pathologies, including evaluations after surgical treatment. SEFAS, the national quality register for foot and ankle surgery was developed in Sweden [12]. The SEFAS questionnaire developed by M. Coster et al. in 2007, based on the General Ankle Function Questionnaire, demonstrated good psychometric properties of the instrument [12–14]. The questionnaire contains 12 items, with 5 response options. Patients score each question on a five-point Likert scale scored from 0 to 4, with 0 representing the worst stage and the sum of 48 representing normal function. The structure of the questionnaire also allows us to assess such aspects as pain, function and limitation of function, which are not in separate scales [12]. Language versions of the SEFAS questionnaire have been developed for use in Germany, Denmark, Spain and France [15–18]. The results of linguistic and cultural adaptation of the Russian SEFAS version were published earlier [19]. As recommended by international methodological standards [20, 21], development of a new language version of the questionnaire to be used in research and clinical practice with a new language environment suggests a validation procedure to assess the psychometric properties: reliability, validity and sensitivity and testing to determine the applicability and clinical interpretability of the questionnaire for a population of patients with a specific pathology. Clinical interpretability of the questionnaire suggests the analysis of the minimal clinically important changes (MCIC) [22] identified during its use and demonstration of their presence in the focal population of patients after treatment.

The purpose of the work was to validate the Russian version of the SEFAS questionnaire and test the instrument in the domestic population of surgical patients with foot pathology.

MATERIAL AND METHODS

The study was performed between April and July 2023 at the trauma department No. 2 of the Pirogov High Medical Technologies Clinic of the St. Petersburg State University. The study protocol was approved by the Biomedical Ethics Committee of the Pirogov High Medical Technologies Clinic of the St. Petersburg State University (protocol No. 07/22 dated 07/07/2022). The study included adult patients with foot pathology requiring surgical treatment, provided they were able to complete the questionnaires. The patients signed informed consent. The study did not include patients with cognitive impairments that prevented adequate completion of the questionnaires. Three questionnaires the patients completed before surgery included SEFAS, health-related quality of life questionnaire SF-36, and the Lower Extremity Functional Scale (LEFS). Patients were requested to fill out the SEFAS questionnaire at 2 months of surgery to assess the sensitivity of the instrument. General and clinical parameters a research physician recorded for each patient included gender, age, socio-demographic data, the nature of the foot pathology and the dorsiflexion (DF) angle at the first metatarsophalangeal joint (MTP1). Some patients were requested to fill out the SEFAS questionnaire twice before the surgery with an interval of one day to assess the reproducibility of the Russian version.

The RAND SF-36 is the most widely used health-related quality of life (HRQoL) survey instrument that can be used to measure the HRQoL in healthy individuals, patients with chronic diseases, including orthopaedic conditions [23]. The survey was constructed for self-administration by persons 14 years

of age and over and consisted of 36 items tapping eight health concepts: physical functioning (PF), physical role functioning (PRF), bodily pain (BP), general health perceptions (GHP), vitality (V), social role functioning (SRF), emotional role functioning (ERF), mental health (MH). Each of the items include 2 to 10 questions with response choices from 2 to 6 offered. Patients can state their answers on a 3-point Likert scale. The weighted answers are calculated into a score between 0 and 100 for each scale. Higher scores indicate better health status.

LEFS is a lower extremity functional assessment scale developed in 1999 by J.M. Binkley et al. [24].It is a 20-item self-report measure in which each item is scored on a five-point gradient: 0, extreme difficulty or unable to perform activity; and 4, no difficulty. The total score may vary from 0 to 80 points, with higher scores indicating better levels of lower extremity function.

The methods chosen for validating the Russian version of the SEFAS questionnaire are based on the approaches used in testing the psychometric properties of the original version of the instrument [13] and developing versions in other languages [15–18], and modern expert recommendations for the use of new language versions of questionnaires [20]. Validation suggested solution of the following tasks:

— reliability analysis was performed through assessment of the internal consistency of the questionnaire by calculating the Cronbach's α coefficient, of the reproducibility of the questionnaire using the test-retest method: for this, patients who had no treatments being in a stable condition were requested to fill out the questionnaire twice with an interval of one day (n = 20) to compare the total SEFAS score at two study points and assess correlations between its values at two study points;

— review of **validity** suggested assessment of the several types:

- assessment of *criterion validity* was based on the correlation of the total SEFAS score and the dorsiflexion angle (DA) in the first metatarsophalangeal joint (MTP1);
- analysis of *discriminant validity* was performed using the "known groups" method based on comparison of SEFAS scores in groups of patients with intact range of motion/mild impairment and with moderate/severe impairment in range of motion according to measurements of the TS angle in MCP1;
- analysis of *convergent validity* was based on the assessment of correlations between SEFAS scores, and SF-36 and LEFS scores;

— *sensitivity* analysis was based on determining the effect size (ES) of changes in the questionnaire filled out by patients before surgery and at 2 months of operation.

Feasibility of the Russian version of SEFAS in the focal population of patients was examined based on an assessment of the understandability and ease of its completion by patients, analysis of the quality of data, and the percentage of minimum and maximum values of the total preoperative SEFAS score. The clinical interpretability of the Russian version of the questionnaire was also determined by calculating the minimum clinically important differences (MCID) in the total SEFAS score. After this, the proportion of patients who had MCID after surgical treatment was analyzed in the overall sample and separately in the group of athletes and in the group of patients who were not athletes.

Statistical analysis. Data are presented as numbers of observations, arithmetic means, standard deviations, 95 % confidence intervals (95 % CI) and percentages. Pattern of distribution was identified with the Shapiro – Wilk and Kolmogorov – Smirnov tests with choice of a criterion for testing the statistical significance of differences between the parameters. Student's t-test was used to compare two unrelated groups with a comparison criterion for two samples. The nonparametric Wilcoxon signed rank test was used to compare two related groups. The intraclass correlation coefficient (ICC) was used to assess the relationship between parameters at two points of questionnairing within the test-retest method. Spearman r correlations were used to assess the relationship

between the parameters of different questionnaires. The strength of the correlation was considered by the *r* value: with $0.1 < r < 0.39$ indicating weak connection, with $0.4 \leqslant r < 0.69$ showing moderate connection and with $r \geqslant 0.7$ indicating strong connection [25]. Cronbach's α coefficient was calculated to identify the internal consistency of the questionnaire. Effect sizes (ES) were determined to examine changes in scores over time using the SEFAS questionnaire. Effect sizes were considered small with ES = 0.2–0.5, medium with ES = 0.5–0.8, and large with ES > 0.8 [26]. The magnitude of minimal clinically important differences (MCID) according to the SEFAS questionnaire was determined based on the calculation of the standard error of the mean (SEM) [27]. Formula for calculation: $SEM = SD \times \sqrt{1-\alpha}$, where SD was the standard deviation, α was the value of the Cronbach alpha coefficient for SEFAS. All tests were two-sided, differences between the groups were considered statistically significant at $p < 0.05$. Statistical analysis was performed using SPSS 23.0 software.

RESULTS

Characterization of the sample

The study included 100 patients with foot pathology. Table 1 presents general characteristics of the sample. The majority of patients were females (92 %). The median age was 55.7 years with a wide range from 25 to 75 years. Hallux valgus was the unbderlying condition for the majority of the patients (97 %). Pathology of the foot of the right limb was detected in 51 %, of the left limb in 47 %, and two patients had involvement of both sides.

Professional athletes made up one quarter (23 %) of the sample. Of these, there were swimmers (5), Nordic walker (4), dancers (4), cross-country skiers (2), cyclers (2), runners (1), horse riders (1), multisport competitors (1), table tennis players (1), artistic gymnastics (1), weightlifters (1).

The mean (standard deviation) of th TC angle at MCP1 before surgery was 34.9 (20.3)°, range 0–60°. As to the extent of impaired range of motion in the MCP1, patients were distributed as follows: no impairment was recorded in 38 % of patients, mild impairment was seen in 8 %, moderate involvement observed in 13 % and 40 % showed severe impairment. The mean preoperative LEFS foot function scored 61.3 ± 14.3. The mean score on the SF-36 scales before surgery ranged from 54.7 ± 18.3 (vitality) to 74 ± 21.2 points (social functioning). Preoperative low values were noted in role functioning with 55.3 ± 41.1 scores for emotional role functioning and 56.8 ± 43.2 for physical role functioning.

Table 1

Patient characteristics

Description		Values
Gender, %	Male	8
	Female	92
Age, years	Mean (standard deviation)	54 (12)
	Median (interquartile range)	56 (44; 64)
	Range	25–75
Marital status, %	Married	81
	Single	10
	Divorced	4
	Widowed person	5
Education, %	Higher	48
	Vocational secondary	33
	Secondary level	18
	Some college	1
Employment, %	Employed	55
	Unemployed	45
Engagement in sports, %	No	77
	Yes	23
Disability, %	No	97
	Granted, from them:	3
	Group 2	1
	Group 3	1
	Group 3	1
Comorbidity, %	None	21
	There is/are	79
Principal diagnosis, %	Hallux valgus	97
	Pes planus	2
	Keller 2	1
Limb, %	Right	51
	Left	47
	Both	2
Localization, %	Forefoot	98
	Mid- and hindfoot	2

Psychometric properties of the SEFAS questionnaire

Reliability

The Cronbach's α coefficient for the total score was 0.846. With items being removed one by one, the Cronbach's α value decreases slightly indicating the consistent structure of the questionnaire. Assessment of the reproducibility of the questionnaire showed no change in the total SEFAS score in patients who were in a stable condition and filled out the questionnaire again (33.53 ± 5.55 vs. 34.06 ± 6.24; ES = 0.1), and a statistically high coefficient was obtained with intraclass correlation ICC 0.962 (95 % CI: 0.906–0.985) between the SEFAS total score with first and repeat completion of the questionnaire. In general, the questionnaire was characterized by good internal consistency and reproducibility indicating acceptable reliability of the Russian version of SEFAS.

Validity

To assess criterion validity, correlations between the total SEFAS score and the TC angle in MCP1 were examined. The Spearman's r correlation coefficient between the total SEFAS score and the TC angle in MCP1 was 0.424 (95 % CI 0.249–0.578, $p < 0.001$). There was a statistically significant positive moderate correlation between the total SEFAS score and the TC angle in MCP1. Assessment of discriminant validity with the known groups method showed statistically significant differences in the total SEFAS score in patients with no/mild impairment in the range of motion in the MCP1 joint compared to the group of patients with moderate and severe impairment in the range of motion in the MCP1 joint (Fig. 1).

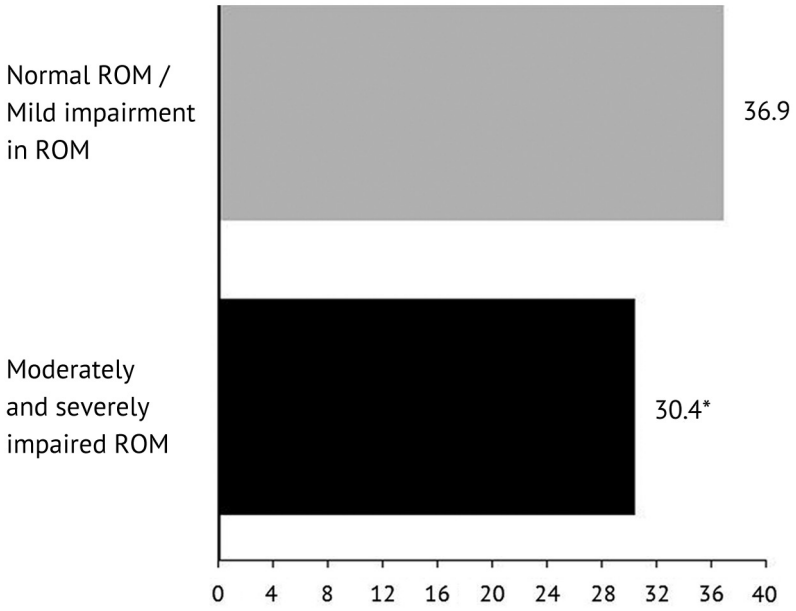

Fig. 1 Mean values of the total SEFAS score in patients grouped according to the extent of impaired range of motion (ROM) based on the TC angle in MCP1; * Student's t test, $p < 0.001$

The total SEFAS score was lower (worse foot condition) in patients with moderately and severely impaired ROM than that in patients with normal ROM and mild impairment (30.42 versus 36.89 scores; $p < 0.001$). The results indicated good discriminant validity of the Russian version of the instrument. Convergent validity analysis was performed by assessing correlations between individual questions, the total SEFAS score and the "external criterion". The "external criterion" included the RAND SF-36

score and the total score on the LEFS questionnaire. Spearman's correlation coefficients between item scores and the SEFAS total score with the SF-36 scores and the LEFS total score are presented in Tables 2 and 3.

Table 2

Correlations between Individual Questions, SEFAS Total Score, and SF-36 Scale Scores

SEFAS questions	SF-36	*r* Spearman*	95 % CI
1. How would you describe the pain you usually have from the foot/ankle in question?	PF	0.311**	0.143–0.42
	PRF	0.239*	0.107–0.366
	BP	0.627**	0.524–0.701
	GHP	0.204*	0.049–0.304
	V	0.215*	0.077–0.376
	SRF	0.269**	0.105–0.383
	ERF	0.193	0.023–0.312
	MH	0.236*	0.079–0.381
2. For how long have you been able to walk before severe pain arises from the foot/ankle in question?	PF	0.264**	0.132–0.394
	PRF	0.222*	0.088–0.383
	BP	0.435**	0.323–0.548
	GHP	0.228*	0.063–0.373
	V	0.111	–0.032–0.286
	SRF	0.247*	0.113–0.387
	ERF	0.047	–0.104–0.185
	MH	0.120	–0.062–0.281
3. Have you been able to walk on uneven ground?	PF	0.559**	0.132–0.394
	PRF	0.404**	0.088–0.383
	BP	0.427**	0.323–0.548
	GHP	0.257**	0.063–0.373
	V	0.232*	–0.032–0.286
	SRF	0.301**	0.113–0.387
	ERF	0.281**	–0.104–0.185
	MH	0.141	–0.062–0.281
4. Have you had to use an orthotic, shoe insert, heel lift, or special shoes?	PF	0.423**	0.311–0.516
	PRF	0.349**	0.206–0.496
	BP	0.317**	0.17–0.457
	GHP	0.141	–0.041–0.265
	V	0.207*	0.065–0.36
	SRF	0.225*	0.037–0.36
	ERF	0.223*	0.049–0.36
	MH	0.168	0.014–0.355
5. How much has the pain from the foot/ankle in question interfered with your usual work including housework and hobbies?	PF	0.514**	0.372–0.637
	PRF	0.394**	0.266–0.558
	BP	0.498**	0.37–0.624
	GHP	0.319**	0.162–0.454
	V	0.196	0.046–0.375
	SRF	0.388**	0.229–0.528
	ERF	0.307**	0.17–0.426
	MH	0.193	0.386–0.65

Continuation of table 2

Correlations between Individual Questions, SEFAS Total Score, and SF-36 Scale Scores

SEFAS questions	SF-36	*r* Spearman*	95 % CI
6. Have you been limping when walking because of the foot/ankle in question?	PF	0.607**	0.504–0.697
	PRF	0.533**	0.414–0.647
	BP	0.595**	0.488–0.68
	GHP	0.170	–0.015–0.313
	V	0.159	–0.038–0.31
	SRF	0.267**	0.109–0.4
	ERF	0.275**	0.128–0.382
	MH	0.091	–0.069–0.239
7. Have you been able to climb a flight of stairs?	PF	0.635**	0.513–0.718
	PRF	0.370**	0.219–0.509
	BP	0.395**	0.251–0.487
	GHP	0.358**	0.194–0.457
	V	0.222*	0.065–0.357
	SRF	0.451**	0.289–0.55
	ERF	0.348**	0.171–0.456
	MH	0.129	–0.043–0.275
8. Have you been troubled by pain from the foot/ankle in question in bed at night?	PF	0.180	–0.002–0.309
	PRF	0.309**	0.161–0.458
	BP	0.227*	0.051–0.338
	GHP	0.084	–0.119–0.214
	V	0.244*	0.082–0.404
	SRF	0.162	–0.01–0.267
	ERF	0.359**	0.198–0.454
	MH	0.251*	0.099–0.388
9. How much has the pain from the foot/ankle in question affected your usual recreational activities?	PF	0.442**	0.279–0.56
	PRF	0.363**	0.24–0.506
	BP	0.551**	0.434–0.641
	GHP	0.132	–0.029–0.267
	V	0.186	0.029–0.35
	SRF	0.323**	0.17–0.445
	ERF	0.187	0.043–0.297
	MH	0.213*	0.04–0.367
10. Have you had swelling of your foot?	PF	0.286**	0.148–0.434
	PRF	0.244*	0.13–0.409
	BP	0.152	0.041–0.291
	GHP	0.243*	0.125–0.39
	V	0.093	–0.035–0.293
	SRF	0.144	0.007–0.313
	ERF	0.201*	0.075–0.364
	MH	0.127	–0.004–0.279
11. After a meal (sat at table), how painful has it been for you to stand up from a chair because of the foot/ankle in question?	PF	0.465**	0.319–0.577
	PRF	0.329**	0.2–0.466
	BP	0.414**	0.28–0.504
	GHP	0.316**	0.151–0.435
	V	0.138	–0.052–0.307
	SRF	0.241*	0.088–0.351
	ERF	0.252*	0.098–0.362
	MH	0.145	–0.014–0.289

Continuation of table 2

Correlations between Individual Questions, SEFAS Total Score, and SF-36 Scale Scores

SEFAS questions	SF-36	*r* Spearman*	95 % CI
12. Have you had a severe sudden pain shooting, stabbing, or spasm from the foot/ankle in question?	PF	0.281**	0.067–0.129
	PRF	0.227*	0.076–0.065
	BP	0.378**	0.07–0.221
	GHP	0.122	0.067–0.048
	V	0.230*	0.074–0.057
	SRF	0.166	0.085–0.022
	ERF	0.207*	0.062–0.063
	MH	0.133	0.073–0.011
Total SEFAS	PF	0.649**	0.536–0.72
	PRF	0.527**	0.421–0.642
	BP	0.685**	0.604–0.737
	GHP	0.304**	0.144–0.406
	V	0.280**	0.142–0.428
	SRF	0.400**	0.251–0.486
	ERF	0.369**	0.205–0.471
	MH	0.247*	0.104–0.386

Note: * correlation coefficients are statistically significant at $p < 0.001$; ** correlation coefficients are statistically significant at $p < 0.05$. SF-36 scales: physical functioning (PF), physical role functioning (PRF), bodily pain (BP), general health perceptions (GHP), vitality (V), social role functioning (SRF), emotional role functioning (ERF), mental health (MH)

The measurements showed statistically significant correlations of varying strength identified between all SF-36 scales and nearly all individual questions of the Russian version of SEFAS, with the total SEFAS score indicating good convergent validity of the Russian version.

Table 3

Correlations between individual questions, SEFAS total score, and LEFS total score

Decription	*r* Spearman*	95 % CI
1. How would you describe the pain you usually have from the foot/ankle in question?	0.370**	0.25–0.483
2. For how long have you been able to walk before severe pain arises from the foot/ankle in question?	0.263**	0.17–0.362
3. Have you been able to walk on uneven ground?	0.600**	0.484–0.702
4. Have you had to use an orthotic, shoe insert, heel lift, or special shoes?	0.246*	0.118–0.373
5. How much has the pain from the foot/ankle in question interfered with your usual work including housework and hobbies?	0.618**	0.531–0.702
6. Have you been limping when walking because of the foot/ankle in question?	0.651**	0.574–0.724
7. Have you been able to climb a flight of stairs?	0.557**	0.449–0.662
8. Have you been troubled by pain from the foot/ankle in question in bed at night?	0.261**	0.132–0.4
9. How much has the pain from the foot/ankle in question affected your usual recreational activities?	0.534**	0.442–0.631
10. Have you had swelling of your foot?	0.362**	0,24–0.495
11. After a meal (sat at table), how painful has it been for you to stand up from a chair because of the foot/ankle in question?	0.457**	0,37–0.551
12. Have you had a severe sudden pain shooting, stabbing, or spasm from the foot/ankle in question?	0.403**	0,278–0.523
Total SEFAS	0.693**	0,624–0.758

Note: *correlation coefficients are statistically significant at $p < 0.001$; ** correlation coefficients are statistically significant at $p < 0.05$.

Table 3 indicates statistically significant correlations (moderate to weak) between the LEFS total score and all individual SEFAS questions indicating acceptable convergent validity of the Russian version of the SEFAS questionnaire.

Sensitivity

The sensitivity analysis of the Russian version of the SEFAS questionnaire was based on changes in the total SEFAS score at 2 months of surgery compared with the preoperative value (Table 4). The total score increased significantly after surgery (33.17 versus 45.22; $p < 0.001$). The effect size (ES) was calculated based on the data in the table.

Table 4

Mean total scores with SEFAS completed before and after surgery ($n = 92$)

Description	Pre-op		Post-op		p*
	Mean	Standard deviation	Mean	Standard deviation	
Total SEFAS	33.17	7.49	45.22	2.63	< 0.001

* nonparametric Wilcoxon signed rank test.

The effect size ES was 1.6, being characteristic of a large effect of change. The Russian version of SEFAS demonstrated high sensitivity to changes in the foot in patients after surgery.

Evaluation of the Russian version of SEFAS

The questionnaire took 5 minutes for the patient to complete. The questionnaires were completed with no gaps (0.04 % missing data for SEFAS). The floor-ceiling effect of the total SEFAS score before surgery was 1 %. The findings indicated the high quality of the data, the ease of understanding the questions causing no discomfort and posing no difficulties when choosing a response, and also reflecting the absence of bias in the sample regarding the total parameter of foot condition. The testing suggested analysis in changes in the total questionnaire score evaluated post surgery separately in athletic and non-athletes. The mean total SEFAS scored 33.0 ± 8.1 in athletes ($n = 23$) preoperatively and 45.5 ± 2.5 postoperatively ($p = 0.001$). The mean total SEFAS scored 31.1 ± 7.4 in non-athletes ($n = 77$) preoperatively and 45.1 ± 2.7 postoperatively ($p = 0.001$). Figure 2 shows the mean total SEFAS score measured in the groups preoperatively and at 2 months.

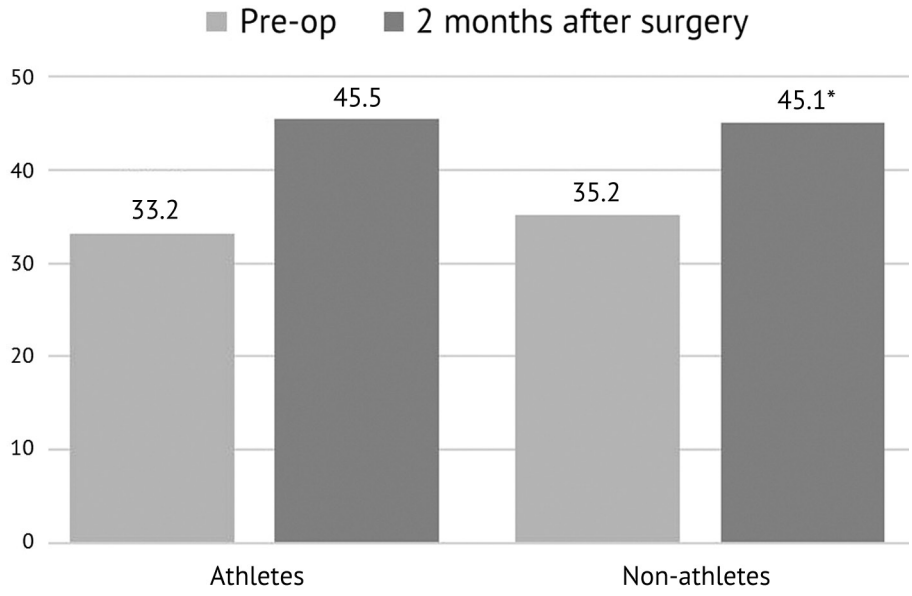

Fig. 2 Mean total SEFAS scores measured in athletes and non-athletes preoperatively and at 2 months (* $p = 0.001$)

MCID was determined as part of the assessment of the clinical interpretability of the Russian version of SEFAS and scored three. The majority of patients (89 %) after surgery demonstrated improved total SEFAS score postoperatively being increased by 3 or more points indicating clinically significant improvement in quality of life seen in 85 % of athletes and in 90 % in non-athletes. MCID scored 3 for the Russian version of the SEFAS questionnaire. The majority of patients experienced significant improvement in the foot condition postoperatively.

DISCUSSION

Questionnaires filled out by the patients were used for comprehensive assessment of orthopaedic patients with musculoskeletal disorders to determine the effectiveness of surgical treatment and rehabilitation [7, 9, 10, 28, 29]. The SEFAS questionnaire is is a patient–reported outcome measure used to evaluate foot and ankle disorders [12–14, 30–32]. There are versions of the questionnaire issued in different languages [14–18]. There has been no validated Russian version of the SEFAS questionnaire. As a result of this study, the Russian version of SEFAS was validated and tested in a Russian sample of patients with foot pathology. The study was conducted in accordance with current international recommendations [20, 21]. The design was based on an algorithm for assessing the psychometric properties of the original version of SEFAS [13], and the works aimed at creating versions of the instrument in other languages [16–18]. The sample included patients with forefoot pathology, with 23 % being athletes. The inclusion of athlete patients in the study was an important advantage of the study to learn characteristics of foot function in individuals participating in sports. Determination of the psychometric properties of the instrument and its testing in a clinical setting with the participation of surgical patients, both related and not related to professional sports, contributed to a more adequate assessment of the reliability, validity and sensitivity of the questionnaire, and allowed us to demonstrate its clinical interpretability in the groups of patients.

The process of validating the Russian version of SEFAS demonstrated various aspects of the reliability, validity and sensitivity of the instrument to changes in the condition of the foot after surgical treatment. With the high Cronbach's α coefficient (0.846) we can conclude that the Russian version of SEFAS has good internal consistency. The parameter is slightly inferior to that obtained during the development of the original version of the instrument (0.96) [13], and is comparable to those in other language versions (0.89 for the German version, 0.93 for the Danish version) [16–18]. With regard to reproducibility, the study demonstrated high intraclass correlations between individual SEFAS questions filled out by the patients twice before surgery in a stable condition with an interval of one day with the ICC measuring 0.962 and satisfying the condition of reproducibility and being comparable with data from other studies for other languages [16–18]. Thus, acceptable reliability of the Russian version of SEFAS characterized by good internal consistency and satisfactory reproducibility was demonstrated.

Validity assessments were performed in three ways. Criterion and discriminant validity was assessed in addition to the analysis of convergent validity by analogy with the validation of language versions of SEFAS by other authors to allow a more detailed psychometric analysis of the Russian version of the questionnaire. The assessment of convergent validity was based on a correlation analysis between SEFAS and SF–36 with the presence of significant correlations between SEFAS and some SF-36 scales reflecting physical aspects of quality of life and indicating the reliability of the Russian version of SEFAS. More pronounced correlations were established between the total score of the Russian version of SEFAS and the physical, role-physical functioning

and pain scales of the SF-36 questionnaire. The least pronounced were found for the mental health and general health scales and role-emotional functioning. These findings were similar to those obtained with testing the psychometric properties of the Swedish and German language versions of the instrument [13, 16]. The total SEFAS score relative to the dorsiflexion angle in the MCP1 was additionally analyzed to demonstrate the validity of the instrument. The correlations between the total SEFAS score and the angle were identified with the total SEFAS score being compared in different groups of patients according to the degree of impairment in range of motion in the MCP1 joint. Statistically significant correlation between the total SEFAS score and the TS angle in MCP1, differences in the total SEFAS score between groups of patients with varying degrees of impairment in range of motion in MCP1, shown in our series characterizes the Russian version of SEFAS as a tool with good criterion and discriminant validity. The sensitivity of the Russian version of SEFAS based on the effect size ES of changes of the foot in the total score of the questionnaire post surgery was evaluated. The ES values exceeded similar parameters reported by the authors of the questionnaire in the original study [13] and in the development of other language versions [16–18]. The ES value in our series was 1.6 versus 1.44 for the Swedish (original) version. The questionnaire period post surgery was shorter in our series and amounted to 2 months, and it was reported as 6 months in other studies. The parameter corresponded to a large effect size and indicated good sensitivity of the Russian version of SEFAS reflecting changes in the condition of the foot after treatment, and the instrument can be recommended for use in assessing the effect of treatment from the patient's point of view.

The results of clinical testing of the Russian version of SEFAS deserve special attention. The questionnaire was well completed indicating high quality of data and the informativeness for monitoring the condition of the foot in orthopaedic patients during treatment. The tool provides additional information from the patient in a convenient format, compactly, with little time spent, and can be used for a comprehensive assessment of the patient's condition and monitoring the effect of the operation. Clinical interpretability in the Russian patient population was performed as part of the testing of the questionnaire. A change in the total score of 3 points was registered as the minimum clinically significant change. Clinically significant improvement in the foot occurred after surgery in the majority of patients (89 %). Significant changes were noted in athletes and non-athletes. The limitations of the study included patients with one type of orthopaedic pathology (forefoot) with the majority of patients being females. The study demonstrated the reliability, validity and sensitivity of the Russian version of the SEFAS questionnaire. The questionnaire showed to be an informative and clinically interpretable tool for assessing the condition of the foot in adult surgical patients with foot pathology. The Russian version of the SEFAS questionnaire can be recommended for research and clinical practice in Russian traumatology and orthopaedics.

CONCLUSION

The Russian version of the SEFAS questionnaire is a reliable, valid, sensitive and informative tool for assessing the foot function in orthopaedic patients. MCID was established in the total score of the questionnaire filled out by the Russian sample of patients to assess the effect of treatment in clinical trials and clinical practice. The SEFAS questionnaire can be recommended for use in Russian traumatology and orthopedics considering the patient's opinion on the condition of the foot at the preoperative stage, after surgical treatment and during rehabilitation to monitor foot function recovery.

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Gait analysis characteristic features in children with spastic hemiplegia

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Abstract

Introduction There are not enough published studies on the impact of early isolated triceps lengthening operations in hemiparesis on the state of motor characteristics and on the development of orthopedic complications in children with GMFCS II.

Purpose Analyze motor locomotion in children with spastic hemiplegia who had not previously been operated on and those who had undergone isolated surgical lengthening of the triceps at an early age.

Material and methods Four groups of children with spastic hemiplegia according to Rodda et Graham types: I) type 2a gait (4 children), II) type 3 (3 children), III) type 4 (7 children), IV) type 4 with previous triceps lengthening (9 children).

Results The features revealed in gait types 2a, 3 and 4 in the sagittal plane correspond to the characteristic and previously described features. In all groups, asymmetric rotational movements of the pelvis and tilt asymmetry in the frontal plane were observed. In the group of early isolated tricep lengthening, a decrease in the moment of force by pushing with the foot at the end of the single-support phase was revealed, in combination with an increase in the moment of forces of knee joint extension in the single-support phase.

Discussion Early isolated triceps lengthening that weakens its function leads to a compensatory increase in the work of the knee extensors which is similar to the mechanism to of iatrogenic crouch gait, but does not result in a complete loss of walking function in the conditions of a contralateral healthy limb.

Conclusions Movement pathology is present in all three measurement planes in gait types 2a, 3, 4 according to the Rodda et Graham classification. The most pronounced deviations were found in gait type 3. The rotational turn of the pelvis is an initially compensatory mechanism due to intratorsion femur deformity. Isolated triceps lengthening surgeries performed at an early age lead to reduced plantar push strength, increased compensatory work of the knee extensors, and probably do not prevent the orthopedic pathology found in Rodda et Graham's gait type 4.

Keywords: gait analysis, children, spastic hemiplegia, kinematics, kinetics

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INTRODUCTION

The hemiparetic form of cerebral palsy is the most common variant of this disease [1]. Spastic hemiparesis is characterized by deficits in motor coordination, disorders of posture and balance, muscle weakness, spasticity, and insufficient selective control, present in the upper and lower limbs of one side of the body [2]. Despite such changes, almost all children develop the ability to walk independently without assistance [3, 4]. The main secondary orthopaedic disorders in spastic hemiplegia are contractures of the ankle, knee and hip joints, equinovarus or equinovalgus foot deformities, torsion deformities of the femur, and limb length discrepancy [5–7].

Computer gait analysis is necessary in most cases for diagnosing motion disorders and determining indications for surgical treatment [8, 9]. Recognized surgical approaches to correction of orthopaedic disorders are one-stage multilevel interventions that provide improvement in gait parameters over a follow-up period of more than 10 years [2, 10, 11]. However, isolated triceps lengthening at an early age of 4–6 years is considered an operation that has indications [3, 12], despite the fairly high rate of contracture recurrence which is associated with leg length discrepancy and poor function of the dorsal flexors [13].

The available classifications of gait disorders in spastic hemiplegia reflect the types of disorders and the general direction of the evolution of disorders as the child grows [3, 14, 15]. It is known that intensive conservative measures can improve the motor abilities of a child with GMFCS level I with spastic hemiparesis [2, 16].

However, there are insufficient literature sources on the effect of early isolated surgeries to lengthen the triceps surae for hemiparesis on the state of motor characteristics and the development of orthopaedic complications in children with GMFCS II level at an age corresponding to stages 2 and 3 of compensated orthopaedic changes (contractures and bone deformities) according to Graham et al. [16].

Purpose Analyze motor locomotion in children with spastic hemiplegia who had not previously been operated on and those who had undergone isolated surgical lengthening of the triceps at an early age.

MATERIALS AND METHODS

Inclusion criteria were age range of 9 up to 16 years, diagnosis of cerebral palsy, GMFCS II, spastic hemiparesis, no previous multilevel surgical interventions. Before surgery, all patients underwent 3D computer gait analysis.

Exclusion criteria were age 16 years and older, diagnosis of cerebral palsy, GMFCS III, spastic diplegia, previous multilevel surgical interventions.

The study groups were formed according to the clinical classification of gait, determined by visual control [3], and according to the criterion of triceps surae lengthening performed in an early age.

During the examination procedure, the patients walked independently or holding one hand of a parent, barefoot on a 7-meter path at their usual speed. Kinematic data was recorded by Qualisys 7+ optical cameras with passive marker video capture technology; synchronized with six KISTLER dynamometer platforms (Switzerland). The IOR model was used for setting markers. The analysis of kinematics and kinetics was carried out in the QTM (*Qualisys*) and Visual3D (*C-Motion*) programs with automated calculation of values [17].

For statistical data processing, the AtteStat 12.0.5 software was used. Given the small number of the sample, nonparametric statistics were used. Quantitative characteristics of indicators in sample populations were presented in tables in the form Me (25 ÷ 75 %), and the statistical significance of differences was determined using the unpaired Wilcoxon test for independent variables, accepting a significance level of $p \leqslant 0.05$.

To conduct the research, permission was obtained from the ethics committee at the Federal State Budgetary Institution Ilizarov National Medical Research Center for Traumatology and Orthopaedics, protocol No. 2 (72) dated 07.10.2022. The studies were 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 "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. Parents of children participating in the study were present during the study and signed informed consent for its conduct and publication of research results without personal identification.

RESULTS

The following groups were formed from the total sample of 23 patients:

— Group I: type 2a according to Rodda et Graham: 4 subjects, aged 10 (9 ÷ 11.8) years, no previous surgery;

— Group II: type 3 according to Rodda et Graham: 3 subjects, aged 10 (9.5 ÷ 10) years, no previous surgery;

— Group III: type 4 according to Rodda et Graham: 7 subjects, aged 11 (9.25 ÷ 11) years, no previous surgery;

— Group IV: type 4 according to Rodda et Graham: 9 subjects, aged 11 (10 ÷ 14) years, triceps surae lengthening was performed at the age of 3–6 years. To lengthen the triceps, the methods of lengthening the Achilles tendon (3 cases) and percutaneous fibromyotomies (6 cases) were used.

Table 1 presents the spatiotemporal characteristics of walking and the integral index of the gait profile score (GPS).

Table 1

Spatiotemporal characteristics of walking, GPS

Parameter		Groups of patients			
		I	II	III	IV
GPS		9 (8.05 ÷ 10.78)	**13.6 (13.1 ÷ 17.8)[1]**	10.6 (8.7 ÷ 12.6)	13.5 (12.6 ÷ 17.2)
Speed; m/sec		1.01 (0.98 ÷ 1.05)	0.9 (0.89 ÷ 0.91)	0.84 (0.66 ÷ 0.98)	0.92 (0.77 ÷ 1.12)
Step width, m		0.11 (0.098 ÷ 0.13)	**0.16 (0.13 ÷ 0.17)[1]**	0.12 (0.07 ÷ 0.15)	0.15 (0.11 ÷ 0.19)
Step period length, m		1.08 (1.02 ÷ 1.09)	0.98(0.95 ÷ 0.99)	1.01 (0.08 ÷ 1.06)	0.99 (0.91 ÷ 1.08)
GPS	A	9 (8.05 ÷ 10.8)	**15.4 (15.35 ÷ 20.5)[1]**	**10.5 (8.9 ÷ 11.8)***	13.7 (11.7 ÷ 18.7)
	C	11.5 (11.1 ÷ 11.9)	10.7 (10.6 ÷ 13.1)	10.7 (8.8 ÷ 12.5)	12.8 (10 ÷ 13.9)
Step length; m	A	0.55 (0.52 ÷ 0.55)	0.49 (0.48 ÷ 0.49)	0.49 (0.39 ÷ 0.52)	0.49 (0.45 ÷ 0.52)
	C	0.53 (0.50 ÷ 0.53)	0.5 (0.5 ÷ 0.52)	0.52 (0.48 ÷ 0.54)	0.49 (0.44 ÷ 0.53)
Gait cycle time; sec	A	0.55 (0.50 ÷ 0.58)	0.61(0.59 ÷ 0.61)	0.58 (0.55 ÷ 0.68)	0.58 (0.55 ÷ 0.63)
	C	0.48 (0.44 ÷ 0.52)	0.5 (0.47 ÷ 0.5)	0.53 (0.48 ÷ 0.59)	0.51 (0.43 ÷ 0.55)
Stance phase, %	A	59.2 (56.7 ÷ 60.1)	57 (57 ÷ 57.8)	60.8 (59.7 ÷ 63)	59.9 (53.3 ÷ 61.1)
	C	62.1 (60.4 ÷ 63.3)	67 (65.5 ÷ 67.5)	64.4 (62.7 ÷ 69.9)	65.7 (64.1 ÷ 66.3)
Swing phase, %	A	41.3 (39.7 ÷ 44.3)	42 (41.9 ÷ 42.5)	39.2 (37 ÷ 40.6)	39.4 (38.7 ÷ 40.7)
	C	38.6 (37.1 ÷ 40.1)	33 (32.5 ÷ 34.6)	35.6 (33.1 ÷ 37.3)	34.3 (34.1 ÷ 36.1)

Note: A — affected limb, C — contralateral limb; * — significant differences according to the Wilcoxon test ($p < 0.05$) between groups III and IV; [1] — significant differences according to the Wilcoxon test ($p < 0.05$) between groups I and II

The significant differences in GPS found between the groups of gait types 2a and 3 rather indicate a natural evolution of motor disorders in increased severity of orthopaedic disorders, which is also reflected in step instability in the frontal plane. The differences between groups of gait types 4 (non-operated) and 4 (operated) are rather functional in nature, which is presented in more detail below. Tables 2, 3 and 4 show the features of the kinematics of the ankle, knee and hip joints in the sagittal plane and the moments of force.

Table 2

Ankle joint kinematics, N·m/kg

Parameter		Groups of patients			
		I	II	III	IV
Foot position at initial contact, °	A	**–6.2 (–13 ÷ –3.7)**	**–27.4 (–30.9 ÷ –26.7)[1]**	–8.2 (–10.2 ÷ –3.4)	–9.7 (–31.7 ÷ –8.4)
	C	6.8 (5.2 ÷ 8.5)	4.4 (3.2 ÷ 5.2)	5 (2 ÷ 5.5)	–0.3 (–3.2 ÷ 1.7)
Maximum dorsiflexion,°	A	–1.5 (–5.5 ÷ 3.5)	**–25 (–28.4 ÷ –24.5)[1]**	4.3 (–5.3 ÷ 6.8)	5.3 (–30.4 ÷ 11.0)
	C	19.1 (13.1 ÷ 23.3)	17 (16.1 ÷ 23)	17.7 (15.3 ÷ 20.6)	17 (13.4 ÷ 21.2)
Maximum plantar flexion,°	A	–12.2 (–19.3 ÷ –11.3)	**–36.7 (–46.9 ÷ –35.9)[1]**	–10.4 (–17.7 ÷ –6.9)	–14.2 (–20.2 ÷ –5.6)
	C	–11.2 (–17.5 ÷ –8.3)	–11.3 (–14.2 ÷ –8.7)	–11 (–20 ÷ –7.3)	–16 (–16.4 ÷ –12.3)
Ankle range of motion during gait cycle,°	A	15.5 (12.4 ÷ 20.9)	11.7 (11.4 ÷ 18.5)	15.3 (1.2 ÷ 20)	15.5 (13.7 ÷ 24.3)
	C	35.4 (29.6 ÷ 37.8)	34 (30.3 ÷ 34.5)	25.9 (23.7 ÷ 31.8)	31.9 (25.9 ÷ 40.5)
Step clearance at forefoot, cm	A	4.1 (3.8 ÷ 5.1)	4.9 (4.8 ÷ 5.2)	4.5 (3.9 ÷ 5.9)	5.3 (5 ÷ 5.5)
	C	5.3 (5.1 ÷ 5.7)	6 (5.8 ÷ 7.4)	5.5 (5.1 ÷ 6.3)	6.3 (5.5 ÷ 7.4)
Relative force moment of dorsiflexion, N·m/kg	F	0 (–0.01 ÷ 0.02)	0.007 (0.0065 ÷ 0.0075)	–0.006 (–0.023 ÷ –0.007)	–0.004 (–0.007 ÷ –0.002)
	C	–0.05 (–0.08 ÷ –0.02)	–0.104 (–0.105 ÷ –0.08)	–0.101 (–0.134 ÷ –0.076)	–0.056 (–0.075 ÷ –0.027)
Relative moment of plantar flexion, N·m/kg	A	0.84 (0.66 ÷ 1.02)	**0.47 (0.39 ÷ 0.48)[1]**	1.05 (0.92 ÷ 1.1)	**0.77 (0.4 ÷ 1.16)***
	C	1.3 (1.1 ÷ 1.4)	**1.43 (1.33 ÷ 1.46)[2]**	1.15 (1.07 ÷ 1.23)	1.32 (1.04 ÷ 1.36)

Note: A — affected limb, C — contralateral limb; * — significant differences according to the Wilcoxon test ($p < 0.05$) between groups III and IV; [1] — significant differences according to the Wilcoxon test ($p < 0.05$) between groups I and II; [2] — significant differences according to the Wilcoxon test ($p < 0.05$) between the affected (A) and contralateral limb (C)

Table 3

Kinematic and kinetics of the knee joint

Parameter		Groups of patients			
		I	II	III	IV
Knee position at initial contact, °	A	24.7 (22.5 ÷ 25.8)	30.1 (29.5 ÷ 40.7)	19.4 (12.4 ÷ 26.8)	22.3 (19.8 ÷ 29.8)
	C	24 (20.6 ÷ 28.6)	17 (15.5 ÷ 27.4)	24.5 (21.6 ÷ 28.4)	19.5 (18 ÷ 31)
Maximum extension, mid single support phase,°	A	9.3 (7.8 ÷ 11.5)	**27 (24.9 ÷ 27.6)[1]**	6.9 (4.8 ÷ 14.2)	10.8 (7.1 ÷ 28.8)
	C	17.4 (14.8 ÷ 20.3)	7.2 (5.4 ÷ 14.6)	11.8 (9.4 ÷ 13.3)	14.6 (10 ÷ 15.8)
Maximum flexion in swing phase,°	A	62.8 (61.5 ÷ 64.9)	54.8 (53.9 ÷ 66.5)	56.5 (52.7 ÷ 66.5)	52 (50 ÷ 59.2)
	C	72.3 (66.4 ÷ 75.1)	63 (61.7 ÷ 66)	61.5 (56.4 ÷ 67.2)	71.2 (65.7 ÷ 71.8)
Range of motion during gait cycle, °	A	50.9 (47.5 ÷ 57.2)	**26 (23.4 ÷ 26.3)[1]**	49.1 (43.9 ÷ 51.4)	**29.3 (27.8 ÷ 46.9)***
	C	54.6 (50.9 ÷ 55.6)	60.4 (58.6 ÷ 77)	48.6 (45.9 ÷ 56.6)	56 (50.4 ÷ 56.6)
Relative force moment of knee extension, N·m/kg	A	0.38 (0.32 ÷ 0.49)	**0.77 (0.7 ÷ 0.93)[1]**	0.3 (0.2 ÷ 0.41)	**0.69 (0.27 ÷ 0.71)***
	C	0.68 (0.59 ÷ 0.79)	1.35 (1.25 ÷ 1.38)	0.65 (0.53 ÷ 0.75)	0.97 (0.71 ÷ 1.17)

Note: A — affected limb, C — contralateral limb; * — significant differences according to the Wilcoxon test ($p < 0.05$) between groups III and IV; [1] — significant differences according to the Wilcoxon test ($p < 0.05$) between groups I and II; [2] — significant differences according to the Wilcoxon test ($p < 0.05$) between the affected (A) and contralateral limb (C)

Table 4

Kinematic s and kinetics of the hip joint

Parameter		Groups of patients			
		I	II	III	IV
Position at initial contact, °	A	33.1 (31.1 ÷ 36.15)	32 (31.6 ÷ 43.2)	28 (18.9 ÷ 33.8)	31.1 (30.4 ÷ 36.3)
	C	44.2 (37.3 ÷ 47.4)	43.3 (38.7 ÷ 47.9)	30.9 (30 ÷ 37.6)	35.4 (32 ÷ 41.8)
Maximum extension, single support phase, °	A	–3.7 (–4.4 ÷ –2.5)	**8 (7.6 ÷ 16.5)[1 2]**	–8.1 (–9.3 ÷ –3.7)	**2.7 (–5.2 ÷ 3.9)***
	C	–6.7 (–7.5 ÷ –3.8)	–11.0 (–12.5 ÷ –11.5)	–6.9 (–13 ÷ –6.3)	–10.1 (–13 ÷ –7.9)
Maximum flexion in a swing phase, °	A	39.3 (38.5 ÷ 41.6)	36 (35.9 ÷ 48.6)	31 (22.4 ÷ 41)	39 (30.9 ÷ 40.7)
	C	44.8 (39.03 ÷ 49)	41 (38.2 ÷ 51.5)	31.8 (30.9 ÷ 35.8)	39.6 (32.4 ÷ 42.7)
Maximum range of motion during gait cycle, °	A	42.6 (40.2 ÷ 46.5)	**29.9 (28.9 ÷ 33)[1 2]**	39.7 (34.4 ÷ 45.5)	36.1 (33.1 ÷ 42.9)
	C	47.6 (37.9 ÷ 57.7)	53.2 (49.8 ÷ 64.1)	37.8 (37.4 ÷ 46.5)	43.5 (40.2 ÷ 50.2)
Relative force moment of hip flexion, N·m/kg	A	–0.44 (–0.52 ÷ –0.35)	–0.34 (–0.49 ÷ –0.29)	–0.41 (–0.57 ÷ –0.31)	–0.46 (–0.53 ÷ –0.39)
	C	–0.42 (–0.52 ÷ –0.38)	–0.78 (–0.79 ÷ –0.75)	–0.4 (–0.63 ÷ –0.34)	–0.69 (–0.74 ÷ –0.66)
Relative force moment of hip extension, N·m/kg	A	0.76 (0.68 ÷ 0.81)	**0.94 (0.85 ÷ 1.195)[1]**	0.52 (0.45 ÷ 0.78)	**0.84 (0.66 ÷ 1.05)***
	C	0.75 (0.56 ÷ 0.97)	0.97 (0.96 ÷ 1.14)	0.63 (0.56 ÷ 0.79)	0.9 (0.85 ÷ 1.21)

Note: A — affected limb, C — contralateral limb; * — significant differences according to the Wilcoxon test ($p < 0.05$) between groups III and IV; [1] — significant differences according to the Wilcoxon test ($p < 0.05$) between groups I and II; [2] — significant differences according to the Wilcoxon test ($p < 0.05$) between the affected (A) and contralateral limb (C)

A clear difference in the parameters of ankle joint movements on the involved side is visible between gait types 2a and 3 in the data presented in Table 2: the limitation in the range of motion is carried out only in the plantar flexion sector at any moment of the gait cycle. This is precisely what explains the positive values of the moment of dorsal flexion forces, when there is practically no change in the position of the foot from the moment of initial contact to the middle of the single-support phase in gait type 3 (Fig. 1). We also note significant differences in the values of the moment of plantar flexion forces during concentric contraction between the healthy and involved limb in patients of the same subgroup, which is explained by the pronounced contracture of the triceps, characteristic of this situation, when the patient practically ceases to articulate in the ankle joint and moves bearing weight on the foot almost in a vertical position with a reduced overall range of motion (Fig. 1).

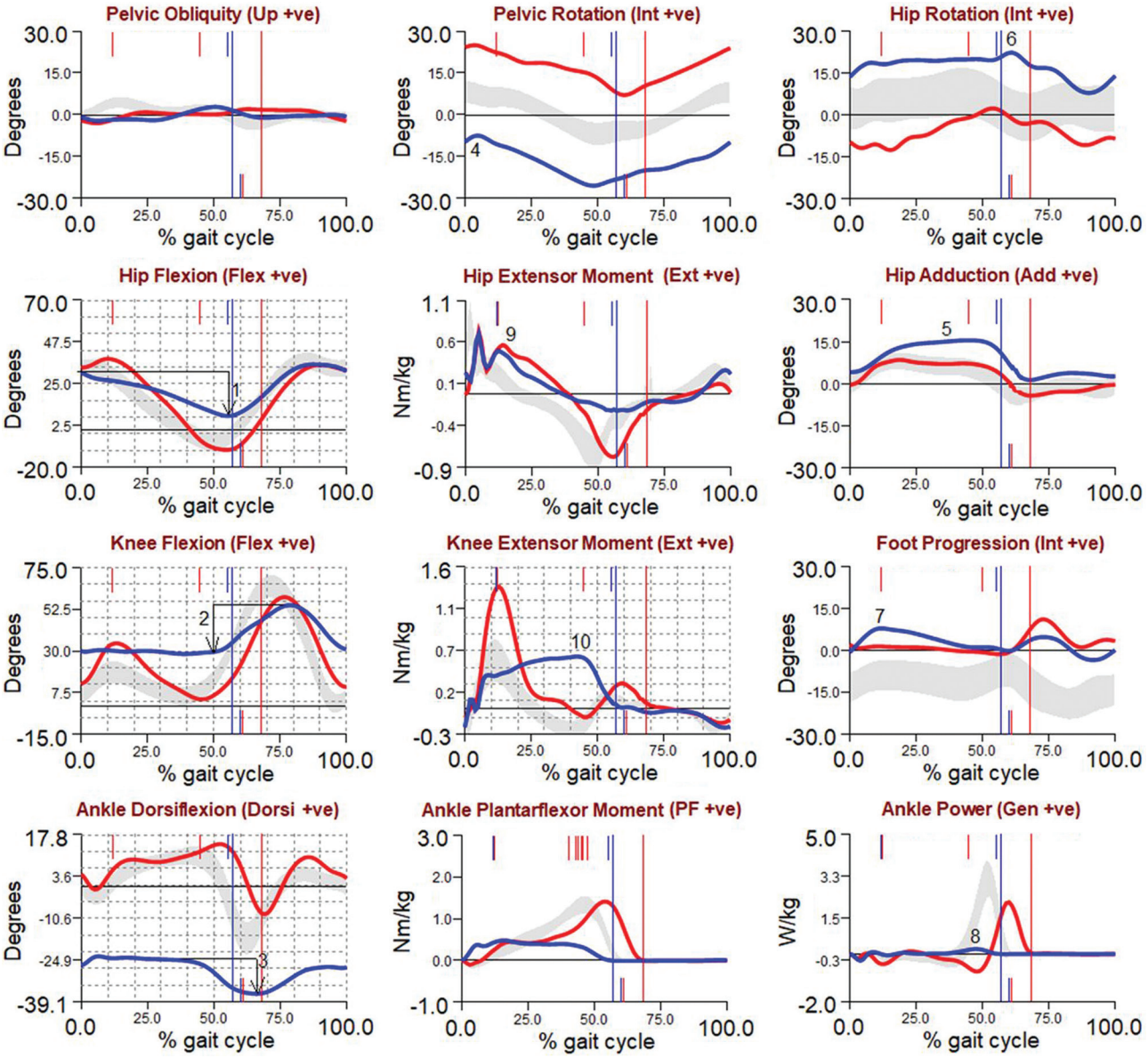

Fig. 1 Example of kinematic and kinetic diagrams of patient E (gait type 3), right-sided spastic hemiparesis (blue lines: involved limb): reduced range of motion in the hip (1), knee (2) and ankle joints (3) in the sagittal plane; these joints are in a flexion position (ankle: plantar flexion); typical pelvic tilt and compensatory rotation (4), moderate hip adduction during walking (5), pronounced torsion of the hip (6) and corresponding internal rotation of the foot (7) relative to the movement vector, reduced power characteristics of the plantar push (8), propulsion is carried out due to an increased moment of force during concentric contraction of the hip extensors (9), the work of the knee joint extensors (10) is aimed only at preventing further flexion in the knee joint in the support phase and can be characterized as an element typical of a stiff knee gait

An interesting finding is a significant decrease in the moment of plantar flexion in patients of group 4 (operated) in comparison with patients who have not previously been operated on (Fig. 2). It is obvious that after the operations performed there was no functional recovery. We also note the appearance of positive values of dorsal flexion in patients of groups 4 (operated). We explain these measurements by the formation of a plano-valgus abducted foot deformity (elevation of the forefoot) at this stage of the orthopaedic problems development, when in the sagittal plane, without taking into account the deviation, the foot is projected in a position of dorsiflexion.

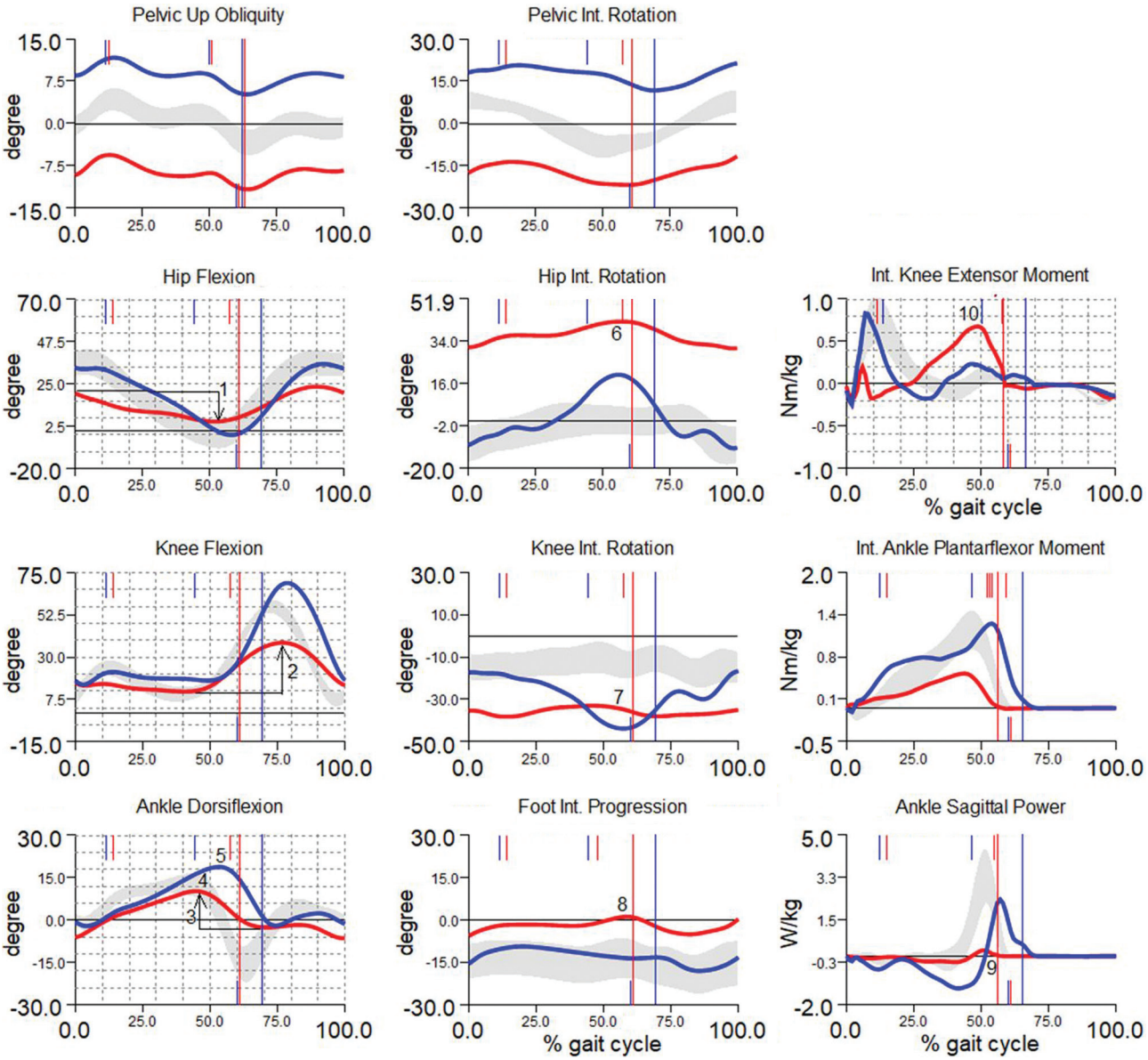

Fig. 2 Example of kinematic and kinetic graphs of patient V. (gait type 4, operative), left-sided spastic hemiparesis (red lines — involved limb): reduced range of motion in the hip (1), knee (2) and ankle joints (3) in the sagittal plane, the hip and knee joint are in a moderate flexion position, at the moment of the support phase there is sufficient dorsal flexion of the foot (4) and excessive (5) on the side not involved on the left, typical tilt of the pelvis and its compensatory rotation, pronounced intrarotational position of the hip (6) is partially compensated by external torsion of the lower leg (7), which is summarized by moderate internal rotation of the foot relative to the movement vector (8), reduced power characteristics of the plantar thrust (9), the work of the knee extensors is significantly increased relative to the uninvolved side (10) and compensates for weakness plantar flexors to maintain a sufficient angle of extension of the knee joint in the support phase, however, a sharp decrease in the amplitude of knee joint flexion in the non-support phase proves the formed compensatory element stiff knee gait

The flexion position of the knee joint in group III with a low range of motion throughout the entire gait cycle (compensatory stiff knee gait; Fig. 1) explains the increased moment of force of knee joint extension in comparison with group II. For group IV (Fig. 2), a significant decrease in the range

of movements throughout the gait cycle, as well as increased values of the knee joint extension moment, reflect an adaptation mechanism in response to the weakened contractile function of the triceps surae.

A decrease in the overall range of motion in the hip joint due to its flexion contracture in the sagittal plane in patients with type 3 (Fig. 1) compared to type 2 leads to the need to increase the moment of extension forces to ensure propulsion (with concentric contractions of the hip extensors) at the end of the single-support gait phase (Table 4). The appearance of foot deformities that provide support not only on the forefoot allows patients of subgroups 4 and 4 (operated) to move with effective hip extension (Fig. 2). However, due to weakening of the triceps surae in patients in group 4 (operated), propulsion is provided not so much by plantar flexion as by extension in the hip joint, which is reflected in a significant difference in the values of the moment of extension forces in the hip joint.

Studies of pelvic and hip movements in the horizontal and frontal planes, as well as changes in the orientation of the common axis of the foot relative to the vector of movements, allowed us to go beyond the Rodda et Graham classification in understanding the kinematics of spastic hemiparesis (Table 5).

Table 5

Kinematics of the pelvis and femur in the frontal and horizontal plane, orientation of the common axis of the foot

Parameter	Limb		Groups of patients			
			I	II	III	IV
Pelvic obliquity, °	A	max	6.2 (4.8 ÷ 6.9)	3.1 (0.75 ÷ 3.5)	4.9 (2.33 ÷ 7.33)	3.5 (0.8 ÷ 6.3)
		min	−3.6 (−6.1 ÷ −1.8)	−3.4 (−4.5 ÷ −3.1)	−1.95 (−5.38 ÷ 0.18)	−3.1 (−5.4 ÷ 0.7)
	C	max	3.7 (1.9 ÷ 6.2)	2.1 (0.5 ÷ 2.3)	2.1 (−2.71 ÷ 4.95)	3.3 (−1.1 ÷ 4.9)
		min	−6.9 (−7.6 ÷ −5.3)	−7.1 (−9.3 ÷ −5.2)	−4.9 (−6.9 ÷ −2.05)	−3.2 (−8 ÷ −1.3)
Pelvic rotation, °	A	max	**9.2 (7.8 ÷ 9.6)**[2]	**4.1 (2.5 ÷ 5.2)**[2]	**1.1 (−4.7 ÷ 4.2)**[2]	**3.2 (−0.5 ÷ 9.1)**[2]
		min	−12.7 (−14.6 ÷ −11.8)	−22.7 (−24.3 ÷ −17.8)	−18.2 (−23 ÷ −14.6)	−18.1 (−21.8 ÷ −10.8)
	C	max	13.5 (12.1 ÷ 16.5)	26.4 (26.1 ÷ 26.7)	18.2 (15.6 ÷ 25.85)	22.9 (12.5 ÷ 26.8)
		min	−7.5 (−8.95 ÷ −6.03)	5.0 (0.9 ÷ 5.9)	−0.3 (−3.4 ÷ 6.15)	−1.2 (−5.4 ÷ 2.9)
Femur adduction, °	A	max	10.1 (7.4 ÷ 11.6)	4.9 (4.75 ÷ 5.15)	7.7 (0.05 ÷ 11.48)	8 (5.4 ÷ 10.9)
		min	−7.6 (−9.7 ÷ −5.4)	−7.8 (−9.7 ÷ −6.3)	−5.05 (−8.2 ÷ −2.65)	−4 (−10.5 ÷ −2.5)
	C	max	8.7 (7.7 ÷ 10.7)	9.3 (9.15 ÷ 9.5)	6.15 (4.75 ÷ 10.5)	7.3 (4.2 ÷ 8.6)
		min	−5.9 (−8.1 ÷ −4.9)	−8.6 (−10.2 ÷ −10.8)	−10 (−12.15 ÷ −4.8)	−10 (−12.6 ÷ −6.1)
Femur rotation, °	A	max	19.2 (12.5 ÷ 27.6)	**24.8 (23.9 ÷ 27.5)**[2]	19.6 (14.05 ÷ 23.2)	**21.2 (16.4 ÷ 30.1)**[2]
		min	−5.3 (−10.1 ÷ 1.95)	8.1 (7.8 ÷ 12.3)	−0.45 (−8.8 ÷ −4.8)	6.4 (0.3 ÷ 12.7)
	C	max	13.9 (12.5 ÷ 14.5)	9.1 (7.9 ÷ 18.9)	11.3 (7.23 ÷ 17.9)	6.1 (−2.7 ÷ 22.7)
		min	−8.6 (−13.3 ÷ 5.95)	−5.6 (−9.6 ÷ 0.45)	−15 (−19.5 ÷ −5.4)	−9.7 (−20.1 ÷ −3.1)
Foot orientation, °	A	max	4.9 (−2.3 ÷ 11.4)	11.0 (9.6 ÷ 24.9)	4.1 (−3.2 ÷ 14.2)	14.8 (7.2 ÷ 20.1)
		min	−16.5 (−19.2 ÷ −11.6)	−3.9 (−4.4 ÷ 2.3)	−15.0 (−20.2 ÷ −2.6)	−3.8 (−11.8 ÷ 6.1)
	C	max	13.1 (11.1 ÷ 14.2)	9.0 (8.7 ÷ 10.5)	3.3 (−5.05 ÷ 9.98)	7.0 (−0.2 ÷ 15.4)
		min	−4.45 (−9.8 ÷ −3.45)	−7.4 (−10.6 ÷ −5.5)	−12.9 (−20.6 ÷ −5.6)	−13.8 (−21.5 ÷ −1.9)

Note: A — affected limb, C — contralateral limb; [2] — significant differences according to the Wilcoxon test ($p < 0.05$) between the affected (A) and contralateral limb (C)

The movements of the pelvis in the frontal plane are identical and similar in amplitude in all subgroups: the predominant tilt of the pelvis towards the involved limb. Let us again note the decrease in the total amplitude of movements characteristic of the type 3 group. Even more demonstrative changes concern the kinematics of the pelvis in the horizontal plane. During the gait cycle, the rotation of the pelvis towards the involved limb dominates, which is significantly different from the uninvolved limb in all groups (Fig. 1 and 2), while the amplitude of pelvic rotation remains almost symmetrical between the involved and healthy limbs. During walking, the femur is evidently in the adducted position, with values significantly different from the uninvolved limb in groups 3 and 4 (operated). At the same time, the range of hip motion in the frontal plane in the patients of this study remains balanced.

Just like on average, there is orientation of the feet relative to the vector of movements. However, internal rotation of the foot of 15 degrees or more was observed in one patient in the type 3 group, two patients in the type 4 group, and four patients in the type 4 group (operated). This position is regarded as decompensation. In our sample, it was caused by torsion deformities of the femur in 4 cases and varus-supination deformity of the foot in three cases.

DISCUSSION

The first proposed classification of gait disorders in unilateral spastic lesions is that of Winters et al. [14], which distinguishes 4 groups based on the pathology of movements of the affected side limb in the sagittal plane. The classification reflects the progression of disorders from the distal level to the proximal level (from movement disorders in the ankle joint to the hip) as the severity of the disease increases. However, it was stated that the identified disorders cannot be determined according to this classification in 23 % of cases [15]. The Rodda et Graham classification is the most general and describes gait features in children with hemiparetic forms of cerebral palsy [3]. The classification reflects the progression of disorders from the distal level to the proximal level (from movement disorders in the ankle joint to the hip) as the severity of the disease increases.

Group 1 is characterized by an equinus position of the foot in the non-support phase of the gait cycle, the absence of the first rocker of the foot at the beginning of the support phase of the gait. The disorders are caused by weakness or underactivity of the tibialis anterior muscle in comparison with the gastrocnemius and soleus muscles. In group 2a, the foot is in an equinus position in the non-support phase of the gait cycle and in a constant plantar flexion; in group 2b, equinus contracture is observed in combination with recurvatum in the knee joint in the support phase. Group 2 disorders are caused by contracture of the triceps surae. In group 3, in addition to the above-mentioned disorders of groups 1 and 2, restriction of leg flexion at the knee joint in the non-support phase of the gait cycle and excessive flexion at the hip joint are added. In group 4 disorders, in addition to the previous disorders, there is a reduced range of motion in the hip and knee joints throughout the stepgait cycle and torsion deformities (pathological rotation of the hip). It should be noted that the classification does not consider lower limb discreapncy in assessing the severity of orthopaedic and motor disorders. We also did not find sufficient evidence in the literature that the progression of gait disorders correlates with the age of the child, as it is typical for spastic diplegia.

A number of additional studies based on computer gait analysis could clarify the features of movement of the foot, its anterior and posterior parts, which is important for choosing a method for correcting foot deformities and/or its intra-torsional position [18]. In addition to understanding the mechanism and elements of movement disorders in hemiparesis, 3D gait analysis enables to determine the level and magnitude of correction of deformities in the horizontal plane [7, 19, 20]. Our study also assists to distinguish torsion deformities (decompensated or compensated [34], there are mutually opposite directions at the level of the femur and lower leg) from foot deformities and determine the degree of necessary correction.

An important finding of our study is the identification of rotational turn in all studied subgroups of patients, which complements the description of gait features in the Rodda et Graham classification [3]. Rotational turn of the pelvis was previously considered as a pathological element caused by the topography of neurological lesions [21, 22]. Currently, torsional rotation of the pelvis is considered either as a result of spasticity and/or retraction of the muscles of the involved side, or as a compensatory mechanism that allows the axis of the foot on the side of the intratorsional deformation of the hip to be set in a more or less correct position relative to the movement vector [19, 23]. We believe that the presence of pelvic rotation in any of types 2–4 gait disorders found in our study is compensatory in nature, as it is combined with symmetrical amplitudes of pelvic movements on both sides. But as violations exist, this compensatory position becomes irreducible, which refers to tertiary violations [24–26]. We also point out that the following factors are associated with and determine the ineffectiveness of isolated surgical correction by the development of pathological rotational position of the pelvis: intratorsional deformity of the femur, Winter type 2

gait, limitations in dorsiflexion of the foot, anterior tilt of the pelvis and asymmetrical position of the upper limb from the side of the neurological lesion [27].

In our study, the most significant deviations in the total gait index (GPS) were observed in type 3. It is obvious that characteristic severe contractures restrict both the possibility of symmetrical support and a sufficient range of movements in the joints, reducing the strength characteristics of movements [2, 3, 8] . From this point of view, even greater impairments should be expected in type 4 according to Rodd et Graham. However, our study did not find such a hypothesized pattern. We hypothesize that the addition of a foot deformity that allows full support on this segment, and in the conditions of a healthy contralateral limb, improves the conditions for the implementation of movements in the knee and ankle joints of the involved limb.

We also note that in the group of patients who had triceps lengthened at an early age, we observe the presence of typical gait disorders for type 4, pathology of movements and orthopaedic disorders, as in the group of patients with the same type of disorders (type 4), but without orthopaedic operations . The only difference is a decrease in the contractility of the triceps for propulsion in combination with a compensatory increase in the moment of force of extension of the knee joint and the development of limited knee flexion in the swing phase (an element characteristic of stiff knee gait). This phenomenon of early isolated operations that weaken the triceps surae is characteristic of spastic diplegia [28, 29]. Obviously, this option of early operations does not lead to an improvement in the orthopaedic situation at an older age and only contributes to an increase in energy consumption for movement.

Limb length inequality in spastic hemiplegia is reflected in pelvic tilt, compensatory flexion of the hip and knee joints and conjugated dorsiflexion on the healthy side [31]. Our study also reflected these features, which emphasizes the importance of different leg length for the biomechanics of walking in hemiparesis. It is expected that correction of length discrepancy will avoid the involvement of a healthy limb in compensation for this orthopaedic pathology [32, 33].

The weaknesses of our study are its cross-sectional nature, without observing the evolution of gait pathology elements over time in children, without studying gait parameters before early orthopaedic operations. Another aspect that requires additional research is the study of adaptive changes in the movements of the contralateral limb, both in comparison with the involved limb and in comparison with healthy peers.

CONCLUSION

Pathology of movements detected by computer gait analysis is present in all three planes of measurements in gait types II, III, IV according to the Rodda et Graham classification. The most pronounced deviations in walking were identified in patients with gait type III.

Rotation of the pelvis is initially a compensatory mechanism caused by intratorsional hip deformation, allowing the axis of the foot to be oriented close to the walking direction vector.

Isolated triceps lengthening operations performed at an early age lead to a deterioration in gait parameters associated with a decrease in the force of the plantar impulse, an increase in the compensatory work of the knee extensors and the overall energy expenditure for walking and probably do not prevent the orthopaedic pathology that occurs in Rodda et Graham type IV gait.

Conflict of interest *None.*

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Ethical review *Not required.*

Informed consent *Not required.*

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Clinical case
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Impaction bone grafting as a method of choice in bone defect management in the revision hip arthroplasty: a cases series

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Abstract

Introduction Reconstruction of the acetabulum during revision arthroplasty is a challenging task in the setting of massive bone defects. Often the only effective method is impaction bone grafting (IBG).

The purpose is to demonstrate the capabilities of the X-Change impaction bone grafting technology in replacing acetabular defects as a method of choice for revision hip arthroplasty.

Materials and methods In the presented series of cases, the use (IBG) turned out to be the method of choice, allowing for high-quality reconstruction. In each presented case, revision hip arthroplasty was performed with augmentation with a reconstructive mesh or trabecular metal augment to create support and contain the defect to retain the osteoplastic material.

Results During follow-up periods of 4.8 to 6.5 years there were no signs of resorption or loosening. According to the Harris hip score the results were 96, 97 and 89 points respectively.

Discussion Impaction bone grafting technology is quite versatile. It can be used in various coditions of revision arthroplasty with contained defects of the acetabulum. In contrast to the use of modular revision augmentation systems and additive technologies it makes possible to achieve dense filling of the smallest defects and profile a bed congruent with the acetabular component. The use of cemented fixation makes it possible to further stabilize the impacted bone chips and use mechanotransduction mechanisms that stimulate the bone remodeling. The use of IBG has proven to be an effective technique for the reconstruction of medium-sized acetabular defects in combination with mesh and cement cup, as well as in combination with trabecular metal augments.

Conclusion The use of IBG during revision hip arthroplasty can be especially effective for small acetabulum sizes. Combining IBG with trabecular metal augments significantly expands the application of this technology. The use of IBG makes it possible to create a bone reserve, which creates more favorable conditions for inevitable repeated revision interventions.

Keywords: Impaction bone grafting, trabecular metal augments, acetabular defects, revision arthroplasty

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INTRODUCTION

Reconstruction of the acetabulum in revision or primary complex arthroplasty is a difficult task in the conditions of massive bone defects. This problem is especially relevant in the treatment of young patients, when it is important to restore the center of rotation of the femur, achieve stable fixation of the implant, restore the anatomy of the acetabulum and the bone mass of the pelvic bone. To date, various methods of bone defect filling have been known such as reconstructive cages [1], structural grafts [2], modular augmentation systems [3], additive technologies that have been developed in recent years [4] and impaction bone grafting [5]. The location, geometric shape, size and bone defect extention usually determine the choice of reconstruction method [6, 7]. Each of the listed above methods has certain advantages and disadvantages, but sometimes the limitations that arise allow the use of only one possible method of effective arthroplasty. In a specific situation, this method may be a fairly universal technology of impaction bone grafting, the main advantage of which is the ability to restore the lost pelvic bone mass and thereby create the prerequisites for the success of subsequent inevitable revisions [8].

Purpose Demonstration of the capabilities of the X-Change impaction bone grafting technology in the management of acetabular defects as a method of choice in revision hip arthroplasty.

MATERIALS AND METHODS

A retrospective analysis of clinical data on the use of impaction bone grafting with the original "X-Change" technology and specialized instrumentation in cases of primary complex and revision hip arthroplasty for management of bone defects in the acetabulum area was carried out.

From 2015 to 2022, 87 operations on the hip joints in 83 patients were performed at the Federal State Budgetary Institution Federal Center of Traumatology, Orthopedics and Arthroplasty of the Ministry of Health of Russia (Barnaul) using impaction bone grafting with the "X-Change" technology as the main technique. Of those, the technology was used for primary complex arthroplasty in 10 cases, three operations on the femoral segment, seven on the acetabulum. In 77 revision arthroplasties, IBG was used in 36 cases on the acetabular component, in 29 cases on the femoral component, and in 12 cases simultaneously on the pelvic and femoral segments. In some cases of pelvic reconstruction, the use of IBG at the time of surgery turned out to be the only available method that enabled to perform high-quality reconstruction of the acetabulum. Three clinical cases were included in this demonstration series which fully reflected the philosophy of IBG.

The indications for the use of IBG on the pelvic segment were massive limited and combined defects of the acetabulum:

1) Case 1 was a massive 3D defect according to Paprosky or type III according to the AAOS classification of complex geometry, caused by secondary deformation due to mechanical wear of a loosened pelvic component;
2) Case2 was 2B Paprosky defect with minimal bone stock due to dysplasia and previous primary arthroplasty failure;
3) Case 3 had a massive iatrogenic defect of AAOS type III after removal of the pelvic component due to periprosthetic infection, which had its own indications for the installation of a spacer and its subsequent removal.

At the time of surgical treatment, infection was excluded in all cases that was proven by cytological, microscopic and bacteriological preoperative examination of synovial fluid aspirate from the joint. It was also confirmed by the results of bacteriological study of biopsies taken during the surgery and removed components.

Bone chips made from allobone that underwent thermal disinfection according to the Marburg bone bank system were used as a bone plastic material (BPM). For pelvic bone grafting, chips were

hand-cut to a size of approximately 10 mm^3 using Luer cutters. The BPM compaction was performed with profiling impactors for the acetabulum from the specialized X-Change instrumentation set (Stryker). In all three cases, additional structures were used in combination with IBG such as reconstructive meshes in two cases and tantalum augment in one.

Case report 1 Female patient B., 38 years old, was admitted to the Federal Center (Barnaul) with complaints of pain in the right hip joint, severe limitation of movements in it, shortening of the right lower limb, and lameness. From the anamnesis it was revealed that at the age of 26 years she suffered hematogenous osteomyelitis of the head of the right femur. Surgical debridement was performed and a flushing drainage system on the right hip joint was installed; the fistulas in the area of the right hip joint closed within a year. A year after the debridement of the source of infection, due to the progression of pain and impaired support function of the limb, arthroplasty of the right hip joint was performed with a DePuy Corail/Triloc anti-hybrid system. Healing after the arthroplasty intervention ran without complications. However, 7 years after the arthroplasty surgery, the patient began to feel periodic pain, which gradually progressed, limited movements, and lameness appeared. The examination revealed signs of loosening of the pelvic component and she was referred to perform revision arthroplasty at the Federal Center for Orthopedics and Arthrplasty in Barnaul. At the time of admission to the Center, she walked independently, limped on his right leg, the configuration of the joint was not visually changed; there was a postoperative scar in the area of the right hip joint without signs of inflammation. She did not feel pain on palpation in the joint area. Moderate muscle hypotrophy of the pelvic girdle and thigh on the right was present. The relative shortening of the right lower limb was 3 cm. Range of active motion was flexion up to 80°, abduction 10°, rotation 5–0–5°, adduction 10°. There was moderate pain by moving. The functional Harris score was 55 points. Radiographs revealed loosening of the pelvic component, IIIB Paprosky defect of the acetabulum, signs of periprosthetic osteolysis in the proximal femur in Gruen zones 1 and 7 (Fig. 1 a). Based on the results of cytological and bacteriological examination of the synovial fluid, no evidence of an infectious process in the joint was detected. However, due to the history of infection and the volume of required reconstruction, a decision was made on a two-stage revision arthroplasty by applying joint spacer at first stage and a repeated microbiological study of intraoperative biopsy specimens. After the first stage of revision arthroplasty and negative results of bacteriological examination, a decision was made to carry out the second stage of revision arthroplasty (Fig. 1 b). The planning of the joint surgery took into account that the use of porous augments for reconstruction would require additional adaptation of the bone bed and would lead to an even greater bone deficit. To fill the defect, several augments would have been required, and filling such an extent with metal, would have made a most probable repeated revision in the future even more difficult due to the young age of the patient. Given the generally limited shape of the segmental defect by the medial wall and superior rim of the acetabulum, which could be constrained by a mesh, acetabular impaction grafting using a cemented pelvic component was chosen as the method of choice at the final stage of reconstruction. The reconstruction surgery was performed 6 weeks after the first stage. Augmentation of the upper edge and medial wall of the acetabulum was performed with a Stryker mesh and fixation with screws. To fill in the bone defect, osteoplastic material (chips of about 8–10 mm3) was prepared. Impaction bone grafting of the acetabulum was performed using Stryker "X-Change" revision instruments. Upon achieving cement-based volume restoration, a Zimmer ZCA 47 mm socket was implanted. The femoral canal was freed from cement residues. Preliminarily, due to low quality of the bone under the lesser trochanter, a wire cerclage was performed and the Zimmer Alloclassic SLL femoral component was implanted (Fig. 1 c). In the postoperative period, the patient was activated; rehabilitation was carried out at stage 1 and without complications she was discharged on the 12th day after the surgery. In the postoperative period, dosed loads on the involved limb were recommended for 12 weeks. At the time of the last

follow-up examination, 6.5 years after the revision intervention, she had no complaints, walked with full weight-bearing without additional means of support, and did not experience any household or social restrictions. On the control radiographs 6.5 years after the operation, there were radiological signs of the osteoplastic material restructuring in the acetabulum area, there were no lucent lines at the bone-plastic material-cement border; the position of the implant components was correct, without signs of migration, subsidence or loosening. There was a decentration of the implant head in the acetabulum, as well as a 4 mm cranial displacement of the center of rotation (Fig. 1 d).

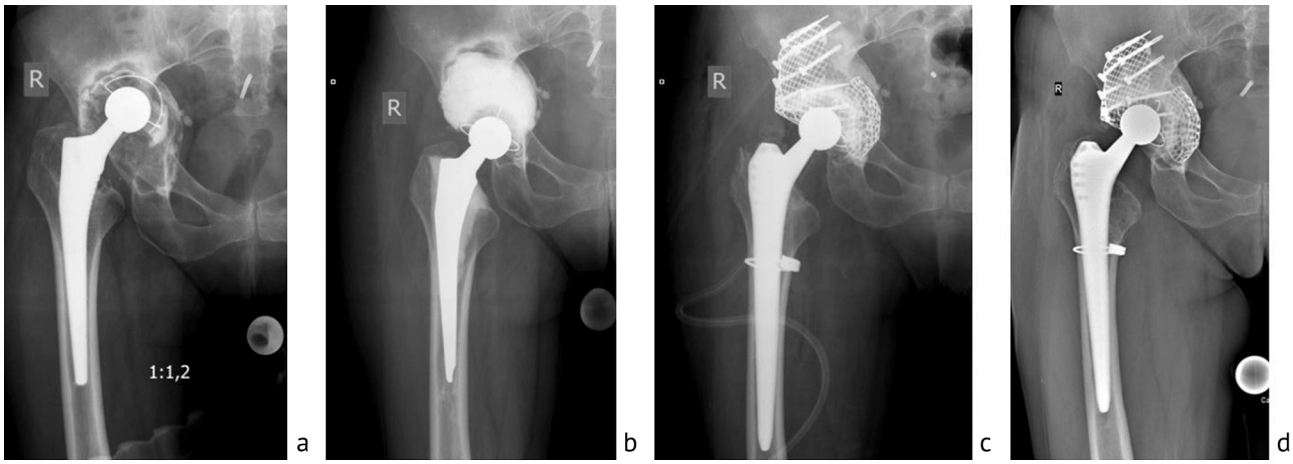

Fig. 1 Patient B., 38 years old. Radiographs of the right hip joint at the main stages of treatment: *a* before surgery; *b* after installing a hip joint spacer; *c* after reconstruction using IBG and mesh; *d* at the last follow-up 6.5 years after joint reconstruction

Case report 2 Female patient B., 37 years old, was referred to the Federal Center for revision arthroplasty of the left hip joint. From her medical record, it was known that reconstructive surgical interventions were performed on both hip joints for bilateral congenital dislocation of the femurs in childhood. Subsequently, due to the development of coxarthrosis, replacement of the left hip joint was performed with the additional use of the Muller Ring strengthening structure. However, 10 years after the operation, loosening and migration of the pelvic component developed. At the time of her admission to the Center, there was left leg lameness, the area of the left hip joint was deformed, but the postoperative scar in the area of the left hip joint was without signs of inflammation. Moderate muscle hypotrophy of the pelvic girdle and thigh on the right was noted. Relative shortening of the right lower limb by 2 cm. Range of active movements was: flexion up to 75°, abduction 0°, rotation movements 5–0–5°, adduction 5°. She experiences moderate pain by moving. The functional Harris score was 52 points. X-ray of the pelvis diagnosed migration of the pelvic component with an associated formation of Paprosky type IIB acetabulum defect (Fig. 2 a). The CT findings also revealed that the minimum transverse size of the pelvic bone at the level of the acetabulum was 45 mm, which is completely insufficient to install the minimum available component at that time with a highly porous coating of 44 mm in diameter (Fig. 2 b). There was also a deficiency of bone coverage of the acetabulum. It was, in total, probably caused by insufficient fixation and subsequent migration of the pelvic component. There were no signs of femoral component loosening. When choosing a method for reconstructing the acetabulum, we considered the extremely small size of the pelvic bone in the area of the left acetabulum, caused by joint dysplasia. Thus, additional treatment of the acetabulum could lead to worsening bone deficiency or the development of a severe complication such as dissociation of the pelvic bone. Therefore, it was decided to consider impaction bone grafting as the method of choice and augmentation of the supra-acetabular mass with a reconstruction mesh. Intraoperatively, trying to form a bed for a 44 mm acetabular component, the findings on the deficit in the bone

coverage of the cavity were confirmed. The patient underwent revision arthroplasty of the left hip joint with reconstruction of the acetabulum using IBG and augmentation of the defect with a Stryker mesh using the "X-change" technology and specialized instrumentation. After filling the bone defect with the IBP using specialized instrumentation and achieving restoration of the shape of the acetabulum on a cement basis, an insert of HH size was installed under the 32 mm head of the Zimmer Trilogy IT pelvic component after its preliminary abrasive preparation for better adhesion of the bone cement. Control radiographs after surgery showed restoration of the center of rotation, filling of the area of the supra-acetabular mass with osteoplastic material reinforced with reconstructive mesh (Fig. 2 c). After 2 years, the patient underwent arthroplasty of the contralateral joint. The results of treatment were monitored over 5.5 years. There were no radiological signs of loosening, implant components migration or graft resorption (Fig. 2 d).

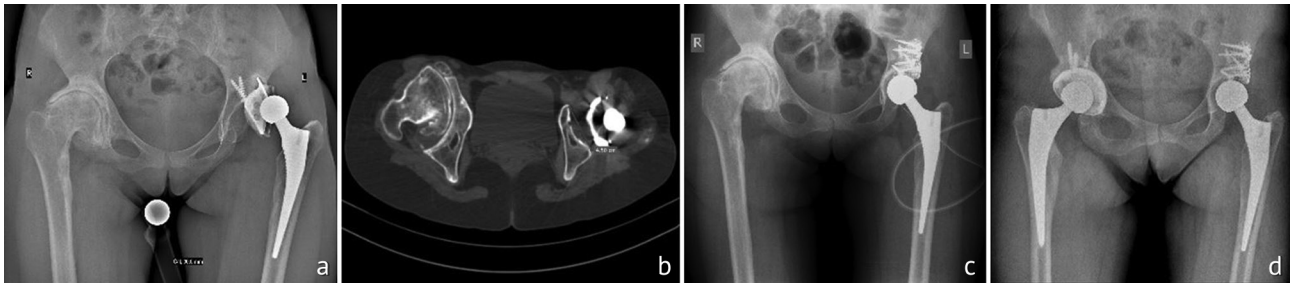

Fig. 2 Patient B., 37 years old. X-ray findings at the main stages: *a* plain X-ray of the pelvis in a direct projection before surgery; *b* CT scan of the pelvis in the axial projection at the level of the acetabulum middle third before surgery, the transverse size of the pelvic bone is 45 mm; *c* control radiograph of the pelvis after surgery; *d* radiograph of the pelvis 5.5 years after revision arthroplasty of the left hip joint

Case report 3 Female patient B., 74 years old, referred to the Federal Center for Traumatology, Orthopedics and Arthroplasty in Barnaul with a massive iatrogenic combined AAOS type III defect of the acetabulum after removal of the unstable acetabulum and femoral components in one of the clinics due to periprosthetic infection (Fig. 3 a). At the time of presentation, the patient moved with the help of crutches, the left lower limb was not weightbearing. The relative shortening of the left lower limb was 16 cm due to the absence of the proximal epiphysis of the femur, acetabulum defect and chondrodysplasia of the left tibia. In the area of the left hip joint, scar deformation of the soft tissues was due to previous surgical interventions. The functional Harris score was 54 points. The examination revealed no clinical and laboratory signs of an infectious process. Since additive technologies were not actively used in our Center at the time of her surgical intervention and taking into account the size of the bone defect, the option of bone grafting in combination with a reconstructive Burch – Schneider cage was considered. However, during the revision operation when installing the Burch – Schneider cage, its iliac flange was placed at the very edge of the bone support, and the screws were thus directed into the defect, so it was impossible to reliably fix the structure. Due to those circumstances, impaction bone grafting in combination with the installation of a trabecular metal augment was considered the most optimal method. In the supra-acetabular mass, along the outer edge of the defect, a bed for the augment was formed using a 60 mm cutter. A trabecular metal augment measuring 54/20 mm was installed on the prepared surface and fixed with two 6.5 mm screws, each 30 mm long. The additional use of the metal augment limited the bone defect and strengthened the supra-acetabular mass, thereby covering a part of the defect. After filling the remaining cavity with bone chips using the "X-change" technique, a Smith&Nephew Polarcup 47 mm double-mobility cement-based socket was implanted. The choice of a cup with dual mobility is due to the high risks of implant dislocation associated with possible positioning errors, compromised muscular system due to repeated surgical interventions, and the initial shortening of the left lower limb due to chondrodysplasia of the left

leg bones. The Zimmer Alloclassic SLL revision femoral component was implanted without any special features. The control postoperative radiographs showed dense IBG filling of the defect, the cup was installed with partial support on the augment and impacted allobone. There was also a cranialization of the center of rotation by 1 cm (Fig. 3 b). At 4.8-year follow-up, clear radiological signs of IBG reorganization and osseointegration of the trabecular metal augment were visible. Signs of loosening of the components and their migration are not determined (Fig. 3 c).

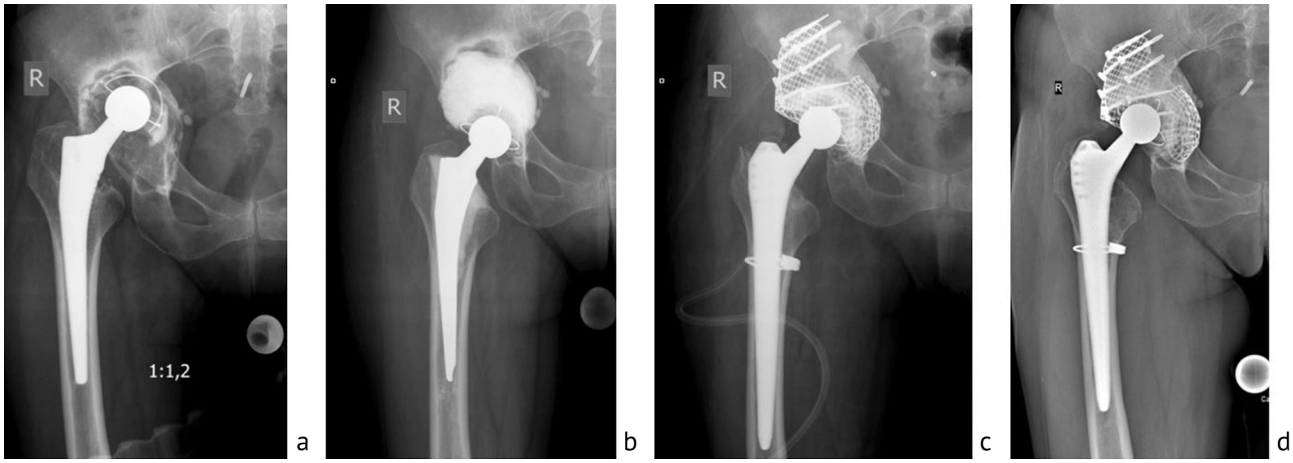

Fig. 3 Patient B., 74 years old. Radiographs of the left hip joint in a direct projection: *a* before revision arthroplasty; *b* after surgery; *c* 4.8 years after hip joint reconstruction

RESULTS

Long-term results were monitored in the case 1 patient for 6.5 years, in case 2 for at 5.5 years and in case 3 for 4.8 years. Excellent and good functional Harris scale score results were achieved, 96, 97 and 89 points, respectively, with complete labor and social rehabilitation of patients. X-rays at the last follow-ups indicated above did not show any signs of loosening or migration of the implant, augment or mesh cage. In the available fields of view there were clear signs of IBG remodeling; no reliable radiological symptoms of osteolysis were detected. In case 1, decentration of the implant head was noted, associated with polyethylene wear, and cranialization of the center of rotation by 4 mm due to IBG retraction.

DISCUSSION

At the present stage of revision hip arthroplasty development, the interest of surgeons has shifted towards more technological methods of bone defect management, such as additive technologies and modular revision systems made of porous metals [3]. The great advantage of modular augmentation systems is their versatility and standardization of indications in various clinical situations [9]. Additive technologies are capable to manufacture customized implants and have largely closed the issue of treating regular bone defects of the acetabulum [4]. However, there are also limitations in using these systems that are associated with the need for additional modeling of the bone bed for the augment, which aggravates the bone deficiency, as well as the time limit required for the design, manufacture and implantation of a customized structure. Filling of massive defects with metal may also limit the possibility of installing revision components during subsequent surgical interventions. Impaction bone grafting technology is more universal in this regard. It can be used in various situations of revision and primary complex arthroplasty, such as protrusion of the acetabulum, aseptic loosening of components and associated defects of the pelvic and femoral bones, and even in the treatment of periprosthetic infection, provided that the limiting structures and cavity walls are preserved and enable to exercise pressure in order to compact

the bone material [5]. We belive that the series of clinical cases presented in our study is an example of the situations in which the use of impaction bone grafting turned out to be the only possible effective method at the time of surgical intervention at our Center.

One of the technical problems in hip replacement for dysplastic coxarthrosis is an extremely small size of the acetabulum, cranialization of the center of rotation and the lack of bone substance for reliable fixation of the cup. Therefore the use of cementless acetabular components with a diameter of 42–44 mm is quite common [10, 11, 12]. Frequently, even these sizes turn out to be excessive, and during revision interventions due to hip dysplasia, reconstruction with standard small implants is also very difficult. In this situation, the question arises about the manufacture of customized implants [13] or the use of various revision structures that make it possible to transfer the load to other parts of the acetabulum and pelvis that retain support [14]. Current revision arthroplasty systems offer a large number of augments of various shapes and sizes, but in most cases the line is designed for standard anatomical sizes. Therefore, in case of repeated operations or complicated situations requiring reconstruction, small anatomical dimensions can become a significant limitation for the use of reconstructive cages or metal augments, as was demonstrated in one of our clinical cases. The use of impaction bone grafting, especially for defects of a relatively small size but significant for small bone sizes, which is typical for dysplasia, has shown its reliability and good results [12]. The possibility of defect augmentation using a metal mesh and impaction bone grafting enables to fill relatively small defects of irregular shape without additional expansion or adaptation for IBG [16].

In massive defects of a segmental nature, especially Paprosky type 3A, the combination of IBG with a reconstructive mesh is prognostically less successful. In defects that accounted for more than 50 % of the acetabular cavity, long-term results showed low survival rate [17].

A number of authors also emphasize that the use of impaction bone grafting with mesh and a cement cup should be considered for the reconstruction of medium-sized acetabular defects, but not for massive combined defects [18, 19].

Wilson et al. from the Exeter Orthopedic Center analyzed 129 cases of primary acetabular arthroplasty using IBG to restore its defects, which were classified as cavitary in 74 and segmental in 55 hip joints. After a mean of 9.1 (6.2–14.3) years, survival was 100 % for cavitary defects compared with 82.6 % for segmental defects [12].

However, the combination of IBG with tantalum augments has significantly improved this technique for large unconfined defects and has shown quite promising results [20]. Gill et al. assessed the results of fifteen revision interventions on the hip joints in 14 patients, with an average follow-up period of 39 (25–83) months. All cases achieved good clinical results and the absence of radiological signs of loosening or migration of the cup [21].

The study of Borland et al. included 24 patients with large Paprosky 3A and 3B defects that were treated with complex acetabular reconstruction using a trabecular metal augment, impaction bone grafting, and a cemented high-density polyethylene cup at a mean age of 62 years. Median follow-up was 61 (32–81) months. In five cases, there was migration of the polyethylene cup of more than 5 mm; an augment fracture occurred in one case and required re-intervention 13 months after the revision surgery. Other patients did not require revision [22].

De la Torre-Escuredo et al. analyzed the results of using IBG in combination with a reconstructive mesh supplemented with a porous tantalum augment in revision hip arthroplasty in 5 young patients (⩽ 50 years old at the time of surgery) with Paprosky defects 3A and 3B who showed significant improvement in clinical scores over a mean follow-up of 79 months (60–101). When radiographic

data were assessed, there were no significant differences in abduction angle (p = 0.27) or cup migration (p = 0.31) between the postoperative position and the last follow-up. No patients had lucency lines at the bone-cement interface at last follow-ups and no patients had signs of loosening around the augments [23].

In our clinical case 3, the use of this combination limited the defect using an augment and created additional support and conditions for retaining the impacted bone mass in the defect that enabled to fill in a significant defect with restoration of the bone mass. To achieve construct stability, it was important that the augment was in close contact with the ilium when placed in the most appropriate position. It was important to use at least two 6.5 mm screws to secure the augment.

In that case, the augment acts as a scaffold for bone ingrowth and remodeling, while providing load-bearing structural support [20, 21, 22]. The excellent results obtained in cases of using trabecular metal augments are confirmed not only by the osteoconductive properties of this material, but also by its osteoinductive properties [24]. Another important advantage of tantalum is the absence of associated resorption, in contrast to structural allografts.

Long-term results of using tantalum augments with a cementless cup in acetabular reconstruction show a high survival rate of the latter [25]. However, in extremely large defects, complete replacement with metal augments requires high-quality preparation of the bone bed, which must geometrically correspond to the shape of the augment [26, 27]. In conditions of bone deficiency, such as AAOS type 3 defect with segmental-cavitary bone deficiency, this can lead to even greater bone loss. Replacing the entire volume of the bone defect with metal also leaves no chance for creating a bone reserve in the acetabulum area for the successful implementation of possible future revisions, especially in young patients. At the same time, the use of bone chips for impaction bone grafting provides dense filling of the smallest defects and shape a bed which is congruent with the pelvic component. The use of cemented fixation implants allows additional stabilization of the impacted crushed graft with the cement mantle itself and mechanotransduction mechanisms that stimulate the restructuring of the osteoplastic material [28].

Quite reliable solutions for managing extremely large bone defects have been currently offered by additive technologies [4]. One important difference between these systems is the filling of defects with a large volume of metal, without further prospects for bone reserve in the acetabulum area. Regarding the extremely high risks in using customized designs in patients, medium-term survival rates of 75–82.7 % [29, 30, 31] may be considered acceptable, but quite modest if life expectancy is up to 85–90 years.

CONCLUSION

Impaction bone grafting is a universal technology for managing acetabular bone defects in revision and primary complex hip arthroplasty. The creation of a bone stock in the defect area provides more favorable conditions for possible repeated revision interventions in the future, which is its main advantage over other current technologies. Combining IBG with metal augments made of trabecular metal enables a stable support for the cemented cavity and limits the defect, providing favorable conditions for reconstruction, which significantly expands the possibilities of using this technology for massive segmental defects of the acetabulum. In some non-standard cases, due to individual anatomy, dysplasia, or ultra-small size of the acetabulum combined with the complex bone defect geometry, IBG can be used as the method of choice, allowing high-quality reconstruction with restoration of the anatomical relationships in the hip joint, which significantly increases the arsenal of technical capabilities for the orthopedic surgeon.

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Clinical case
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Soft-tissue origin joint contractures treated with the Ilizarov fixation method

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Abstract

Introduction Soft-tissue origin joint contractures are a common orthopedic problem. It could be due to various etiologies. Treatment options are available from conservative to surgical methods. These joint contractures slowly become irreversible causing impairment in activities of daily routine. The Ilizarov method is a well established and time-tested method used for management of bone pathologies, but its use in the management of soft-tissue origin contractures is also possible. It has an established role in neoosteogenesis and histogenesis. Fixator assisted soft-tissue stretching done at sustained slow pace leads to histoneogenesis that avoids stretching of neurovascular structures and reduces the possibility of recurrence.

Aims To determine usefulness of the Ilizarov method in management of joint contractures of soft tissue origin; to meet functional requirements of patients; to study complications of Ilizarov method in management joint contractures due to soft tissue origin.

Material and methods A total of 6 cases of soft-tissue origin joint contractures due to tuberculosis, post-traumatic stiffness, post-burn contracture, deformity due to a snake bite in the age group from 3 to 55 years were treated with gradual distraction of joint with the Ilizarov method from January 22 to October 23. Two cases were of triple knee deformity, two were post-traumatic elbow stiffness, one was post-burn great toe contracture and one was post snake bite valgus foot contracture. All cases were operated with transarticular Ilizarov frame application and gradual distraction of joints and soft tissue with the help of hinge- and rod distractor assembly done. All cases completed follow up of 1 year. Aggressive physiotherapy was given postoperatively.

Results All cases obtained a reasonable functional outcome, with no recurrence of deformity. All patients walk independently.

Conclusion The Ilizarov method can be used for treating joint contractures due to traumatic and non-traumatic pathologies.

Keywords: Gradual distraction, Ilizarov method, Hinges, Histoneogenesis

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INTRODUCTION

Joint contractures of soft-tissue origin are a common orthopedic problem [1, 2]. It could be due to idiopathic, infective, traumatic, post-burn or neuropathic etiologies. Management of these deformities has always been challenging not only in terms of gaining functional requirements of patients but also preventing recurrence. Multiple treatment options are available: from traction, splinting, casting, manipulation to surgical methods like osteotomies, soft tissue release, tendon transfer, scar excision and skin grafting [3]. Soft-tissue origin joint contractures slowly become irreversible causing impairment of activities of daily routine [4]. This demands surgical intervention to fulfill functional requirements of a patient. Acute correction of contractures may lead to skin necrosis, vascular compromise, nerve palsy, and recurrence is also frequent [1, 2, 5, 6]. Additional plastic surgical procedures may also be required [1, 7, 8].

The Ilizarov method is a well established and time tested method that is very frequently used for management of bone deformities, non-union, bone infection and complex trauma [1, 2, 9]. It is three dimensional, stable and minimally invasive fixation which allows not only deformity correction but also early functional rehabilitation [1, 2, 10, 11]. Dynamic deformity correction is possible during the entire treatment period [9].

Use of the Ilizarov method in the management of soft tissue contractures is also possible. Its role in neoosteogenesis and histogenesis has been very well proved [1, 12]. Gradual deformity correction by soft tissue stretching is possible with this method. Soft tissue stretching at sustained slow pace lead to histoneogenesis avoiding stretch damage to the neurovascular structures and the possibility of recurrence of the deformity is minimized [7, 8, 12].

Aims To determine usefulness of the Ilizarov method in management of joint contractures of soft tissue origin; to meet functional requirements of patients; to study complications of Ilizarov method in management joint contractures due to soft tissue origin.

MATERIAL AND METHODS

It was a prospective study in which a total of 6 cases of soft-tissue origin joint contractures were treated from January 2022 to October 2023. Amongst them, four cases were males and two females in the age from 3 years to 55 years. The study was initiated after receiving approval from the institutional ethics committee.

Etiology included:

— Two cases of severe flexion deformity of knee due to tuberculosis;

— Two cases of post-traumatic elbow stiffness;

— One case of post-burn contracture of the great toe and one case was post-snakebite valgus contracture of the foot;

Patient with active infection and neurovascular compromise were excluded from the study.

In all the cases, initial conservative treatment such as traction, splinting, manipulation was not done; and the patients did not undergo regular physiotherapy. Standard radiography of affected extremity joint was taken. The angle between the anterior cortical line and long bones was calculated to determine the extent of deformity. Pre-operative arterial color Doppler study was done in all cases. All cases were operated by one and the same surgeon.

Severe knee flexion deformity

Two cases with triple deformity of the knee (flexion, posterior subluxation, and external rotation) secondary to tuberculosis were treated with the Ilizarov method. Both patients were unable to stand and walk for one year.

After taking X-rays of the affected joint, the extent of deformity and the level of articular damage, if any, were determined. Trans-articular Ilizarov external fixation frames were applied fixing the femur and the tibia, perpendicular to the long axis of the shaft. Medial and lateral hinges were applied at the level of the knee. Threaded rods were placed along the posterior aspect of the knees and gradually distracted the knee at the rate of 2 degrees per day. Anti TB drugs were initiated after taking synovial tissue biopsy which was performed during frame application.

Post-traumatic elbow stiffness

Patients developed elbow stiffness following a compound run-over injury 2 years ago. During the initial insult, one patient also had head injury and she was in a comatose state for a long time that delayed orthopedic treatment and she developed flexion deformity. Since conservative management failed, operative management in the form of limited scar tissue release and Ilizarov frame application was done. Transarticular rings were applied to humerus and forearm in the midprone position. Medial and lateral hinges at the level of the elbow and an anterior distraction rod was applied. Distraction was done at the rate of 2 degrees per day. Serial checking X-rays were taken to determine elbow subluxation.

The other patient had post-traumatic elbow stiffness after being treated by a quack physician and was managed by us in the similar manner (Table 1).

Post-burn contracture of the great toe

It was flexion contracture at the interphalangeal and metatarsal phalangeal joint of the great toe due to post-burn scar in a 4-year old male.

A limited scar tissue excision and Z-plasty of flexor tendons was done followed by placement of a modified Ilizarov foot frame with medial and lateral hinges at the level of the metatarsal phalangeal joint to correct the associated adduction forefoot deformity and a puller rod to extend the interphalangeal and metatarsophalangeal joints gradually. Complete toe extension was achieved in 3 weeks' time (Table 1).

Table 1

Patient characteristics

Age (years)	Gender	Joint involved	Etiology	Clinical presentation	Pre-operative ROM (Degrees)	Ilizarov frame duration (days)	Post-operative ROM(degrees)	Complications
4	M	Great toe DIP Joint	Post-burn scar contracture	Thick scar sole getting toe in flexion	Extension — Not Possible	21	Extension — 10	Pin tract infection
					Flexion — 40		Flexion — 0	
14	M	Elbow	Post-traumatic stiffness	Healed scar over posterior surface	Extension — 40	11	Extension — 25	—
					Flexion — 90		Flexion — 120	
21	F			Healed scar over posterior and anterior surface	Extension — 80	22	Extension — 30	Pin tract infection
					Flexion — 90		Flexion — 125	
55	F	Knee	Bone TB	Triple deformity	Extension — 80	45	Extension – 10	—
					Flexion — 90		Flexion — 120	
12	M			Triple deformity	Extension — 75	40	Extension — 0	Pin tract infection
					Flexion – 90		Flexion — 120	
16	M	Ankle	Post-snakebite contracture	Plantar flexion and valgus deformity	Plantar flexion — 20	15	Plantar flexion — 30	—
					Dorsiflexion — 10		Dorsiflexion — 25	
					Supination — Not possible		Supination — 20	
					Pronation — 25		Pronation — 10	

DIP – distal interphalangeal joint; TB – tuberculosis

Post-snakebite valgus foot contracture

It developed due to snakebite scar contracture in a 16-year old male.

Contracture evolved gradually over the period of 2 years following multiple debridement of the infected wound. The patient did not use splint. Scar tissue was released and then the frame was with hinges on either side of the ankle and a distraction rod anteriorly to correct the deformity. The ankle joint behaved as a natural hinge along which correction was done (Table 1).

Treatment period was divided in two phases:

Distraction continued during a dynamic phase. It was variable as per the extent of the deformity calculated preoperatively.

Static phase It was maintenance phase during which the soft tissues, being stretched fully, were maintained in overcorrected position. Its duration was twice longer of the dynamic phase.

During the entire treatment, the patients were ambulatory and encouraged to do regular exercises as per training.

In both phases aggressive physiotherapy is a key factor.

RESULTS

The average length of hospital stay was 3 weeks.

No case required secondary bone procedures like osteotomy along with frame application. The soft tissues were stretched to overcorrected position to prevent recurrence.

Limited soft tissue releases such as percutaneous tenotomy, percutaneous capsulotomy, scar tissue excision were done in one case of knee contracture, great toe contracture and foot contracture, respectively.

Distraction rate was calculated by initial deformity assessment on X-rays and also by the rule of triangle, and accordingly the estimated time of correction was also determined.

No neurovascular complication following distraction was noted in any case.

No joint dislocation or peri-articular fracture was seen.

No case required skin grafting.

Pin tract infection was detected in 3 cases which resolved with dressings and antibiotics.

No case required premature frame removal.

Treatment was divided in two phases, dynamic and static; fixator application time was variable depending upon pathology and deformity severity. However, average fixator application time was 6 weeks and soft tissues were maintained in overcorrected position for 2 more weeks in static phase, so average time for fixator removal was 8 weeks.

Post-operative use of splints was required in all cases to maintain soft tissue stretching and prevent recurrence. Initially, use of a splint continued for 1 month after frame removal and intermittent physiotherapy was encouraged. In later 6 months, night time splinting and intermittent daytime splinting continued.

Physiotherapy regimen: all patients were subjected for passive stretching, range of motion exercises. Patients were assessed at every visit for recurrence of deformity, range of motion and ability to perform activities of daily routine. Visits were made at 1, 3, 6, 12 months following initiation of treatment.

Average follow-up time was 1 year.

No evidence of recurrence of deformity was seen in any case; however post-frame splinting and aggressive physiotherapy has a pivotal role in preventing recurrence.

The objective of this treatment was to give reasonable function and aesthetic appearance to the limb

which was achieved in this series to significant extent. Final outcome was determined by amount of flexion contracture calculated in degrees preoperatively and the residual one at the end of treatment. Accordingly, up to 5 degrees was excellent, up 15 degrees was good, up to 30 degrees was fair and more than 30 degrees was poor. Thus, one case was excellent, four cases were good and one patient had a poor result.

Fig. 1 Pre-operative flexion contracture of the knee

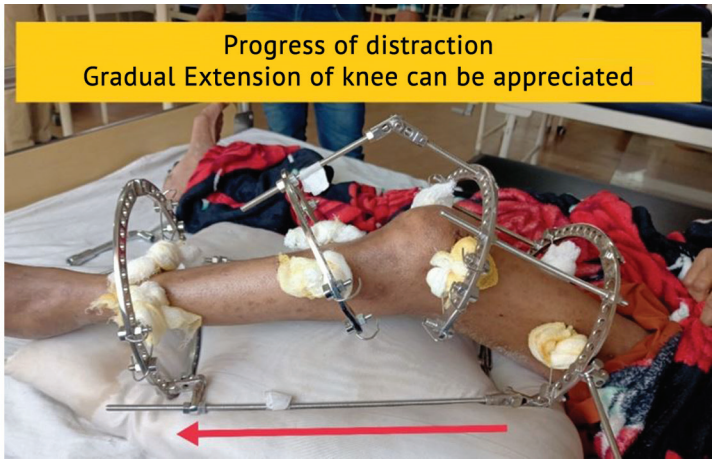

Fig. 2 Flexion contracture of the knee after frame application

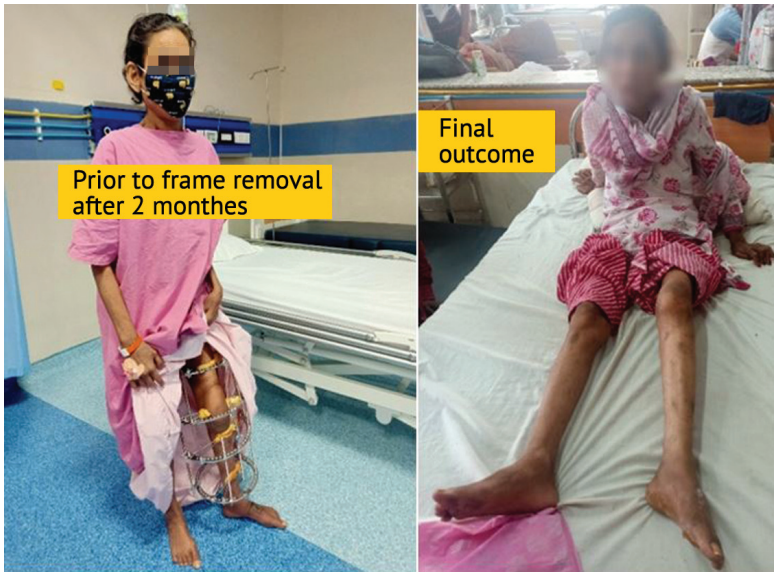

Fig. 3 Knee contracture: final outcome

Fig. 4 Post-burn great toe contracture (a); soft tissue release (b)

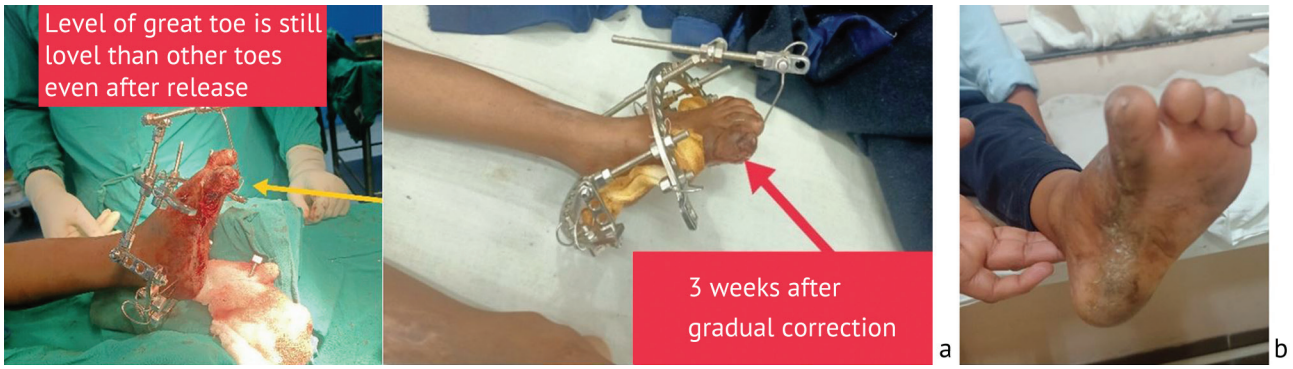

Fig. 5 Correction achieved with frame (a); final outcome (b)

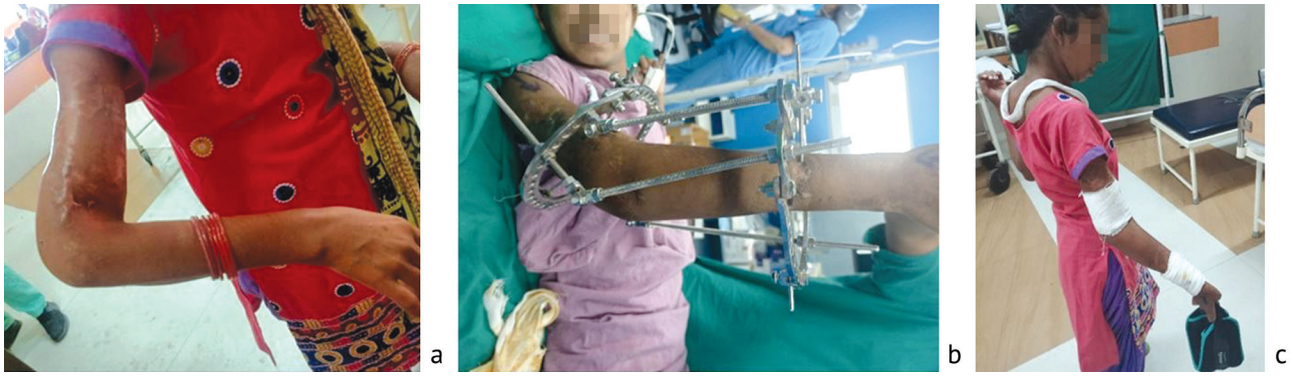

Fig. 6 Elbow flexion contracture (a); after frame application (b); elbow extension achieved (c)

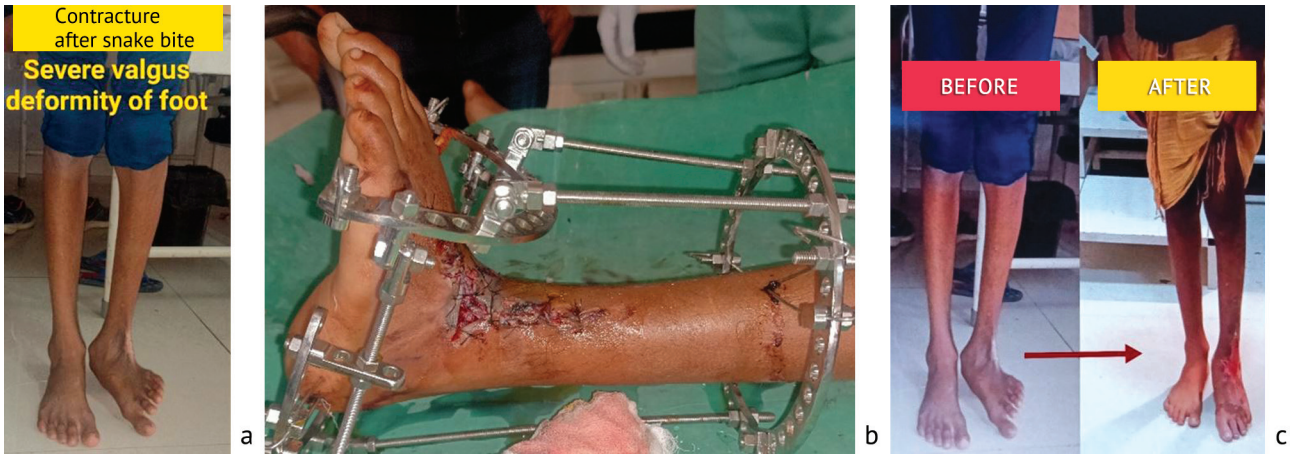

Fig. 7 Post-snakebite foot contracture (a); frame applied (b); final outcome (c)

DISCUSSION

Management of deformities due to soft tissue contractures is challenging as treatment varies from conservative forms like splints, manipulations under anesthesia, physiotherapy to surgical intervention which includes osteotomies and at times plastic surgery [1, 2, 10, 13].

The Ilizarov fixation technique is widely used for management of bone deformities, complex fractures, bone loss, non-union and bone infection [1, 2, 12].

Its use for tissue growth and regeneration is accepted worldwide [1].

With due course of time the indications of the Ilizarov method have extended for management of non-traumatic deformities which are of soft tissue origin [6, 8, 9, 11, 14, 15, 16].

The use of this method for management of joint contractures, post-burn contractures, triple deformity, Volkman ischemic contracture has been reported [6, 15, 17].

Correction of deformity with the Ilizarov method is possible due to sustained controlled distraction of soft tissues leading to histoneogenesis [1, 2, 11, 17, 18, 19]. This process leads to progressive stretching of the juxta-articular and intra-articular connective tissues resulting in deformity correction. Gradual distraction process also leads to concomitant lengthening of blood vessels and nerves [2, 7, 8, 12, 14, 17, 18].

The hinge is a key component of the frame. Its place should be planned and done in appropriate manner to reduce the possibility of joint subluxation [2, 4, 11, 13]. Rate of distraction was calculated by initial deformity assessment on X-rays and also by rule of triangle, and estimated time of correction was also determined accordingly [2].

In our study, we have done preoperative arterial Doppler study of all patients, as soft tissue stretching might endanger the blood supply in patients with only single supplying blood vessel [1, 12]

No osteotomies were performed for deformity correction but overcorrection was done to reduce the recurrence rate [1, 3]. It is always good to start correction of the deformity as early as possible to gain good results [10].

In children the compliance for physiotherapy is lower; therefore this treatment can be considered as salvage treatment option [1, 14].

Patients are ambulatory during the entire process of treatment. Aggressive physiotherapy, post-frame splinting has equally an important role in preventing recurrence [6, 14, 15].

The Ilizarov fixator is a versatile, biomechanically stable, minimally invasive three dimensional construct which can be tailored as per need of deformity [1, 2, 4, 5, 6, 12, 16, 19]. This method permits dynamic deformity correction during the entire period of treatment and also allows weight-bearing [2, 7, 10, 13, 20]. It is known that the ideal way to avoid joint stiffness or contracture is complementary treatments such as aggressive physiotherapy and splinting [6, 14, 15, 17, 18]. In order to maintain long-term results and prevent recurrence post-frame splinting and aggressive physiotherapy is extremely important. Final outcomes were determined by residual amount of flexion contracture calculated in degrees, comparing the values at the beginning and at the end of treatment. Accordingly, up to 5 degrees was excellent, up 15 degrees was good, up to 30 degrees was fair and more than 30 degrees was poor [1, 2]. So, one case was an excellent result, 4 cases presented with good outcomes and, unfortunately, one patient had a poor prognosis. Though it was a small series but our results are parallel to the ones reported in the literature worldwide. However, to strengthen our conclusion a larger sample size with long follow-ups is required.

A short sample size was a limitation of our study and we plan to continue with our study prospectively, with a large number of subjects in the future.

CONCLUSION

The Ilizarov method can be used successfully for treating joint contractures of soft tissue origin due to traumatic and non-traumatic pathologies. It is a minimally invasive versatile method. It can be considered an addition to the armamentarium for treatment of joint soft-tissue origin contractures. However, exact positioning of hinges over the center of rotation of joint is mandatory. Detailed preoperative planning and postoperative execution are required to achieve desired results. For preventing recurrence, aggressive physiotherapy and splinting is equally important as frame application. Secondary procedures like osteotomies, skin grafting may be required and should be explained to the patient prior to the intervention.

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Review article
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Promising osteoplastic materials and surgical technologies in reconstructive treatment of patients with bone nonunion and defects

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Abstract

Introduction Some progress has been made in the development of innovative implantation materials for osteoplastic surgery. However, the problem of bone defect management still remains relevant due to the continued high prevalence of injuries resulting from road accidents, catatrauma, man-made disasters and military operations.

The purpose of the work was to analyze the relevant literature and to identify options for solving the problems of bone nonunion and defect management using materials developed on the principles of orthobiology and surgical technologies based on autologous repair.

Materials and methods The search for sources was carried out with the ConnectedPapers analytical tool and the capabilities of the eLibrary electronic library using keywords and without restrictions on publication date.

Results and discussion Recent publications contain information about the effectiveness of the combination of Masquelet technology and Ilizarov bone transport in patients with acquired and congenital defects, including in the conditions of active purulent infection. According to the literature, a promising autologous bone plastic material is the contents of the bone marrow cavity, containing osteogenic growth factors and bone morphogenetic proteins. Biomaterial is collected using the Reamer-Irrigator-Aspirator system (RIA) from the intramedullary canal of the femur or tibia. Currently, the effectiveness of bone morphogenetic proteins rhBMP-2 and rhBMP-7 in the restorative treatment of patients with bone defects and nonunion of various etiologies has actually been proven. The use of bone morphogenetic proteins has been introduced into foreign treatment protocols. Recent positive results of a combination of surgical technologies have proposed the combined use of the Ilizarov and Masquelet technologies, supplemented by PRP therapy. The basis for the expected effect from the combination of surgical technologies and orthobiological materials are the results of preclinical studies of the osteogenic potential of PRP therapy.

Conclusion There are grounds for studying the clinical effect of the combined use of surgical technologies based on autologous reparative processes and materials developed on the principles of orthobiology. It is necessary and advisable to clinically implement the use of bone morphogenetic proteins rhBMP-2 and rhBMP-7 in the reconstructive treatment of patients with bone defects and nonunion of various etiologies. Multicenter clinical studies of a high level of evidence are needed to determine the effectiveness of PRP therapy in the reconstructive treatment of patients with bone nonunion and defects.

Keywords: innovative implantation materials, osteoplastic surgery, bone defect, orthobiology, autologous reparative processes, Masquelet, Ilizarov, osteogenic growth factors, bone morphogenetic proteins, platelet-rich plasma therapy

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INTRODUCTION

Despite the progress achieved in osteoplastic surgery and in the development of innovative implant materials, there is no doubt about the relevance of the problem of bone defect management due to the consequences of injuries and high prevalence of injuries resulting from road traffic accidents, catatrauma, man-made disasters and military operations . According to most researchers, the optimal implantation material is still an autologous bone graft, but, unfortunately, the possibilities of osteoplastic surgery using free bone autografts are limited by the available donor material. The classical non-free Ilizarov plastic surgery and its variants when bone defect is treated by lengthening the fragment(s) are not without drawbacks. Basically, the opponents of the method stress its long treatment periods, loss of quality of life during external fixation and the risks of soft tissue inflammation in the area of transosseous fixation elements. The use of bone grafting according to Masquelet also has limitations in terms of indications for its use which is associated with long-term and incomplete organotypic massive implant remodeling, the risk of nonunion and pathological fractures, and infectious complications. At the same time, current literature contains information about the effective use of a combination of surgical technologies and autologous osteoplastic materials and products developed on the principles of orthobiology.

The purpose of the work was to analyze the relevant literature and to identify options for solving the problem of bone nonunion and defect management using materials developed on the principles of orthobiology and surgical technologies based on autologous repair.

MATERIALS AND METHODS

The search for foreign literature sources was carried out using an analytical tool based on artificial intelligence ConnectedPapers with the application of the Seminal works functions to display a list of key thematic works and Derivative works to display new, relevant works, systematic reviews and meta-analyses that are in the area of interest of the authors. A search for Russian-language sources was carried out in the eLibrary electronic platform with the keywords; the list was supplemented with publications from bibliographic lists, as well as with authors' own early publications. There were no restrictions on publication dates for selecting sources.

RESULTS AND DISCUSSION

Restoration of lost bone tissue in nonunion and defects is a key problem in reconstructive surgery and requires the use of innovative osteoplastic materials and new surgical approaches. It is known and generally accepted that the "gold standard" of osteoplastic materials are autografts. The literature review is devoted to the analysis of the results of the use and prospects for further improvement of autologous osteoplastic materials developed on the principles of orthobiology and surgical technologies to solve the problem of bone defect filling.

Non-free Ilizarov bone grafting (bone transport) is based on the fundamental scientific discovery "The general biological ability of tissues to respond to dosed stretching with growth and regeneration (Ilizarov effect)" (priority date: November 24, 1970, No. 355) [1].

The Ilizarov bone transport involves discrete and controlled movement of a blood-supplied autograft within a preserved soft tissue envelope in the interfragmental gap to fill the bone defect with newly formed bone tissue, which subsequently undergoes complete organotypic remodeling. The Ilizarov non-free bone grafting is able to recover the loss of any bone volume and completely restore the original anatomical shape of the bone segment that was injured [2–4].

Some authors use free autografts with arteriovenous shunting and non-free autografts along with the Ilizarov bone transport as alternative technologies and osteoplastic materials. Evaluating and comparing their effectiveness, researchers have not identified any fundamental advantages between these technologies in achieving anatomical and functional treatment results in bone defect repair [5–11].

The fundamental advantage of free and non-free autografts is their adequate blood supply and, accordingly, the possibility of union and complete organotypic restructuring of both the free replant after arteriovenous shunting and the transported bone fragment. Adequate vascularization of autografts ensures their resistance to infection, reduces the risks of purulent complications and ensures complete remodeling of bone tissue and the vascular network of implants [12–15].

The undoubted advantage of free bone grafting with blood-supplied autografts was the duration of treatment. In positive clinical outcomes, bone defect filling took place at once, and the union of the replant and recipient bone occurred in a time term close to the consolidation of uncomplicated fractures of an involved localization [7, 8, 14, 15–19].

A generally accepted and universal free blood-supplied autograft with a complex of tissues is the fibula with restored arteriovenous anastomoses [7, 12, 14, 17, 19–27].

At the same time, there is information in the literature about the effective use of the fibula as a free autograft, the role of the implant was performed by a resected fragment of the fibula. Organotypic restructuring of the fibula, remodeling of the newly formed vascular network, consolidation with fragments of the recipient bone occurred without surgical restoration of arteriovenous shunts [28–31].

The most favorable conditions for the reconstruction of the fibula are created when a free autograft was implanted into the zone of closed reaming of the medullary canal at the level of pseudarthrosis, when autogenous osteoplastic material was localized along the periphery of the reaming zone [32, 33].

The available literature contains information about the effective use of the fibula for total and subtotal defects of the tibia under the conditions of transosseous osteosynthesis. Reconstruction of the tibial skeleton is ensured by dosed tibialization or transport of the fibula into the defect area and formation of tibiofibular bone blocks and synostoses. The fibula plays the role of a non-free blood-supplied autograft, which undergoes complete organotypic restructuring. However, hypertrophy of the fibula and achievement of the strength characteristics of the tibia require dosed functional load and long-term use of additional immobilization means (plaster, splints, orthoses) [34].

However, free bone grafting with blood-supplied autografts has its own drawbacks. Typically, surgical intervention that is technically complex due to the need to use microsurgical techniques was two-stage: at the first stage of treatment, deformities and shortening of the segment were gradually corrected using transosseous fixation devices, a bed for the replant was prepared; transplantation was carried out simultaneously at the second stage of osteosynthesis. After a long microsurgical operation, there was a risk of thrombosis of arteriovenous shunts, which required the administration of expensive drug support. In case of blood-supplied fibula as an osteoplastic material, there was a risk of instability of the ankle joint in the donor segment, and a possible phantom pain in the donor area. In case of lower limb defect management

with vascularized autografts, the ability to substitute a missing bone part was limited by the amount of donor material available. As a rule, the bone autograft did not match the size of the bone defect; therefore, time was required for hypertrophy of the substituted bone tissue, long-term immobilization of the lower limb with orthoses, splints, and the use of additional means of support [12, 14, 16, 35–37].

Non-free Ilizarov bone grafting also features some problems. If the lengthening technology of the fragment(s) is incorrectly implemented, and first of all, if there is a traumatic violation of the integrity of the fragment(s) with damage to the contents of the bone marrow cavity and intraosseous artery, or an inadequate rate of non-free bone autograft transport, there are risks of an “ischemic” distraction regenerate of the hypoplastic type [38–42].

According to the literature, the slowdown in the activity of distraction osteogenesis and the risks of the hypoplastic distraction regenerates increase in one-stage lengthening or defect filling for more than 4–5 cm [43–46].

Highly appreciating the anatomical and functional results of long bone defect management by lengthening the fragment according to G.A. Ilizarov, opponents considered the main disadvantage of the method to be the long period of external fixation that impairs the patient's quality of life and determines the need for patient monitoring by medical staff [5, 47–51].

The need to reduce the duration and stages of treatment determined the evolution of the Ilizarov technology of non-free bone grafting with the development and implementation of new technological solutions. Thus, it was proposed to compensate for sub- and total defects of long bones with polyfocal distraction regenerates that undergo complete organotypic restructuring during a shorter period of external fixation.

The effectiveness of the methods for defect filling with polyfocal formation of regenerates has been proven by a 1.5-fold reduction in the duration of transosseous osteosynthesis and its stages (the distraction period is 2.5 times, the fixation period is 1.3–1.9 times shorter) with the achievement of greater completeness of bone defect filling within one treatment stage. At the same time, the fragments transported polyfocally retained vascular connections and were adequately supplied with blood, and therefore resistant to infection, and formed distraction regenerates underwent complete organotypic remodeling [44].

However, the proposed and implemented original technologies certainly increased the effectiveness of the Ilizarov non-free bone grafting but did not solve all the problems of reconstructive treatment of patients with defects and nonunion.

A promising autologous osteoplastic material is the bone marrow cavity contents harvested from the intramedullary canal of the femur or tibia using the Reamer-Irrigator-Aspirator system (RIA). Due to the widespread introduction of technologies for locked intramedullary osteosynthesis, minimally invasive approaches to the bone marrow canals are not technically complex and have been developed, and the amount of available donor material is quite sufficient to perform osteoplastic surgical interventions [52, 53].

Autologous bone plastic material contains osteogenic growth factors necessary to stimulate osteogenesis in areas with weakened bone tissue regeneration: fibroblast and platelet growth factors, bone morphogenetic proteins [53, 54].

According to some authors, the use of the Reamer-Irrigator-Aspirator system (RIA) is a promising and effective technology and can be an alternative or complement to the use of non-free bone autografts from the iliac wing [55, 56].

Despite the development of innovative implantation materials, the use of autografts is still the "gold standard" in osteoplastic surgery. Currently, there is a need to develop improved biomaterials based on the principles of orthobiology, and new technological solutions for implantation which would best meet the capabilities and in a number of characteristics would be superior to autografts. Innovative biomaterials can be combined with autoplastic material, resulting in the development of an implant that meets the requirements for osteoconduction, osteoinduction and osteogenesis [57, 58].

Recently, in the available literature there have appeared publications demonstrating high efficiency and identical results of the clinical use of the morphogenetic proteins BMP-2 and BMP-7 in comparison with autogenous bone grafts in orthopaedic correction of the spine and reconstruction of limbs after consequence of injuries [58, 59].

Congenital bone defects present the greatest difficulty for limb reconstruction, which predetermines multi-stage duration of treatment and high risks of disease relapse [60, 61].

Currently, foreign protocols for the treatment of patients with congenital pseudarthrosis include the use of bone morphogenetic proteins rhBMP-2 and rhBMP-7, with preference given to the use of autologous bone chips from the iliac wing as a scaffold [61–66].

It should be noted that orthopaedic surgeons give preference to transosseous osteosynthesis for fixation of tibial bone fragments, or to a combination of external fixation with intramedullary metal implants (intramedullary rods and bone plates) [11, 23, 60, 65, 67].

According to the literature, human recombinant proteins BMP-2 and BMP-7 are considered as osteogenic growth factors necessary to stimulate osteogenesis in areas with reduced bone tissue regeneration (congenital and acquired pseudarthrosis and bone defects, consequences of open fractures, osteonecrosis) [68, 69].

Bone morphogenetic proteins are thought to promote the chemotactic proliferation and differentiation of osteoblast and osteoclast precursors, thereby triggering the process of bone formation [66, 70, 71].

The lack of morphogenetic proteins in the domestic traumatology and orthopeadics is obviously due to their absent certification in the Russian Federation and cost (about $4500 for one clinical application). This fact should motivate researchers to search for clinically effective and financially accessible alternative osteoplastic materials and surgical approaches [72].

Non-free Ilizarov bone grafting and the filling of bone defects with autografts with arteriovenous shunting was recognized and developed in the 80s of the 20th century. At that time, A.C. Masquelet developed the induced membrane technique (IMT) [3, 4, 73].

The Masquelet technique involves reconstruction of the segment in two stages. In the first surgical session, a segmental bone defect is formed and a polymethyl methacrylate cement spacer is implanted. For fixation of the tibial bone segment, preference has been given to the Ilizarov apparatus. After 6–8 weeks, the spacer is removed, the defect is filled with free bone autografts, or in case of autograft deficiency, alloplastic implants are used [73, 74].

According to the literature, an induced membrane with a newly formed vascular network is formed around the spacer. The membrane contains mesenchymal stem and epithelial-like cells, fibroblasts, myofibroblasts, and produced morphogenetic proteins BMP-2, BMP-7 and growth factors (VEGF, TGF-beta 1) [74–76].

Peak levels of membrane-induced growth factor secretion were recorded at 4 and 6 weeks after spacer implantation [77].

In the available literature one can find information about the antimicrobial activity of the induced membrane, which is associated with the secretion of antioxidant chemicals by growth factors that caused the degradation of DNA microflora. The authors suggested the possibility of blocking the secretion of biofilm microorganisms by local peptides [78].

However, the Masquelet technology is not without its drawbacks either. Thus, the use of bone grafting according to Masquelet has limited indications, primarily in older patients, due to the low activity of reparative processes, and consequently long-term and incomplete organotypic reconstruction of massive implants, the risk of pseudarthrosis and pathological fractures, infectious complications, and problematic healing of postoperative wounds. [73, 79].

Lasanianos et al. conducted a comparative analysis of the treatment results of the Ilizarov bone transport (37 articles) and the outcomes of the Masquelet technique (41 articles). In the comparison groups, patients had similar sizes of bone defects. The researchers found that the results of surgical treatment using the Masquelet and Ilizarov technology did not have statistically significant and reliable advantages in restoring the anatomical integrity of the limb, formation of malunion, and the risk of infectious complications [79].

At the same time, a certain dissatisfaction with the results of surgical rehabilitation of patients using Masquelet bone grafting and Ilizarov bone transport prompted a group of authors to combine technologies in anticipation of optimizing the treatment process, reducing the duration and stages of osteosynthesis, reducing the risks of infectious complications, relapses of the disease while restoring anatomical bone segment integrity. The authors reported on the possibilities and effectiveness of the combination of Masquelet technology and Ilizarov bone transport in patients with acquired and congenital defects, including in conditions of active purulent infection [80–83].

With the application of the combination of Masquelet technology and Ilizarov non-free bone grafting, bone transport was carried out under favorable and optimal conditions for distraction osteogenesis. An induced membrane, which produces morphogenetic proteins and growth factors and also has bactericidal properties, was formed around the distraction regenerates and transported non-free autografts. As a result, bone defects were filled in with distraction regenerates undergoing complete organotypic restructuring, thus avoiding deformations and pathological fractures at the level of newly formed bone areas and reduced the risks of relapses of congenital pseudarthrosis and exacerbations of the osteomyelitic process [80–83].

The positive results obtained from the combination of surgical technologies enabled to develop the idea and propose the combined use of the Ilizarov and Masquelet technologies and supplement them with the use of orthobiological materials [84].

The basis for the expected effect from the combination of surgical technologies and orthobiological materials are the results of preclinical studies on the osteogenic potential of PRP therapy on cell cultures of human osteoblasts in vitro [85–87].

The results of the combined use of PRP therapy with osteoplastic materials seem promising. Thus, the results of creeping filling of a segmental defect of the tibia in experimental animals under the conditions of external osteosynthesis using an allograft with the addition of PRP were comparable to the results of autologous bone grafting. It must be emphasized that autologous bone grafting is still the “gold standard” and the reference osteoplastic material [88].

In the literature, there are optimistic results in meta-analyses of the experimental use of PRP therapy for low bone tissue potential to regenerate as an orthobiological material that stimulates histiogenesis [89–91].

A significant part of the work is devoted to studying the effectiveness of PRP therapy in combination with various orthobiological materials; therefore, it is difficult to associate the achieved results in the healing of nonunion and bone defect management only with platelet-rich plasma [91–93].

Thus, at the moment there is a need for works with a high level of evidence and reliable effectiveness of PRP therapy in the restorative treatment of patients with pseudarthrosis and bone defects.

CONCLUSION

The analysis of literature has shown that there are grounds for studying the clinical effect of the combined use of surgical technologies based on autologous reparative processes and materials developed on the principles of orthobiology.

Based, first of all, on foreign literature data, there is a need and feasibility for clinical trials on the use of bone morphogenetic proteins rhBMP–2 and rhBMP–7 in the reconstructive treatment of patients with bone defects and nonunion of various etiologies.

Currently, multicenter clinical studies with a high level of evidence are required to determine the effectiveness of PRP therapy in the reconstructive treatment of patients with bone defects and nonunion.

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Review article
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Current state of the treatment problem in the patients with elbow joint contractures due to ossification

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Abstract

Introduction Surgical treatment of stiff elbow caused by ossification often result in poor outcomes due to anatomical and physiological characteristics, significant functional load and higher patient requirements for the elbow functionality.

The purpose was to determine ways of improved surgical treatment for patients with elbow contractures caused by ossification, based on an analysis of literature reporting surgical strategy and outcomes.

Material and methods An internet search of PubMed, Medline, Elibrary.ru, CyberLeninka, Google Scholar, International Clinical Trials Registry of the US National Institutes of Health, ISRCTN Registry of International Standard Randomized Clinical Trial Numbers, German Clinical Trials Registry DRKS, WHO Registry was performed. Search words and phrases included elbow contracture, ossification, surgical treatment, stiff, elbow, surgical treatment, ossification. The search depth was 10 years.

Results and discussion Some important parameters (recurrence of stiffness, pain, decreased quality of life, etc.) are reported as "very unassertive" in patients with stiff elbow due to ossification at mid and long terms (12–24 months or greater). Poor outcomes are reported in approximately 50 % of the cases due to the range of motion decreased to the preoperative level or less. Many patients (more than 90 % according to some authors) need a repeated surgery and are at risk for the stiff joint.

Conclusion A critical analysis of the literature indicates lack of preoperative instrumentation examination of patients with use of new visualization methods (3D modeling). Preoperative examination and surgical planning based on additive technologies are essential for surgically treated patients with stiff elbow caused by ossification.

Keywords: elbow joint, contracture, ossification, surgical treatment, arthroscopy, manipulation under anesthesia/redressal, prosthetics, reconstructive plastic surgery, long-term results

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INTRODUCTION

Despite the improvements in surgical techniques and technology treatment of elbow contractures due to ossification remains one of the biggest challenges in trauma and orthopaedic surgery [1, 2]. Although traumatic injuries to the bones forming the elbow joint are not common and account for less than 5 % of all skeletal injuries [3], post-traumatic and postoperative complications occur in a third of patients (29.9 %) [4–7]. With this parameter, the elbow joint consistently ranks first, which often contributes to poor outcomes and persistent disability of patients, despite seemingly adequate treatment and rehabilitation [8]. Difficulties in management of the patients are associated with persistent contractures developing shortly after injury due to periarticular ossification [9]. The extremely high importance of the elbow joint in the human physiological activity leads to the fact that its stiffness, including that caused by ossification resulting from traumatic injuries, surgical interventions and diseases and other factors associated with this phenomenon often can lead to functional failure of the limb [10–13]. The range of motion in the elbow joint decreased by 50 % reduces the functional activity of the upper limb by 80 % [14]. Elbow contracture can limit individual's ability to work, perform household chores or participate in recreational activities [3, 8, 15, 16]. Repeated functional restorative surgical interventions can be required for 30 to 60 % of patients operated on for injuries or diseases of the elbow joint [17–19]. Heterotopic ossification (HO) of the elbow occurs frequently after mechanical damage to the joint, which is not typical and is extremely rare for other joints [3, 20, 21].

Rapid development of persistent elbow contractures due to the tissue's propensity for various types of ossification (including paraarticular) is a serious problem in the treatment of this target patient population [9, 22, 23]. The strategy of surgical treatment of the patients requires discussion and may need improvement, one of the options may be the use of New methods of preoperative examination and planning, based on current computer technologies can be applied to allow an accurate localization (for various types of ossification) and the severity of the pathological process [24].

The purpose was to determine ways of improved surgical treatment for patients with elbow contractures caused by ossification, based on the analysis of literature reporting surgical strategy and outcomes.

MATERIAL AND METHODS

An internet search of PubMed, Medline, Elibrary.ru, CyberLeninka, Google Scholar, International Clinical Trials Registry of the US National Institutes of Health, ISRCTN Registry of International Standard Randomized Clinical Trial Numbers, German Clinical Trials Registry DRKS, WHO Registry was performed. Search words and phrases included elbow contracture, ossification, surgical treatment, stiff, elbow, surgical treatment, ossification. Most publications corresponded to a search depth of 10 years. Single (fundamental) studies on the problem dated back to the 1990s. In addition to that the cited sources mentioned in the bibliographic sections of the articles and contained relevant information were used after preliminary examination.

A total of 186 thematic publications were identified, of which 81 articles published in Russian and 105 were foreign articles (mostly in English). With abstracts, patents, experimental studies, etc. being excluded the references reduced to 92. The review did not include articles on stiffness (contracture) of other joints, with the exception of articles reporting treatment of combined contractures of several joints of the upper limb, including the elbow. Articles published in languages other than Russian and English, as well as articles on elbow replacement due to contracture, were not used in this work. Literature sources reporting elbow stiffness caused by extra-articular causes, case reports and case series were not included in the review. Articles in full-text format and humans trials describing outcomes at mid term and/or long term were primarily included in the review.

Demographical data (gender and age of patients), the nosology, surgical techniques and assessment of mid-term and/or long-term outcomes of the patients were explored. New imaging methods (3D reconstruction of the joint based on computed tomography) are used preoperatively to improve the methodology of surgical treatment of patients with elbow contractures caused by ossification. In this regard, the review includes articles reporting the use of the (additive) technologies in different medical fields, including traumatology and orthopaedics, and the results of a patent search on this issue.

RESULTS AND DISCUSSION

Many authors emphasize that comparison of surgical outcomes of patients with elbow contractures, including those caused by ossification of different origin can be considered objective if the review includes data from one clinical center with surgical treatment performed using a single technology (standards of examination and treatment, and type 1 system errors) by the same specialists [25, 26]. In this regard, reviews and publications of retrospective studies on this issue are practical for assessing mid-term and/or long-term results of surgical treatment of contractures (including the elbow joint) [24, 25, 26].

Qian et al. reported the use of multivariable logistic regression analysis to evaluate long-term outcomes of 461 patients treated for elbow contractures and found that risk factors for progression of stiffness might include increased “cast immobilization time” (immediately after injury and following surgical procedure; OR = 2.020; $p = 0.014$), multiple surgeries (OR = 1.943; $p = 0.026$) and alcohol abuse (OR = 3.082; $p = 0.025$) [26]. Haglin et al. reported a retrospective record review of 103 patients with elbow contractures who underwent open surgical treatment (arthrolysis) of the joint. At the initial procedure, 85 % of patients “demonstrated elbow extension/flexion arc of motion of 100°”. A 19-to-24-month follow-up showed that 93.2 % (!) of the total cohort of cases required repeated surgical treatment for various reasons. Radiographic recurrence of HO occurred in 17 % after surgery. Not including recurrence of contracture, a subsequent complication occurred in 10 patients. The authors reported repeated operations being common including neurolysis of the ulnar nerve, debridement and use of drains for postoperative infection. The authors concluded that “patients must be counseled that contracture may reoccur, and some patients may require or elect to have more than one procedure to achieve functional motion” [24].

Spitler et al. explored the efficacy of repeated surgical interventions for recurrent elbow contractures [27]. Patients were stratified based on the duration of the time interval between primary and repeat surgical interventions. Patients who had repeat surgery within 3 months of their most recent surgical procedure (n = 28) were included in the "early manipulation" group. Patients who underwent repeat procedure after 3 months (n = 17) were included in the "late manipulation" group.

A comparative analysis of the improvement in elbow arc of in the study groups revealed clinical significance (the difference in the increase in the average arc of motion between the groups was +38.5° and +3.1° in the comparison groups, respectively) and statistically significant difference ($p \leqslant 0.001$) in favor of the early manipulation group. Other authors reported similar patterns in the treatment of patients [28]. A clinically significant increase in the amplitude (+10° or more) was detected in less than half of the cases of the late manipulation group. An average arc of motion decreased in approximately 30 % of patients (6 out of 19). Four patients required additional surgical treatment, and 2 of them developed clinically significant HO. The authors reviewed the long-term outcomes and the literature data and concluded that patients with osteogenic and heterotopic ossification were "unlikely to benefit" from such surgical treatment [29–33].

In addition to osteogenic ossification, which causes incongruity of the articular surfaces and requires simulating resection, the elbow joint can be susceptible to other types of ossification, such as myositis ossificans (MO) and HO [34]. Elbow contractures with these types of ossification are reported to occur in 10 % in MO and about 7 % in HO [34–36]. There is a paucity of therapeutic methods for elbow contracture due to ossifying processes. Conservative methods, methods of static and dynamic splinting and "manipulation under anesthesia", redressment cannot be used for the target population of patients [37]. Surgical treatment is indicated for patients with elbow joint stiffness in presence of ossification [34, 38, 39].

Mittal concluded that the best results in the treatment of the condition can be achieved with the surgery performed within the first year of the contracture to prevent extra-articular factors aggravating the pathological process (muscle and tendon spasticity, decreased elasticity of the joint capsule due to chronic inflammation, etc.) [34, 40, 41]. Preoperative planning for repair of elbow contracture, including that caused by ossification, must address all the pathological structures and/or other factors that contribute to loss of mobility due to recurrent condition or complications [24, 42–44].

The role of preoperative planning in improving surgical strategy and treatment results

Osteophytes and calcification of soft tissues contributing to contractures often raise difficult questions for clinicians in terms of diagnosis, treatment, clinical and social rehabilitation and prognosis of the disease [9, 23]. is also The elbow joint is of greatest interest in this regard being prone to such pathological conditions [6, 22]. Accurate identification of the position and size of pathological bone structures in the preoperative period suggests more rational planning, minimal surgical aggression and better treatment results [8, 45, 46]. Standard radiological examination using several views is considered the main instrumentation examination used as the basis for preoperative planning. However, a two-dimensional image

can fail to show the exact size and location of ossifications. In addition to that, computed tomography (CT) can help "visualize joint structures much better", and magnetic resonance imaging (MRI) is "rarely required when assessing elbow stiffness" [34].

Mellema et al. reported surgical treatment of elbow contracture with use of modern methods of three-dimensional reconstructions based on CT images for a more complete assessment of the articular and periarticular structures [25]. Objective results of surgical treatment of patients with elbow contractures of the joint due to improved examination strategy using modern computer technologies could not be found in the available literature. Most works in the Russian-language literature on the topic are theoretical and/or controversial [47–50].

Some works reporting additive technologies in traumatology and orthopaedics address aspects related to joint replacement [51, 52] or patient rehabilitation [53]. There is no universal surgical technique reported for treating elbow contractures, including those caused by ossification [37, 43, 46, 54–56]. Considering the tendency of this joint to overproduction and heterotopia of bone tissue, most authors agree that all surgical interventions should be performed with minimal surgical aggression [13, 24, 34].

It is quite obvious that conventional radiological examination and even MSCT of the affected joint, recommended as standards for preoperative examination of patients, do not provide a complete picture of the prevalence and severity of ossification and other pathological conditions [7, 8, 25, 26, 45]. The surgeon is forced to make decisions in the operating room during the operation resulting in increased operating time and numerous risks (including those contributing to the relapse of contracture), and contradicting the concept of minimal surgical intervention, reported in many works on the treatment of elbow contractures [7, 8, 20, 28, 34, 44, 45, 57, 58].

Analysis of literature data on the surgical treatment of patients with elbow contractures indicates that various types of ossification resulting from diseases and injuries, surgical interventions can lead to significantly impaired elbow function and contracture. Currently, surgical treatment of patients with elbow joint contractures due to ossification is somewhat reminiscent of a vicious circle. The surgical interventions (and re-operations, in particular) produced to remove ossification (arthroscopy, simulating resection of bone structures, excision of ossification foci) are one of the factors provoking the development of ossification. The high tendency of the elbow joint to develop stiffness is due to the specific anatomical structure. The presence of three separate joints within one capsule, the large number of periarticular nerve trunks, the abundance of vulnerable soft tissues necessary to provide joint stability, and the proximity of the brachialis muscle to the anterior capsule predisposes the joint to the development of contracture even with minor levels of alteration. With the arsenal of methods for treating elbow joint contractures, not all of them can be used in patients with various types of ossification. There is not enough clinical data to recommend a universal method for treating contractures caused by ossification, even from a relatively small arsenal of surgical methods. With a surgical intervention performed in a delayed manner (at 3 months or later after the development of contracture), a sufficient range of motion (about 4 %) can hardly be achieved intraoperatively and the range of motion

in the elbow joint decreases in some patients (about 30 %) after surgery. Recurrent condition is observed in approximately 17 % of patients with contractures caused by ossification after surgical treatment.

Most studies focus on the fact that there is no single protocol for surgical or combined treatment of patients with elbow contractures, and it is difficult to compare the results of studies. There is a paucity of information regarding preoperative planning and examination of patients using new imaging methods. Recommendations on this issue are usually limited to performing radiographs (in standard projections) or MSCT studies. A few studies contain references to the use of three-dimensional reconstructions based on CT images for a more detailed assessment of the articular and periarticular structures. An analytical review of literature data on the surgical treatment of patients with elbow contractures of the joint allows us to conclude that:

— surgery is the main treatment method for elbow contractures, including those caused by ossification to be performed with arthroscopic techniques or open access;

— each of the surgical techniques has advantages and disadvantages, and the treatment strategy would differentiated in each specific case;

— mid-term and long-term results indicate a significant decrease in the range of motion in the operated joint below acceptable values in half of the patients;

— a significant number of patients operated on for contractures caused by ossification may require repeated surgical interventions due to the anatomy and physiology of the elbow joint, however, early repeated and delayed (later than 3 months) procedures are considered as risk factors for recurrent condition;

— surgical interventions for elbow contracture (in the presence of ossification, in particular) should be performed with minimal surgical aggression, since a surgical procedure in this case is a risk factor for recurrence of the disease and for an increased period of immobilization (after injury or surgery);

— authors pay little attention to preoperative examination of patients, but the use of additive technologies in the process of examining patients with elbow contractures, including those caused by ossification, can provide the most complete information about are able to provide the most complete information about the condition of bone and articular and para-articular structures to be used for preoperative planning and surgical intervention to be performed with minimal surgical aggression and greater efficacy.

CONCLUSION

A critical analysis of the literature shows a paucity of information on preoperative examination of patients using new visualization methods (3D modeling). In our opinion, preoperative examination and planning based on additive technologies are essential for surgical treatment of patients with elbow contractures caused by ossification having a more significant role than that which was identified based on the analysis of literature data.

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Review article
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Lumbosacral transitional vertebrae in children and adolescents (literature review, illustrated with clinical observations)

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Abstract

Introduction An analysis of the medical literature devoted to various aspects of transitional lumbosacral vertebrae shows that there are very few publications covering the course of this disease in the pediatric and adolescent population.

Aim To study the issues of epidemiology, diagnosis, treatment and prevention of transitional lumbosacral vertebrae in paediatric and adolescent patients based on the analysis of current medical literature and illustrate the material with our own clinical observations.

Material and methods To analyze the literature on the topic, 75 papers published between 1984 and 2023 were selected. Among them, there were 7 (9.3 %) domestic literary sources, 68 (90.7 %) were foreign. In the process of searching for scientific articles, the resources of the electronic databases of current medical information PubMed and CyberLeninka were used.

Results and discussion The incidence of transitional vertebrae in children and adolescents is 16.8 % of clinical observations, as reported. In the structure of the transitional vertebrae in children, type II of the disease predominates according to the classification Castellvi et al (1984), 43.2 % of cases. The main clinical symptom of the pathology is pain of lumbosacral location, the intensity of which on the visual analog scale in children corresponds to an average of 3.0 points. In adult patients with similar pathology, the average pain intensity measured with the same scale is 7.5 points. The most informative method for diagnosing the disease is computed tomography, which allows obtaining both 3D images and sections at the level of pseudarthrosis between the enlarged transverse process (or processes) of the suprasacral vertebra and the wing of the sacrum. To relieve pain in children with transitional vertebrae, both conservative and surgical methods are used. The most commonly used procedure is pseudarthrectomy. The study of long-term results one year after the intervention allowed us to record the absence of pain in children who underwent surgery. Prevention measures for transitional lumbosacral vertebrae have not been developed.

Conclusion The analysis of the published literature shows that transitional vertebrae are a frequently diagnosed pathology in children and adolescents. Current methods of imaging are able to accurately detect not only the presence of the disease, but also to differentiate its type. The main clinical symptom of transitional vertebrae is pain in the lumbosacral spine which is difficult to relieve with conservative therapy. Pseudarthrectomy is the most frequent surgical method of treatment in children and adolescents that provides stable relief of vertebrogenic pain syndrome. Measures for specific prevention of the disease have not been developed.

Keywords: children, adolescents, lumbosacral transitional vertebrae, pseudoarthrosis, lumbar pain, diagnosis, treatment, pseudoarthrectomy, pain relief, long-term result, literature review

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INTRODUCTION

Transitional lumbosacral vertebrae in the form of L5 sacralization and S1 lumbarization are classified as a congenital pathology caused by a mutation of the Hox gene at the 4th week of intrauterine development of the fetus [1]. The incidence of the pathology may reach 46 % of clinical observations [2] and depends on what categories of patients are examined, what radiation imaging methods are used and how the results are interpreted [3, 4].

The analysis of current scientific literature devoted to various aspects of the transitional lumbosacral vertebrae shows that there are very few publications covering the course of sacralization and lumbarization in the paediatric and adolescent population [5]. This fact is difficult to explain, given the congenital nature of the disease, and therefore there is high probability of manifestation of clinical symptoms and radiation signs of the pathology in growing patients [6].

Purpose To study the issues of epidemiology, diagnosis, treatment and prevention of transitional lumbosacral vertebrae in paediatric and adolescent patients based on the analysis of current medical literature and illustrate the material with our own clinical observations

MATERIALS AND METHODS

The search for scientific sources was carried out in the PubMed search engine and the CyberLeninka electronic library for the period from 1984 to 2023. The following search words were used in Russian and English: lumbosacral transitional vertebra, children and adolescent population, incidence of pathology, intensity of vertebrogenic pain syndrome (intensity of vertebrogenic pain syndrome), computed tomography, conservative therapy, surgical treatment methods, long-term treatment results, and prevention.

Criteria for inclusion of scientific publications in the study were:

— Full-text scientific articles that report fundamental information about the transitional lumbosacral vertebrae (etiology, classification);
— Full-text scientific publications that provide current information on the course of transitional vertebrae disease (clinical symptoms, issues of radiation diagnostics, conservative and surgical methods of treatment, selected results of therapy) in paediatric patients and adolescents;
— Full-text scientific papers reporting the results of mono-center cohort studies and case-control studies and illustrating clinical cases of children and adolescents that have pain syndrome caused by transitional lumbosacral vertebrae.

Exclusion criteria were abstracts of scientific and practical conferences, scientific articles that do not contain information that the clinical material for the study was children and adolescents with transitional vertebrae of the lumbosacral location.

In total, 75 publications were selected for writing a literature review, of which 7 (9.3 %) were domestic sources and 68 (90.7 %) were foreign ones.

RESULTS AND DISCUSSION

The analysis of the reported information shows that the minimum incidence of the pathology being studied is 6.1 % of clinical cases [7], the maximum is 30.0 % of cases [8], and an average incidence is 16.8 % (Table 1).

General population incidence of diagnosing transitional vertebrae, established on the basis of clinical examination and radiological imaging methods in patients of all ages is in the wide age range, from 4 to 30 % [9], but with the same average incidence of 16 % of cases studied [10].

The main clinical symptom of the disease is pain in the lumbosacral region [11]. The onset of pain regularly starts at the age of 30 years and over [12]. The cause of pain is most frequently degenerative processes in the intervertebral discs and facet joints located above the abnormal spinal motion segment [13–15]. In children and adolescents, due to the anatomical and physiological features of the spine, degeneration of discs and joints is minimally expressed or absent, therefore they do not complain of pain even if the radiation symptoms of the transitional vertebrae are detected [7], or the pain syndrome is mild and rarely exceeds 3 points on the visual analogue scale [16]. In adult patients, the intensity of lumbar pain on a similar scale averages 7.5 points [17].

An important clinical characteristic of pain in adolescents with transitional lumbosacral vertebrae is its site located in the projection of pseudarthrosis or concrescence between the enlarged transverse process of the L5 vertebra and the sacral wing on one or both sides, depending on the type of pathology [7]. The patient, at the request of the physician conducting the clinical diagnosis, can place one of his fingers at the indicated point (1 cm below and medial to the posterior superior iliac spine), localizing the pain and, if it is felt, this fact must be regarded as a positive Fortin finger test [18], inherent in transitional vertebrae [19].

In adolescents, pain in the lumbosacral spine can radiate to the buttock and distally along the lower limb, reaching the level of the foot [20]. The cause of such pain is degenerative damage to the intervertebral disc, up to the stage of sequestration, usually located immediately above the abnormal one [21]. The frequency of diagnosis of transitional vertebrae in pediatric patients with herniated intervertebral discs can reach 30 % of the cases [8].

A number of authors describe cases with pain localized not in the area of pseudarthrosis, but in the projection of the intervertebral joint on the contralateral side, immediately above the abnormal spinal motion segment [22]. A similar clinical situation was reported Brault et al. and showed a possible location of pain on the opposite side in a 17-year-old athlete [23].

Of all the diseases of the paediatric spine, multiplanar scoliotic deformity is the most thoroughly studied (Fig. 1), which occurs and often progresses against the background of transitional vertebrae [24, 25].

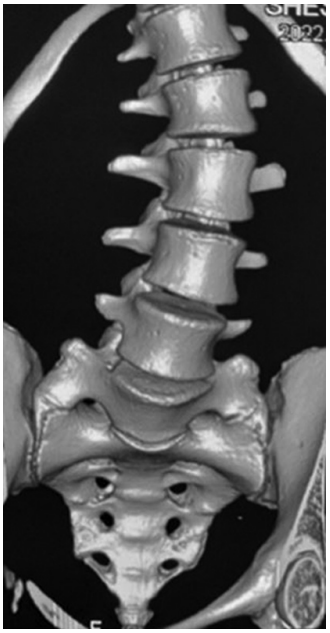


Fig. 1 CT scan of the lumbar spine and sacrum of patient Sh., 15 years old: compensatory left-side lumbar curvature, transitional (lumbarized) lumbosacral vertebra, type IIb (authors' clinical case)

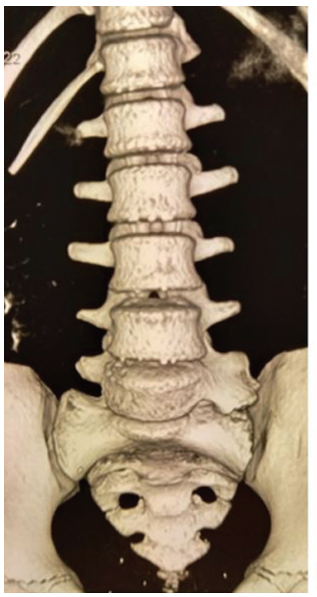
The incidence of comorbidity of these two nosological forms of vertebrogenic pathology ranges from 6.3 [26] to 25.1 % [27]. The gender and age of patients, as well as the type of deformities they have, frequently do not correlate with the known subtypes of transitional vertebrae [28, 29]. However, opposing opinions have also been published. Thus, Can et al. provide data that among 125 children with sacralization of the L5 vertebra, 66 (52.8 %) subjects had scoliotic spinal deformity, while cases of unilateral sacralization, in contrast to bilateral ones, in teenage girls were more often accompanied by spinal curvature [30]. In children with genetic Williams-Beuren syndrome, one of the manifestations of which is scoliosis, the incidence of dtecting transitional vertebrae is 57 % of clinical observations [31], which is several times higher than the known general population comorbidity [27, 32].

Only a few publications in the available medical literature are devoted to the peculiarities of treatment tactics in children with scoliosis associated with transitional vertebrae. Thus, Hu et al. warned the colleagues against performing operations at the wrong level. This is due to incorrect numbering of the vertebrae, which is often found in clinical practice [33]. Lee et al. recommended that the extent of the fusion zone in the distal parts must be limited to the L3 vertebra in patients with scoliosis and transitional vertebrae [28]. Yamauchi et al. analyzed 5-year results of surgical correction of type 5 scoliosis according to the Lenke classification in 15 children with lumbosacral vertebrae and found that at all periods of studying long-term results (after 2 weeks, after 2 years and after 5 years post-surgery), the angle of inclination of the L4 vertebra anteriorly exceeded by three degrees on average the values of patients in the control group who had no anomalies [34].

An equally severe type of vertebrogenic pathology in pediatric patients is spondylolysis of the interarticular part of the arches and spondylolytic spondylolisthesis of the lower lumbar vertebrae [35]. Transitional lumbosacral vertebrae in children and adolescents with these serious diseases are diagnosed in 14.7 % of the cases (Fig. 2).

Such incidence of sacralization and lumbarization was established during complex radiological study of 109 children aged 3–17 years with spondylolytic spondylolisthesis of the L4 and L5 vertebrae of severity grade I–IV and spondyloptosis [36].

Yao et al. are confident that increased stability (the authors' term) between the sacralized L5 vertebra and the sacrum leads to excessive mobility at the level of the spinal motion segment L4-L5, which implies an excessive load on the interarticular part of the arch of the L4 vertebra, and means it is a high risk factor for the development of vertebral spondylolysis. The authors diagnosed radiation symptoms of transitional vertebrae in a group of 102 patients of various ages with L4 spondylolysis in 36 % of clinical cases [37].



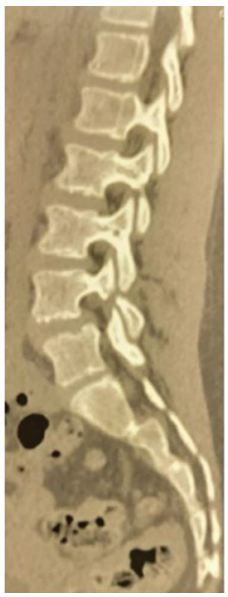
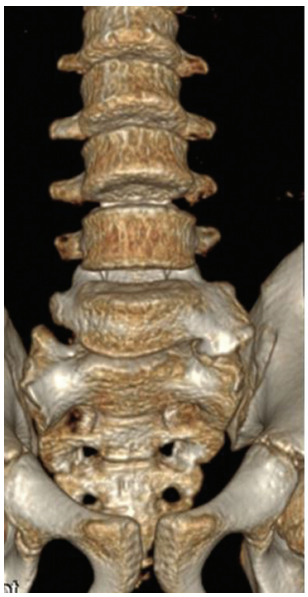


Fig. 2 CT scans of the lumbar spine and sacrum of patient D., 11 years old: transitional (sacralized) lumbosacral vertebra, type IIa; aplasia of the left transverse process of the vertebra T12 and rib 12 on the left (*a*); spondylolysis of the interarticular part of the L4 vertebral arch; spondylolisthesis of the L4 vertebra, grade I (*b*) (authors' clinical case)



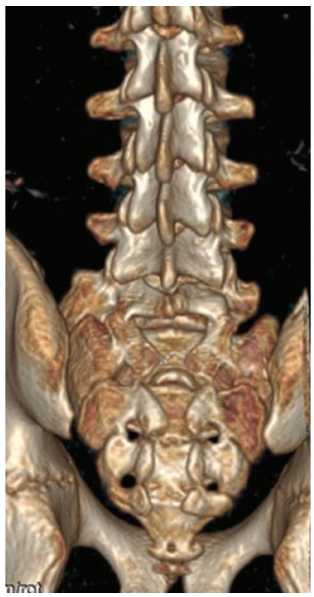


Fig. 3 CT scans of the lumbar spine and sacrum of patient M., 13 years old. Transitional (lumbarized) lumbosacral vertebra, type IIa, front view (*a*). Non-fusion of the posterior part of the arch of the transitional vertebra, non-fusion of the sacral canal (*b*); authors' clinical observations

Nonfusion of the posterior part of the vertebral arches (spina bifida posterior) is one of the most frequently diagnosed developmental anomalies of the lumbosacral location [38]. In children and adolescents with transitional lumbosacral vertebrae, radiation imaging reveals nonfusion of the arches with an incidence of 22.7 (lumbarization) to 27.3 % (sacralization) of cases [39] (Fig. 3).

The main clinical symptom of the comorbid course of these anomalies in children is pain syndrome [40, 41], the severity of which on a visual analog scale usually corresponds to 3 points [16], but in rare cases it can reach an 8-point value [42]. The mutually aggravating impact of the transitional vertebrae and spina bifida posterior is a high risk factor for the formation of degeneration of the intervertebral discs, up to the stage of their sequestration [43]. Thus, Milicic et al. found the presence of disc pathology in 56 (86.1 %) clinical cases in a group of 65 children who had transitional vertebrae and nonfusion of the posterior part of the vertebral arches which was regarded as the cause of lumbar pain. The authors used magnetic resonance imaging for diagnosis [16]. In order to relieve pain in the lumbar region and lower extremity, Kundi et al. administered gabapentin at a dosage of 100 mg three times a day. The result of conservative therapy was pain relief in patients from the initial 8 to the final 4 points on the visual analogue scale [42].

It is known that there are four types of transitional lumbosacral vertebrae, and the first three have subtypes “a” and “b” [44]. In the paediatric and adolescent population, type II predominates while subtypes “a” and “b” occur with almost equal incidence and are characterized by the presence of a zone of pseudo-articulation between the enlarged transverse process of the suprasacral vertebra and the wing of the sacrum from one side (subtype a) or on both sides (subtype b) (Fig. 4).

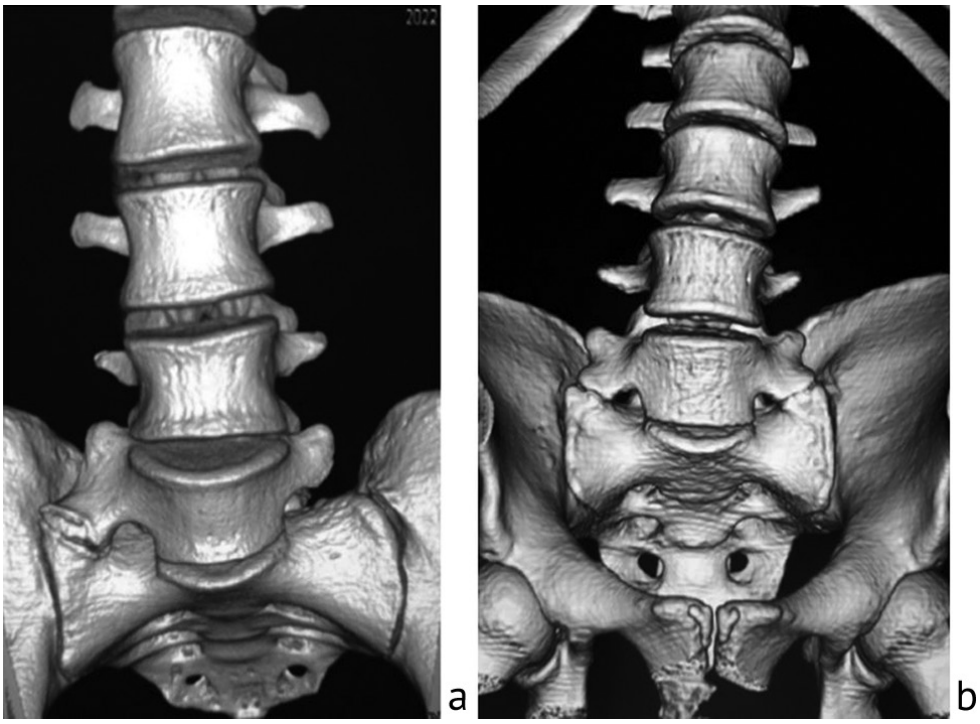


Fig. 4 CT scans of the lumbar spine and sacrum of 17-year-old patients: transitional (sacralized) lumbosacral vertebrae, type IIa (*a*) and type IIb (*b*), authors’ clinical observations

The incidence of detecting transitional lumbosacral vertebrae in paediatric and adolescent patients was reported in 10 scientific articles in the current medical literature, and is based on examination of 3,663 clinical cases (Table 1).

Table 1

Reported information on the incidence diagnosing transitional lumbosacral vertebrae in children and adolescents

Author, country, year, source	Type of study	Number of studied patients	Pathology	Rate of diagnosis, %
Skryabin et al., Russia, 2023 [7]	Monocenter cohort	312	Lumbar spine injury	6.1
Zhang et al., China, 2017 [8]	Case report	80	Intervertebral disc hernia, no complaints	30.0
		92		7.0
Ibrahim et al., USA, 2013 [26]	Monocenter cohort	364	Idiopathic scoliosis	10.4
Chiu et al., Malasia, 2023 [27]	Monocenter cohort	998	Idiopathic scoliosis	25.1
Lee et al., South Korea, 2017 [28]	Monocenter cohort	385	Idiopathic scoliosis	12.2
Garg et al., India, 2021 [29]	Monocenter cohort	198	Idiopathic scoliosis	18.2
Hu et al., China, 2016 [33]	Monocenter cohort	657	Idiopathic scoliosis	10.6
Yamauchiet al., Japan, 2023 [34]	Monocenter cohort	61	Idiopathic scoliosis	24.5
Illeez et al., Turkey, 2022 [43]	Monocenter cohort	400	Low back pain	16.8
Gennari et al., France, 2015 [45]	Case series	116	Low back pain	6.9
Total		3,663		16.78

We analyzed scientific articles written by 17 teams of authors that reported information on the incidence of diagnosing the known types of transitional vertebrae in patients of different ages [4, 10, 37, 43, 46–58]. It turned out that in total of their structure, type II pathology accounts for 43.2 % of clinical observations while types I, III and IV of the disease occur with the incidence of 32.2, 18.0 and 6.6 %, respectively. Detailing the pathology by disease subtypes showed a predominance of type IIa with an incidence of 26.9 %, and type IIb with an incidence of 25.9 % of clinical observations [43, 50, 55].

The most informative method of radiological visualization of transitional vertebrae in the pediatric population is computed tomography, which allows obtaining both 3D images and sections at the level of pseudarthrosis between the enlarged transverse process (or processes) of the suprasacral vertebra and the wing of the sacrum [59]. Our own clinical observations presented above (Figures 1 to 4) fully illustrate what has been said.

In order to relieve pain in patients with transitional vertebrae, including children, both conservative (medical drugs, physiotherapeutic procedures) and operative (pseudoarthrectomy, radiofrequency ablation, minimally invasive interventions, interbody fusion) methods have been used [6, 60–66].

It is not rare that the positive short-term effect of conservative therapy, especially with medicinal therapeutic blockades, is considered as an indication for surgical intervention [67]. Among surgical techniques in pediatric patients, the most widely used method is pseudoarthrectomy [68]. The essence of the method is to bisect the base of the transverse process of the transitional vertebra with a high-speed drill in order to decompress the mechanical stress in the area of pseudarthrosis [69].

Our study of scientific articles devoted to the use of pseudoarthrectomy in clinical practice found four publications that provide examples of its use in pediatric and adolescent patients (Table 2). In all four publications, the effectiveness of pseudoarthrectomy was pain relief, while conservative therapy had a short-term therapeutic effect.

Table 2

Scientific publications that provide information on the use of the pseudoarthrectomy in the treatment of pain caused by transitional lumbosacral vertebrae in children and adolescents

Author, country, year, source	Type of study	Patients			Duration of pain before surgery	Follow-up duration
		number	sex	age, years		
Sumarriva et al., USA, 2022 [62]	Monoticenter cohort	1	m	17	2 years	4 years
Babu et al., USA, 2017 [70]	Monocenter cohort	1	f	17	4 years	1 years
Cuenca et al., France, 2019 [71]	Monocenter cohort	1	m	13	4 years	1 years
Louie et al., Germany – USA, 2019 [72]	Monocenter cohort	2	f	15	9 months	1 years
					2 years 3 months	

The analysis of the information presented in Table 2 shows that in all cases the authors managed to achieve a positive effect for a long period of time. According to Mikula et al. who compared the results of using pseudoarthrectomy and posterior spinal fusion techniques in a group of patients with lumbar pain caused by transitional vertebrae, the effectiveness of spinal fusion in achieving a positive result exceeds the effectiveness of resection in long term follow-up, more than 1 year, 78 and 28 % of clinical cases, respectively [73]. In pediatric patients that suffer from low-back pain caused by transitional vertebrae, the transpedicular fusion technique was used in one patient with a positive therapeutic effect [61].

A relevant problem in the contemporary paediatrics is prevention of pain associated with congenital spinal diseases [74]. The above fully applies to such pathology in children as transitional vertebrae [75]. Considering the fact that the disease is congenital in nature, and therefore develops in utero, it is not impossible to influence the process of ontogenesis for preventive purposes [76]. The proposals of some authors to conduct a preventive X-ray examination of the spine in children to identify anomalies of its development [12] is not a preventive measure, but is aimed at diagnosing a suspected pathology and is not advisable from some points of view including deontological and anti-radiation ones [36].

CONCLUSION

A small number of scientific articles are devoted to various aspects of transitional lumbosacral vertebrae in paediatric patients. However, the review of the published literature shows that transitional vertebrae are a frequently diagnosed pathology in children and adolescents. Current imaging methods are able to accurately detect not only the presence of the disease, but also to differentiate its type. The main clinical symptom of transitional vertebrae is pain in the lumbosacral spine which is difficult to relieve with conservative methods of therapy. One of the surgical methods most frequently used in children and adolescents is pseudoarthrectomy, which is able to relieve the vertebrogenic pain syndrome. Due to the fact that the disease develops in utero and manifests clinically at different age periods, measures for its specific prevention have not been developed.

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Orthopaedic complications of hemiparetic forms of cerebral palsy: problems of the lower extremities (literature review)

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Abstract

Introduction Spastic hemiplegia (a unilateral neurological disorder) is encountered more often in full-term infants. In most cases, the cause of the condition is intrauterine or perinatal stroke. Children with hemiparetic forms maintain cognitive and functional capabilities in combination with the ability to move independently. Among other forms of cerebral palsy, hemiparetic spastic forms range from 10.4 to 15.3 %. Types with mild motor impairments predominate according to the Gross Motor Function Classification System: 87.8 % are level I GMFCS, 7.1 % are level II GMFCS.

The purpose of the work was to summarize information on the use of orthopaedic interventions for hemiparetic forms of cerebral palsy, both from the point of view of their planning and completeness of correction of anatomical disorders including lower limb length discrepancy, and assessment of functional results based on gait analysis.

Materials and methods The search for publications was carried out in open electronic sources of medical literature PubMed, eLIBRARY, Scopus, Elsevier, Springer, Research Gate with a search depth of 20 years (2002–2022). The following inclusion criteria were used: systematic reviews of the literature, review articles, cohort studies on the topic of multilevel interventions for hemiparetic types of cerebral palsy.

Results and discussion Lower limb length discrepancy of 1 cm or more affects the kinematics of the affected and intact contralateral limb. The unaffected limb is characterized by a compensatory flexion in the hip and knee joints and excessive dorsal flexion in the stance phase. On the affected side, the contribution of shortening to the development of pathological kinematics of the pelvis and spine is especially important. There is a high probability of equinus contracture after surgical correction due to unresolved discrepancy in the length of the lower extremities. Methods for correcting length discrepancy are conservative (compensation with shoes), and surgical lengthening of the lower leg, epiphyseodesis of the contralateral limb, shortening of the contralateral limb. There is no opinion in the literature about the preference of this or that method, and on the necessary magnitude of limb length correction.

Conclusion The assessment of limb length discrepancy and contribution of this orthopaedic component to systemic movement disorders in spastic hemiparesis is based on computed tomography or magnetic resonance imaging, as well as on computer gait analysis. In the literature, the issue of limb length correction is considered separately from the complex of other orthopaedic interventions, while the features of correction with regard to spontaneous growth potential or after growth completion have not been defined. The advantage of equalizing the limb length in children with temporary epiphyseodesis over distraction osteogenesis is only supposed. There is not enough data on the effect of the limb length correction magnitude in patients with spastic hemiplegia on the parameters of computer gait analysis.

Keywords: unilateral cerebral palsy, orthopedic surgery, lower limb length discrepancy

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INTRODUCTION

Cerebral palsy (cerebral palsy) is a primary neuromotor disorder of the central nervous system that occurs in the prenatal or perinatal period and causes disturbances in muscle tone, movements and posture [1, 2]. Although the neurological disorder is not progressive, secondary complications that arise, mainly orthopaedic, lead to serious loss of functional abilities [3–5]. The incidence of cerebral palsy varies from 1.5 to 4.2 per 1,000 newborns, depending on the geographic region and the financial status of the population [6, 7].

Spastic hemiplegia (a unilateral neurological lesion), which orthopaedic complications are the subject of this review, occurs more frequently in full-term infants, and in most cases the cause of the disorder is an intrauterine or perinatal stroke [8]. Regularly, children with hemiparetic CP have preserved cognitive and functional capabilities in combination with the ability to move independently [9, 10]. Among other forms of cerebral palsy, hemiparetic spastic forms range from 10.4 to 15.3 % [7, 11]. Types with mild motor impairments predominate according to the Gross Motor Function Classification System [12]: 87.8 % are level I GMFCS, 7.1 % are level II GMFCS [11].

Hemiparetic forms of cerebral palsy are rarely accompanied by significant intellectual disorders, but the resulting orthopaedic disorders seriously affect the motor abilities and quality of life of children and adults [13–18]. The main orthopaedic secondary disorders in spastic hemiplegia are contractures of the ankle, knee and hip joints, equinovarus or equinovalgus foot deformities, torsion deformities of the femur, and limb length discrepancy [13, 15, 19–21].

The modern concept of surgical treatment of orthopaedic complications in children with cerebral palsy is multilevel surgical interventions on all components of the biomechanical limb chain, including cases of hemiparetic forms of cerebral palsy [15, 22–25].

Analyzing treatment planning and assessing the results of interventions, the researchers focus on the problem of limb length discrepancy in patients with spastic hemiparesis [26], on the anatomical and functional changes in the contralateral, neurologically intact limb [19, 27–29], as well as on a detailed computer analysis of the gait parameters in these patients [20, 30–33].

Purpose To collect and summarize the information on the use of orthopaedic interventions for hemiparetic forms of cerebral palsy, both in terms of their planning and completeness of anatomical correction, including lower limb length discrepancy, and the assessment of functional results based on gait analysis.

MATERIALS AND METHODS

The search for available publications was carried out in open electronic sources of medical literature PubMed, eLIBRARY, Scopus, Elsevier, Springer, Research Gate with a search depth of 20 years (from 2002 throughout 2022). The following inclusion criteria were used: systematic literature reviews, review articles, cohort studies on the topic of multilevel interventions for hemiparetic forms of cerebral palsy. The selection was carried out using key phrases in Russian and English: multilevel orthopaedic interventions (single-event multilevel surgery; lower limb length discrepancy; growth arrest, guided growth, epiphysiodesis; bone lengthening; gait analysis; unilateral cerebral palsy).

Exclusion criteria were case reports or case series, abstracts, duplication publications. The search revealed a total of 1,261 articles in the field of hemiparesis (unilateral cerebral palsy), 173 articles about multilevel interventions (single-event multilevel surgery), published between 2002 and 2022. Of these, 16 publications on multilevel orthopaedic interventions for hemiparetic forms of cerebral palsy were selected and analyzed, and 5 articles were selected on correction of limb length discrepancy in this disorder and 9 articles on the study of the functional results of multilevel operations for hemiparetic forms using gait analysis. We also selected 4 articles on the effect of orthopaedic pathology on a healthy limb in spastic hemiparesis.

RESULTS

Elements of orthopaedic pathology, the use of gait analysis in diagnosis and surgical planning

Table 1 presents orthopaedic problems in the lower limbs in patients with cerebral palsy which were the reason for seeking medical assistance, the object of diagnostic studies, as well as parameters of gait analysis.

Obviously, torsion deformities of the femur, ankle contractures, and foot deformities are the primary areas of concern. A minority of publications indicates or mentions specifically the correction of leg length discrepancy within the framework of multilevel interventions [34]. Moreover, some of them deal only with the methods for instrumental diagnosis of length discrepancy [14, 26] or with the study of the quantitative effect of shortening on gait parameters and the contralateral limb [19, 35, 36].

Table 1

Described orthopaedic CP complications, use of gait analysis in patients with hemiparetic forms of cerebral palsy

Published source	Hip and knee contractures	Ankle contracture	Femur and/or tibia torsion	Planovalgus foot deformity	Varus-supinated (adducted) foot deformity	Limb length discreapancy	Gait analysis
Krzak et al., 2015 [21]	+	+	–	–	+ (4 types are classified)	–	Computer 3D-analysis
Sclavos et al., 2023 [50]	+	+	–	+	–	–	Computer 3D-analysis
Winters et al., 1987 [37]	+	+	–	–	–	–	Observational analysis
Rethlefsen et al., 2006 [17]	+	+	+	–	+	–	–
Kim et al., 2022 [4]	–	+	–	–	–	+	–
Corradin et al., 2018 [27]	–	+	–	–	–	+	Observational analysis (Edinburgh scale)
Lee et al., 2013 [15]	+	–	+	–	–	–	–
Mork et al., 2001 [14]	+	+	+	+	+	+	–
McCahill et al., 2022 [20]	–	–	+	+	–	–	Computer 3D-analysis
Schranz et al., 2017 [31]	+	+	+	+	+	–	Computer 3D-analysis
Saraph et al., 2006 [45]	–	+	+	–	–	+	–
Schmid et al., 2016 [48]	+	+	–	–	–	+	Computer 3D-analysis
Rodda et al., 2001 [38]	+	+	+	+	+	–	Computer 3D-analysis
O'Sullivan et al., 2013 [40]	+	+	+	–	+	–	Computer 3D-analysis
Wren et al., 2005 [58]	+	+	+	+	+	–	Computer 3D-analysis
Elnaggar et al., 2020 [34]	+	+	+	+	–	–	Computer 3D-analysis

Classification of gait disorders in hemiparetic types of cerebral palsy

The first proposed classification of gait disturbances in unilateral spastic lesions is that of Winters et al. [37], which distinguishes 4 groups based on the pathology of movements of the limb on the affected side in the sagittal plane. The classification reflects the progression of disorders from the distal level to the proximal level (from movement disorders in the ankle joint to the hip) as the severity of the disease increases. Group I is characterized by an equinus position of the foot in the non-support phase of the step cycle, the absence of the first roll of the foot at the beginning of the support phase of the step. The disorders are caused by weakness or underactivity of the tibialis anterior muscle in comparison with the gastrocnemius and soleus muscles. In group II disorders, the foot is in an equinus position during the non-support phase of the gait cycle and in a constant position of plantar flexion during the stance phase. Group II disorders are caused by contracture of the triceps surae. In group III, in addition to the above-mentioned disorders of groups I and II, there is limitation of leg flexion at the knee joint in the non-support phase of the gait cycle, excessive flexion of the hip joint and lumbar hyperlordosis. In group IV disorders, in addition to previous disorders, there is a significantly restricted range of motion in the hip and knee joints throughout the gait cycle.

Winter's classification was refined by Rodda et Graham in 2001 [38], who added group (type) IIb (equinus contracture combined with hyperextension or recurvatum in the knee joint), and torsion deformities (pathological rotational alignment of the femur) were added to group IV. The Rodda classification [38] also proposes principles of conservative and surgical orthopaedic treatment for the correction of gait deviation. These two classifications are generally accepted and are used in determining the patient's motor status and in planning multilevel interventions [39]. However, we underline that these classifications do not consider lower limb length disparities in assessing the severity of orthopaedic and motor impairments.

The problem of lower limb length discrepancy

A number of studies indicate the importance of the impact of difference in the lengths of the lower extremities on the formation of orthopaedic pathology and gait disorders [40], among other factors, demonstrating a significant correlation between length discrepancy and impaired parameters.

Zonta et al. [41] found a correlation between the magnitude of limb shortening and the degree of dependence of a patient with spastic hemiplegia on outside assistance. The same study showed a relationship between the amount of shortening and the duration of the initial double support phase for the affected limb. Researchers attribute these changes to decreased biomechanical leverage combined with muscle weakness and impaired selective control of muscle contraction.

In a walking test on an uneven surface, patients with lower limb length discrepancy due to hemiplegia show a larger step width and a more medial location of the center of body mass in the single-support phase of the gait compared to healthy peers [42, 43].

Eek et al. [44] found a decrease in walking speed and step length in children with spastic hemiplegia if the shortening value was 1 cm or more when walking barefoot.

The contralateral unaffected limb is also in unfavorable conditions, potentially leading to orthopaedic pathology [27]. During the stance phase of the gait cycle, excessive flexion at the knee and hip joints as well as excessive dorsiflexion of the foot is observed on the unaffected side [44, 45].

Yoon et al. [46] found valgus deformity of the foot of the contralateral unaffected limb in 40 patients (52 %) with spastic hemiplegia in a sample of 76 patients. The authors pointed to a 1 cm difference in the length of the legs as a significant limit for the development of pathology in a healthy limb.

The pathological anterior tilt of the pelvis and the magnitude of its asymmetrical rotations in spastic diplegia depend on the magnitude of limb shortening, which was found in children (sample 91 patients, average age 10.8 years), which was not considered in the above mentioned classifications [47]. Differences of more than 1SD from the group of healthy peers were found in 61.5 % of cases for pathological rotation of the pelvis and in 60.4 % of cases for its pathological tilt.

Schmid et al. [48] indicate the dependence of kinematic disorders of the spine on leg length discrepancy in combination with contractures of the hip joint on the affected side. Moreover, compensation for shortening with orthotic products is not enough, and the need for complex intervention and subsequent physical therapy is assumed.

A difference in length of 1 cm or more predisposes to recurrence of equinus contracture (deformity) after primary triceps lengthening (aponeurotomy by Strayer and other techniques), as Sala et al., indicated [49]. In another work, Sclavos et al, [50] defined the average statistical probability of plantar flexion of the foot in the non-support phase of the gait cycle after operations to eliminate equinus contracture being 25 %, but this risk is significantly higher for patients with spastic hemiplegia, up to 42 %. The authors opine that the combination of length discrepancy with reduced dorsal flexor strength and low selective control of these muscles is the cause.

In terms of diagnosing problems in spastic hemiplegia, including limb length discrepancy, Mork et al., [14] note the difficulties of fully identifying all pathological components by general specialists, suggesting a leading role of the neuropediatrician.

In relation to orthopaedic problems, in addition to computer gait analysis [39], computed tomography and magnetic resonance imaging (MRI) play a significant role in identifying structural disorders [51]. Thus, shortening of the lower limb in hemiplegia is almost completely determined by the segment distal to the knee joint: mainly the tibia, but shortening of the talus and calcaneus also contributes, which was revealed by MRI findings [26].

Correction of limb length discrepancy within the framework of multilevel interventions has not been defined in the literature. Multilevel orthopaedic interventions for spastic hemiplegia are aimed at eliminating torsion deformities in order to restore the magnitude of biomechanical levers, correct joint contractures and foot deformities [52, 53].

To correct the discrepancy in the length of the lower limbs, we observed several different strategic approaches (Table 2).

Based on the data, temporary epiphysiodesis looks preferable. The possibility of its use in combination with other elements of surgery for flexion of the tibia in children with cerebral palsy has been shown [53]. Bone age is a classical orientation for planning epiphysiodeses. However, the methodology of its interpretation in children with unilateral forms of spastic paralysis is controversial. Erickson et al., [54] found no effect of the hemiparesis side on the interpretation of bone age from hand radiographs, but Lee et al, [55] indicate a lag in bone age values on the side of hemiparesis in comparison with the intact arm. It is in this situation that the technique of temporary epiphysiodesis seems preferable, since it is reversible [56, 57], and there are no risks of its early use with overcorrection [58]. It should be noted that the epiphysiodesis material used should be strictly a titanium alloy for children with cerebral palsy: the possibility of performing MRI remains possible [59].

Table 2

Strategy for correcting length discrepancy in spastic hemiparesis, impact on gait parameters

Published source	Number and average age of patients	Method of correction	Impact on the gait parameters	Comments
Corradin et al., 2018 [27]	10 patients, 12.7 years old	Epiphysiodesis. Initial mean length discrepancy 3.4 cm, final discrepancy 1.2 cm (mean follow-up period after surgery 6.7 years)	Improved kinematics of the healthy (disappearance of compensatory excessive flexion in the knee and hip joints and excessive dorsiflexion of the foot) and the affected limb	Edinburgh Visual Scale — Observational Gait Analysis
Eek et al., 2017 [44]	10 children, more than 1-cm shortening	Shoe compensation	Increased step length and walking speed, symmetry of the duration of the support phase of the gait cycle	Comparison with 10 healthy peers. Computer 3D gait analysis
Schmid et al., 2016 [48]	10 adolescents, shortening of more than 1 cm	Compensation with orthotic products	Compensation for shortening using conservative methods did not lead to an improvement in the kinematics of the pelvis and spine due to the presence of contractures of the hip joint	Comparison with 10 healthy peers. Computer 3D gait analysis
Saraph et al., 2006 [45]	11 children, 11.7 year old, discrepancy more than 2.5 cm	Tibial lengthening with external fixation	Improvement of kinematics of the healthy side (disappearance of compensatory excessive flexion in the knee and hip joints and excessive dorsiflexion of the foot)	Computer 3D gait analysis, study period — 3 years after lengthening
Jahmani et al., 2020 [60]	1 patient with hemiparesis among 6, mean shortening in the group 4.2 cm	Simultaneous shortening on an intramedullary rod	Only the anatomical result achieved was stated	X-ray telemetry only, no gait analysis

DISCUSSION

The relevant literature that was reviewed considers limb length correction as a separate problem in the complex of other surgical interventions. However, features of this correction in regard to potential spontaneous growth or after its completion have not been defined. The advantage of equalizing the length of the limbs in children with the method of temporary epiphysiodesis over distraction osteogenesis is only assumed and is performed as a separate procedure. There is insufficient data on the influence of the limb length equalization magnitude in patients with spastic hemiplegia on the parameters of computer gait analysis.

In the literature, there is also no established opinion regarding the magnitude of correction. Given the low selective control and weakness of the dorsal flexors of the foot, Corradin et al. [27] recommend leaving a residual discrepancy of 0.5–1.5 cm. On the other hand, length discrepancy of 1 cm or more negatively affects the kinematics of the pelvis and spine during walking [47, 48] and thus has indications for compensation [44, 48].

Such a wide uncertainty in the issue of correction of orthopaedic components of hemiparetic forms of cerebral palsy justifies a comprehensive study that would compare the results with known publications.

The assessment of length discrepancy and the contribution of this orthopaedic component to systemic motion disorders in spastic hemiparesis are based on computed tomography or magnetic resonance imaging, as well as computer gait analysis. The same methods should be used for assessing long-term treatment results.

CONCLUSION

Currently, the researchers are turning their focus to the problem of limb length discrepancy in patients with spastic hemiparesis, to the anatomical and functional changes in the contralateral, neurologically intact limb.

A fairly wide range of methods for correcting limb length discrepancy, both conservative and surgical, are found in the literature. But the total of such studies is extremely limited in number, and patient samples are small. It can be concluded that, despite the consensus on the need to correct shortening as an important component of the kinematic disorder, there is no consistent consensus on the method of choice. Moreover, the available works present surgical correction of length discrepancy as a separate stage, and not as a part of multilevel interventions.

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Evolution of tactical approaches to eliminating limb length discrepancy

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Abstract

Introduction Limb length discrepancy (LLD) can be debilitating and may cause other medical and social problems. LLD is a serious physical condition and have a significant impact on the patient's quality of life changing the gait, forming pathological adaptive mechanisms and causing long-term musculoskeletal disturbances in children.

The objective was to analyze the evolution of tactical approaches to the rehabilitation of patients with lower limb length inequality.

Material and methods The original literature search was conducted on key resources including Scientific Electronic Library (www.elibrary.ru) and the National Library of Medicine (www.pubmed.org). Literature searches included both Russian and English studies. The search strategy was comprised of keywords: lower limbs, limb length inequality, approaches and means of limb length correction, osteosynthesis. Clinical guidelines, clinical recommendations, systematic reviews, randomized controlled trials and multicenter cohort studies were selected for analysis.

Results and discussion Normal individuals can often experience a difference in the length of the lower limbs from several mm to 1.5 cm and have no effect on the gait, condition of adjacent joints and joints of the opposite limb. Some authors report inequality of 5 mm leading to orthopaedic pathology. A variety of conservative and surgical treatments are offered for limb length equalization. Elimination of LLD is a common and unresolved medical problem. Conservative treatment of LLD can be considered as one of the stages of rehabilitation. Some patients can benefit from conservative treatments. Alternatively, surgical equalization is a treatment option for patients with LLD.

Conclusion Surgical methods offered earlier to address LLD had disadvantages, which ultimately minimized their use, and orthopaedic surgeons abandoned some of them due to the high risk of severe complications. The device and the technique developed by Dr. Ilizarov in the 50s of the last century was an epoch-making event in the elimination of LLD and are constantly being improved.

Keywords: lower limbs, length inequality, methods and means of length correction, osteosynthesis

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INTRODUCTION

Limb length discrepancy (LLD) can be debilitating and may cause other medical and social problems. LLD is a serious physical condition and have a significant impact on the patient's quality of life changing the gait, forming pathological adaptive mechanisms and causing long-term musculoskeletal disturbances in children. The pathology is often progressive and causes secondary deformities of the spine, pelvis, adjacent joints and joints of the opposite limb, which is accompanied by impaired biomechanical conditions for their functioning and overload. LLD causes persistent scoliotic deformities, pelvic and lumbodynia, disc herniations, cervicalgia, chronic fatigue and discomfort which are caused by constant mechanical overload of the musculoskeletal system as a result of suboptimal body statics [1, 2]. LLD worsens the quality of life of patients: it limits motor activity, reduces communication capabilities, complicates the educational process, the choice of profession, and often becomes a problem for starting a family [3]. Progression of LLD can lead to disability in patients with post-traumatic conditions and hemihypertrophy [4–8]. The presence of an orthopaedic defect in LLD patients (consequences of injury and hemihypertrophy) leads to negative self-esteem and personality isolation. This provokes the development of depressive disorders and can aggravate orthopaedic problems over time with the appearance of social maladjustment and social phobia. The combination of the above components of LLD leads to a pronounced regression in the quality of life of the patient and his/her immediate environment. In recent years, there has been an increase in the number of patients with LLD requiring its elimination. This circumstance can be associated with improved orthopaedic diagnosis and increased availability of highly specialized medical care [9–21].

The objective was to analyze the evolution of tactical approaches to the rehabilitation of patients with lower limb length inequality.

MATERIAL AND METHODS

The original literature search was conducted on key resources including Scientific Electronic Library (www.elibrary.ru) and the National Library of Medicine (www.pubmed.org). Literature searches included both Russian and English studies. The search strategy was comprised of keywords: lower limbs, limb length inequality, approaches and means of limb length correction, osteosynthesis. Clinical guidelines, clinical recommendations, systematic reviews, randomized controlled trials and multicenter cohort studies were selected for analysis. Exclusion criteria invluded experimental and case studies, observations, reports, clinical cases, uncontrolled cohort studies. 195 articles that met the inclusion criteria were reviewed, 64 publications were explored with 9 between 2016 and 2021, 15 articles were published within 10 years, 40 articles were published more than 10 years ago, one of them was published about a hundred years ago and was the starting point of the research.

RESULTS AND DISCUSSION

Upright walking can suggest the presence of a slight difference in the length of the lower limbs with a longer leg having greater functional loading, leads to the development of the following process: a leg that has a greater length has a greater functional load, being engaged in greater performance, receiving more nutrition due to increased blood flow and growing faster. A leg with a shorter functional length experiences less loading, less performance, receiving less nutrition due to less intense blood supply than the opposite limb and, as a result, it grows more slower. The process occurring in opposite directions would result in relative LLD with age [22].

One more orthopaedic feature of the human population requires no use of any orthopaedic products or surgical treatment, and the authors treat this condition as normal: normal individuals may have a difference in the length of the lower limbs from several mm to 1.5 cm, which does not affect the gait and condition of adjacent joints and joints of the opposite limb [2]. Rush and Steiner

reported the length of the lower limbs measured from radiographs of 1,000 military personnel discharged from the army. Identical leg length was established in 23 % of cases; asymmetrical length of the lower limbs was observed in 77 % of those examined [20].

Similar data were reported by Kovaleva et al. who noted different leg length in 40–90 % of the population [1]. Some authors reported gait disturbances even with a difference in leg length of about 1.5 cm. However, most orthopaedic surgeons agree with the opinion of Marx, who established gait disturbance with the difference in leg length of greater than 2 cm, and shortening of 1 to 2 cm causing no lameness being compensated by adaptive mechanisms [4, 23–34]. The use of orthopaedic shoes cannot compensate for shortening completely and satisfy patients. Impaired biomechanics of the limb, the patient's dependence on prosthetic manufacturing, psychophysical discomfort associated with wearing orthoses and orthopaedic shoes, and cosmetic defects force patients to seek surgical help [35].

Only 10 % of the population have the same length of the lower extremities, and 90 % of the population has a LLD of up to 1.0 cm. Moreover, pathology of the large joints of the lower extremities is noted in many patients with LLD of greater than 5 mm. Modern authors agree with the opinion of Marks that LLD greater than 2.0 cm are often a problem, but there is evidence that LLD of 5 mm can lead to orthopaedic pathology [36]. Khamis and Carmeli came to similar conclusions [37]. They examined the clinical role of LLD and found a significant association between anatomical LLD and gait disturbance. The data obtained indicated that deviations in the gait can occur even with a length inequality of more than 1 cm, and the severity correlated with an increase in leg length inequality. Different techniques have been offered by orthopaedic surgeons to eliminate LLD and depended on the general level of development of medicine and orthopaedics, in particular and on the doctor's own preferences.

For example, in the pre-surgical era, doctors tried to conservatively stimulate limb growth "tapping" the heel of the short limb. At the beginning of the last century, it was a tourniquet that was applied at the level of the proximal metaphysis of the leg to create venous stasis lasting 30 minutes. With the tourniquet removed active hyperemia of the limb occurred stimulating physeal function. The procedure had to be repeated daily for a long time until the end of the patient's natural growth. Autologous blood to be introduced into the knee cavity was used to stimulate the growth of a short leg in an attempt to stimulate the growth zones by exposing them to ultraviolet and ultrashort rays. Iodine growth stimulation technique of a short lower limb suggested the use of iodine tincture to the skin of the knee joint to ensure increased blood flow in the underlying tissues and improve physeal function [23, 39].

Conservative treatments using insoles, prosthesis, orthosis are still applied to address LLD. However, their long-term use may fail to compensate for biomechanical disorders [40]. Campbell et al. reported low-quality evidence that shoe lifts reduce pain and improve function in patients with LLD and common painful musculoskeletal conditions [41]. Iv. Cahanin et al. reported conflicting evidence on the relevance of LLI and conservative treatment options, the associated material costs and concluded that they may be unnecessary and potentially harmful in short-term [42].

In addition to conservative methods, attempts were made to surgically stimulate the growth zones of the short segment. For example, some surgeons offered a longitudinal osteotomy of the tibia or cortical bone perforation near the epiphysis. In other cases, the so-called "biogenic stimulation" was used in some cases by placing a bouillon bone pin into the distal femoral metaphysis, proximal tibial metaphysis or greater trochanter. These methods caused aseptic inflammation and increased local circulation near the physis enhancing the function [39, 43, 44]. All of the above measures did not produce the results expected and could only be used in children. This circumstance stimulated orthopaedic surgeons to look for more effective ways to solve the problem.

New methods of surgical compensation for LLD have been proposed to include acute bone lengthening or shortening to be followed by immobilization of the limb, compression-distraction osteosynthesis (external, combined and internal osteosynthesis) and operations on growth zones (temporary or permanent epiphysiodesis) [23, 25, 39, 43]. Shortening osteotomies have used by orthopaedic surgeons for a long time, and some surgeons, although much less frequently, still use them. It is generally accepted that the maximum acute surgical shortening of the femur can be 5–6 cm, while that of the tibia can be not greater than 3 cm. This type of osteotomy allows for acute elimination of LLD and can be traumatic in terms of surgical technique and controversial in terms of justification for its use. The main disadvantage of limb shortening techniques in eliminating LLD is that the procedure is performed for a healthy segment and has been shown to be a rare surgical intervention used by orthopaedic surgeons [6, 23, 45].

An acute lengthening osteotomy was first used for an orthopaedic case by the Russian surgeon Dmitriev in 1891. He performed a Z-shaped lengthening osteotomy of the femur followed by immobilization. However, the method has not found wide application due to the limited elongation capabilities [37, 38]. Abbott and Malakhov reported many cases of lower limb lengthening at the beginning of the twentieth century [23, 43]. In 1923, Bier reported his experience of limb lengthening in seven patients. In 1929, Jones and Lovett reported femur lengthening of 6 to 10 cm. In 1937, Bogoraz first reported his attempt in Russia to rapidly increase growth that was associated with to a high level of complexity of the treatment process and high rate of postoperative complications [23, 43]. It is generally accepted that the type of osteotomy can affect osteoregeneration, creating different conditions for the callus. Oblique or Z-shaped bone osteotomies can provide optimal conditions for regeneration with the length of the osteotomy exceeding the expected length gain by 2 to 5 cm. Complicated bone osteotomies (polygonal and differently shaped) which were difficult to perform and highly traumatic were initiated to improve the spatial orientation of bone fragments, which would affect the strength of the callus. More than 40 different techniques of osteotomy were offered, including a number of stepped and “tongue-shaped” ones, and were mainly used by the authors [4, 32, 39, 46]. We encountered conflicting data on the determining influence of osteotomies on the formation of a distraction regenerate. Researchers justify the merits of the osteotomy they use based on personal preferences, established national traditions and orthopaedic schools. Nahm, Boyce Nichols, reported percutaneous osteotomy for pediatric cases as low-energy and circulation-preserving showing benefits and indications for various types of osteotomies, including multihole drill hole osteotomy, corticotomy, and Gigli saw osteotomy. However, the authors believe that some types of osteotomies are technically difficult and should be performed only by experienced surgeons [47]. The authors suggest that some types of osteotomies are technically demanding and should be performed by experienced surgeons [47].

The rate of acute lengthening and its relationship with the complication rate deserves special attention. Burnei et al. reported the analysis of their 25-year clinic's experience with the amount of lengthening per segment varying between 3 and 17 cm, the longest staged lengthening measuring 20 cm, in two stages, and the greatest overall lengthening being 25 cm for an entire lower limb. The authors concluded that limb lengthening procedures up to 5 cm le d to rapid consolidation of the distraction regenerate and minimal complications. Lengthenings exceeding 5 cm required a good psychological preparation and careful monitoring. In lengthenings more than 10 cm, a faster rate of consolidation requires a double corticotomy, the use of intramedullary fixation and the immobilization of adjacent joints. The authors suggested that good results in restoring LLD could be achieved using an Ilizarov external fixator, and temporary epiphysiodesis at the age of 10–12 years was the least aggressive and quite effective method of treatment. Limb shortening by segmental resection should become ‘obsolete’ [48].

Poor outcomes of one-stage correction of lower limb length inequality forced orthopaedic surgeons to look for more advanced ways to achieve results, which are based on a gradual tensile effect

on osteotomized bone fragments. The earliest surgical methods of limb lengthening suggested "stretching" the limb through the bone osteotomy and subsequent skeletal traction on its distal fragment by using a load of 15–20 kg in adult patients.

The operations were also not widely used due to high morbidity, unstable bone fixation and high complication rate that prevented from achieving a length gain. The long-term hypomobility of the patient was an important factor with this lengthening technique since the individual was bedridden in a forced position for a long time [5, 23, 39, 43, 44].

Skeletal traction for lengthening lower limb segments was replaced by distraction devices that amounted to more than 1000. The devices can be divided into seven types: mono- and bilateral devices, arched (sectoral) and semicircular, circular and combined (hybrid) devices, intramedullary distractors. Of the many devices offered, the external fixation device developed by the Soviet doctor G.A. Ilizarov in the 50^{s} of the last century has become the most widely-used fixators in the world. G.A. Ilizarov developed a fundamentally new method of treating orthopaedic and trauma patients. The Ilizarov method is based on the natural physiological factors arising in the tissues of the operated limb in response to directionally created distraction or compression stress. Maintaining forces in the device for the required period of time provides the possibility of dosed correction of the segment, including restoration of the length and biomechanical axis [7, 38, 45, 49]. Osteosynthesis with the Ilizarov apparatus allows you to control the distraction process, lengthen and correct multiplanar deformities at the same time. Many modern authors suggest that the Ilizarov method provides comprehensive solution of the problems associated with shortening and deformities of the lower extremities, despite the difficulties of its application [20, 25, 26, 39, 45, 50–56]. The Ilizarov bone lengthening suggests stable fixation of the "segment-apparatus" system; preservation of osteogenic tissues and blood supply in the segment being lengthened; adherence to LL protocol; control of correction efforts and functional load of the operated limb; maintaining a harmonious general somatic balance in the "patient-device" system throughout the entire period of osteosynthesis [4, 5, 25, 46, 57–61].

The problem of limb length correction, according to the available literature, has almost a century-long history and has undergone many evolutionary improvements. Each of the methods offered involved either certain modifications of existing approaches, or the use of new methodological and technological techniques and devices, and both had certain advantages and disadvantages. However, all the technologies proposed in the "pre-Ilizarov" era did not have universality to be widely used in clinical practice for solving specific clinical problems. Ilizarov's methodology, which is based on natural biological processes and regularities facilitated optimal conditions for tissue regeneration during elongation, and construction design and modifications of the apparatus ensure stability throughout the entire time required for the organotypic restructuring of newly formed tissues. Therefore, we can conclude that the Ilizarov method of transosseous osteosynthesis has shown to be the most effective technique for limb length equalization among global orthopaedic technology.

CONCLUSION

The evolution of limb lengthening is associated with a long history of research, struggle for the new techniques, improvements and continuous training, and the elimination of LLD remains a challenging issue in orthopaedic surgery when coupled with multiplanar deformity correction. Conservative treatment of LLD can be considered as a stage of rehabilitation and a variety of conservative modalities for LLD may fail to result in a good outcome, and surgical treatment is the priority in solving the problem. The Ilizarov apparatus and method developed in the 50^{s} of the last century were an epoch-making event in the elimination of LLD and are being constantly improved.

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Evolution of the first metatarsophalangeal joint replacement

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Abstract

Introduction The diseases of the first metatarsophalangeal (1 MTP) joint that require surgical treatment include osteoarthritis (69 %), rheumatoid arthritis (26 %), tumors, tumor-like diseases and purulent arthritis (5 %). The treatment of arthritic 1 MTP is aimed at reducing pain and improving function. Joint replacement implants are meant to support body weight, maintain the length of the first metatarsal, provide metatarsal-sesamoid joint functioning and restore joint motion.

The purpose of the work was to analyze data from foreign and domestic literature on endoprosthetics of the 1 MTP, and briefly present analytical data on the results of using various implants.

Material and methods The article presents the summary of the Russian and foreign publications on 1 MTP joint replacement. The original literature search was conducted on key resources including PubMed, eLIBRARY, MedLine, Scopus. The search strategy was comprised of keywords: “replacement of the first metatarsophalangeal joint”, “surgical treatment of hallux rigidus”, “osteoarthrosis of the first metatarsophalangeal joint”, “results of endoprosthetics of the 1st metatarsophalangeal joint”, "modernization of implants of the 1st metatarsophalangeal joint". Publications brought out between 1968 and 2022 inclusive were analyzed.

Results and discussion The ideal implant should restore functional range of motion, improve function, maintain joint stability, distribute the stress across joint surfaces being wear-resistant. Over the years, various materials have been used to provide simple and reliable designs. Implants have been improved and divided into groups based on material and design, limited degrees of freedom, tribological pair composition, and the amount of articular surface replacement.

Conclusion New generation implants have a more durable design, anatomical shape and improved osseointegration. The advances in joint replacement have resulted in greater patient satisfaction and increased service life. The complication rate for replacement of the 1 MTP joint remains high. This indicates the need for continued research and further work to improve implants to make them more effective and easier to use.

Keywords: endoprosthesis replacement of the first metatarsophalangeal joint, osteoarthritis of the first metatarsophalangeal joint, evolution of endoprosthesis replacement of the foot joints

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INTRODUCTION

The presence of longitudinal and transverse arches is one of the main features of the foot to ensure uniform distribution of the load between the heel tubercle and the 5th metatarsal bones and provide a shock-absorbing function during walking and running. An average 50 % of the support falls on the head of the first metatarsal bone, which is part of the first metatarsophalangeal joint (1 MTP). The 1 MTP joint is the important joint for the biomechanics of human walking, providing the body with horizontal acceleration in the stance phase [1, 2]. Even minor damage to this joint can lead to impaired foot functioning, limited employment and everyday activities.

The diseases of 1 MTP joint that require surgical treatment are osteoarthritis (69 %), rheumatoid arthritis (26 %), tumors, tumor-like diseases and purulent arthritis (5 %). The treatment of arthritis of the 1 MTP is associated with the high incidence of diseases of this anatomical structure. Osteoarthritis 1 MTP joint (hallux rigidus) is a degenerative disease associated with damage to articular cartilage. The etiology of the pathology is multifaceted and is associated with various traumatic, biomechanical, metabolic, neuromuscular, postoperative and other factors [3, 4]. The doctor has to choose the treatment strategy depending on the degree of arthritis, the patient's age, his/her expectations and level of activity. Conservative treatment can provide satisfactory results in selected patients with grade 0 and grade 1 arthritis of the first metatarsophalangeal joint with low functional demands. Organ-preserving operations are saved for middle stages of arthritis to include isolated cheilectomy or osteotomies of the proximal phalanx and metatarsal bone. Arthrodesis, total joint replacement and Keller arthroplasty can be offered for Grade 3 arthritis with the articular surfaces being completely destroyed [5].

Although arthrodesis of the first metatarsophalangeal joint remains the "gold standard" for hallux rigidus, the technique may fail to provide a significant functional improvement. Arthrodesis can be associated with such complications as nonunion, malaligned axis of the first ray, and broken metal fixators [6, 7]. Reconstruction joint replacement has become common for joint surgery to allow weight-bearing function using an implant. Modern implants provide restoration of movements in the 1st PFJ and support the function of the metatarsosesamoid joints [8]. Indications for total replacement of 1 MTP joint include idiopathic, post-traumatic and degenerative arthritis, revision surgeries using the Brandes – Keller and Morbus Köhler methods and rheumatoid arthritis. There are many types of endoprostheses for the 1 MTP joint differing in structure, materials, and tribological friction pair. Although each type of implant has gone through a long evolutionary path of several decades, endoprosthetics of 1 MTP joint leads to conflicting results and high rate of postoperative complications [9].

The objective of the work was to analyze foreign and Russian publications on total replacement of the 1 MTP joint and present analytical data on outcomes with various implants.

MATERIAL AND METHODS

The article presents generalized information from Russian and foreign publications on joint replacement of 1 MTP joint, evolution of the development and design of implants for the 1 MTP joint and presents a classification of the most common 1 MTP joint implants. The original literature search was conducted on key resources including PubMed, eLIBRARY, MedLine, Scopus. The search strategy was comprised of keywords: total replacement of the first metatarsophalangeal joint, surgical treatment of hallux rigidus, osteoarthritis of the first metatarsophalangeal joint, results of endoprosthetics of the 1st metatarsophalangeal joint, modernization of implants the 1st metatarsophalangeal joint. The analysis was based on materials published between 1968 and 2022. In addition to that, the review included information from articles reporting functional anatomy and biomechanics of the 1 MTP.

RESULTS AND DISCUSSION

Knowledge of the anatomy and biomechanics of the 1 MTP joint plays an important role for successful total replacement of the joint and prevention of intra- and postoperative complications.

The 1 MTP joint consists of 4 bones and includes the head of the first metatarsal, the base of the proximal phalanx of the first toe, and two elliptical sesamoid bones. The joint is shaped spherical and has 3 degrees of freedom: flexion/extension, abduction/adduction, external/internal rotation. There are two grooves separated by a ridge, forming articular facets for the sesamoid bones, included in the thickness of the joint capsule, which is a platform and forms a sesamoid hammock on the plantar surface of the head of the first metatarsal bone [10]. The 1 MTP joint capsule is attached to the lower part of the head of the first metatarsal proximally and to the base of the proximal phalanx of the first toe distally. On the sides, the capsule is strengthened by collateral ligaments to provide additional stability. On the medial side, the tendon of the adductor hallucis muscle and the medial head of the tendon of the big toe short flexor are fixed to the sesamoid hammock ligament. The sesamoid bones are involved in uniform distribution of the load, protecting the metatarsal and phalangeal articular surfaces, and serve as support at push-off phase. The sesamoid hammock is part of the fibrocartilaginous plantar plate and creates a strong connection between the links of the joint. The 1 MTP joint is strengthened by the tendon of the short extensor pollicis muscle, which is attached to the superior portion of the main phalanx, and the tendon of the long extensor pollicis muscle, which is fixed to the distal phalanx on the dorsal side. Both tendons are secured by a fibrous hood, which is woven into the capsule and provide additional strength to the joint [11, 12].

About 40 % of the stride cycle falls on the forefoot and is gradually redistributed from the lateral to the medial portion, so that the 1 MTP joint has an important function in the biomechanics of the gait. The motion in 1 MTP joint normally ranges from 45° plantar flexion to 90° dorsiflexion during passive movements, and 44° with the load. Based on the assessment of the load on the 1 MTP joint during gait, measured during the final stance phase of the foot, a mean value of the force acting on the joint is proposed to be 0.86 × body weight. For a 70-kg person, this value is 61 N [13, 14].

Recent research showed that the links of anatomical structures in the form of ligaments, muscles, bones and capsule of the 1 MTP are a single whole, and a pathology of a component leads to a cascade of biomechanical disorders and irreversible consequences [15].

Historically, the original goal of creating a 1 MTP joint implant was to develop a design that was as simple and reliable as modern knee or hip implants. However, engineering design was associated with structural and functional difficulties of 1 MTP. Classifications of the most common 1 MTP joint implants are presented in Table 1.

Endoprostheses of the 1 MTP joint are divided into the following groups:

1) by limited degrees of freedom: constrained or unconstrained;

2) by tribological pair: metal-metal, metal-polyethylene, ceramics-ceramics, pyrocarbon, silicone;

3) by articular surfaces to be replaced: unipolar or bipolar [16].

The extent of destruction of the articular surfaces of the metatarsal head and the base of the proximal phalanx are essential for the selection of the implant design. There are no recommendations in the literature for choosing a particular implant; in most cases, it is the surgeon who determines the strategy based on his own experience, familiarity with the endoprosthesis and the equipment used for the operation [17].

Table 1

Classification of Common First Metatarsophalangeal Implants [18, 19]

I. Hemi-Joint implants	
	Swanson silicone implant, 1968; Swanson design/Weil modification, 1977
	Swanson metal implant, 1986; Townley, 1986; HemiCap first generation manufactured by Arthrosurface, 1998; HemiCap second generation manufactured by Arthrosurface, 2012
II. Total MTP replacement	
Constrained	Double-stemmed silicone implant of the 1 MTP joint designed by Swanson, 1974
	Kampner-designed implant - double-stemmed prosthesis with a central hinge. The implant was made from a silicone-polyester composite made by Cutter Biomedical, 1971
	The Lawrence-designed silicone intermedullary, double-stemmed, hinged implant ; the LaPorta-designed silicone intramedullary double-stemmed hinged total implant manufactured by Sutter Corporation Inc., 1982
	Helal silicone elastomer implant reinforced with a Dacron core 1977. Double-stemmed great toe implants with titanium grommets designed by Swanson manufactured by Wright Medical, 1985
Non-constrained with metal-polymer friction pair	Total first arthroplasty system produced by Richards Manufacturing with the two-piece implant having a phalangeal component made of ultrahigh molecular weight polyethylene (UHMWPE) and a metatarsal component of stainless steel, 1975
	Total great toe implant, manufactured by Biomet Inc., is a two-component, press-fitted implant with the metatarsal component made from a titanium alloy, while the phalangeal base component being made of UHMWPE or UHMWPE with a metal base (Warsaw, USA), 1989
	Bio Action great toe implant (OsteoMed, Addison, Texas). The metatarsal component is constructed from cobalt-chrome, while the phalangeal component is constructed from titanium, and polypropylene (Texas, Unired States), 1991
Non-constrained ceramic on ceramic	Moje Ceramic implant (Germany), 2004
Non-constrained metal on metal	The Integra Movement Great Toe System total arthroplasty (New Jersey, United States), 2019
III. Interposition arthroplasty	
	Interpositional arthroplasty using a Regno stainless steel implant, 1975
	Interpositional arthroplasty using a Barouk stainless steel implant, 1987
	Polyvinyl alcohol (PVA) hydrogel implant, Cartiva (Alpharetta, GA), 2016

Silicone implants

Swanson was the first who developed two types of silicone semi-interpositional implants in 1968. The first metatarsal head implant was used and was later replaced by an implant for the base of the proximal phalanx of the first toe. It was a single-stem design with a silicone head and stem designed to replace the articular surface of the base of the proximal phalanx (Fig. 1a). Swanson suggested that an implant placed on this side of the joint would be more stable being not subjective to excessive stress. The implant was used according to the principle of Keller arthroplasty and acted as a spacer in the interarticular space with slightly increased range of motion [20, 21]. Ris et al. reported a 48-month follow-up of 53 patients who were treated with 68 Swanson silicone hemi-implants. Physical examination of the patients revealed a decreased range of motion in 1 MCP joint compared with preoperative level recorded in 62 % of patients. Implant destruction was noted in 57 % of cases during radiological examination [22].

In 1971, Kampner developed the first double-stemmed silicone implant, which was made of silicone and polyester. The first design contained polyester grommets attached to the stems, suture material for fixation to the periosteum and improved stability of the implant. The polyester grommet was later discontinued due to joint stiffness and increased load on the hinge [23, 24].

In 1974, Swanson introduced a double-stemmed design with two tapered stems and a flexible u-shaped hinge to provide dorsiflexion (Fig. 1b). The hinge of the implant was criticized for absence of physiological range of motion. The stems did not bend in the frontal and lateral planes. Placement of the original design suggested shortening of the stem of the phalangeal implant. A year later Swanson et al. presented a silicone implant with shortened stems [25].

In 1985, Wright Medical manufactured the Swanson design double-stemmed implant with titanium bushings. The grommets were designed to protect the stems at most vulnerable sites between the edge of the resected bone and the hinge. The grommets were pressed in the bone marrow canals before placement of the implant [26]. In 1991, Gerbert reported a retrospective review of the patients undergoing arthroplasty with Swanson implants with titanium grommets. Twenty-two patients were examined over a period of 33 months, with a mean age of 61 years. The survey was performed using the PASCOM scale (Podiatric Audit in Surgery and Clinical Outcome Measure), and satisfactory results were obtained in 72 % cases. The angle of dorsiflexion of 1 finger averaged 21° [27, 28].

In 1982, Sutter Biomedical introduced LaPorta and Lawrence designs of silicone hinged implants of the 1 MCP (Fig. 1c, d). The implants are currently manufactured by Futura Biomedical. Both designs include rectangular-taper stems. The proximal stem was slightly larger and longer than the distal one, tilted 15° dorsally to provide physiological inclination of the first metatarsal preventing stress to the hinge. The LaPorta implants include right, left and neutral models with different angle of inclination of the stems in the horizontal plane. The angle of inclination of the stems of the neutral design is 0° in the horizontal plane in the right and left versions the inclination angle is 10°. The Lawrence implant has a neutral shape. The hinge of both implants is shaped like an hourglass, with flexion occurring at the central part of the joint. The LaPorta design is symmetrical from dorsi to plantar and is designed for 60° of dorsiflexion. Both sides of the heads have a flat surface to ensure complete adherence to the bony edges. The Lawrence design includes the hinge portion of the main phalanx being extended dorsally and slanted downward. Its main advantage is 85° of dorsiflexion. The plantar angle on the phalangeal side of the hinge reduces the amount of resection of the main phalanx and increases the stability of the joint by preserving the insertion of the flexor tendon pedicles [29, 30, 31].

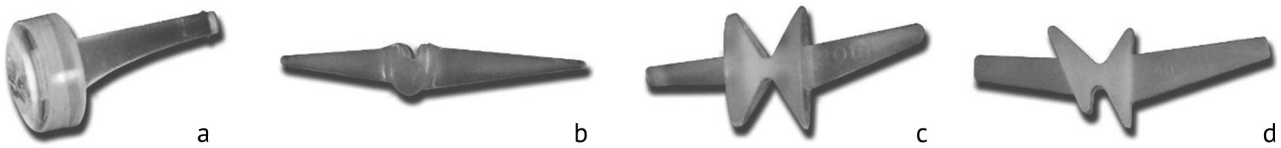

Fig. 1 Appearance of silicone implants of the 1 MTP joint: (*a*) Swanson design of the single-stemmed implant of the 1 MTP joint, 1965; (*b*) Swanson design of the double-stemmed hinged implant of the 1 MCP, 1974; (*c*) LaPorta design of the double-stemmed hinged implant of the 1 MTP manufactured by Sutter Biomedical, 1982; (*d*) Lawrence design of the double-stemmed hinged implant of the 1 MTP manufactured by Sutter Biomedical, 1982 [26]

Several studies have been conducted to evaluate the effectiveness of flexible articulated implants. In 1989, Granberry et al. reported a retrospective study of 90 patients who underwent 1 MTP joint replacement with silicone flexible hinged implants for three years. Most patients reported satisfactory results in terms of pain intensity. Granberry found three main disadvantages with flexible articulated implants. At follow-up examinations, 30 % of patients had less than 15° of dorsiflexion at 1 MTP joint (dorsiflexion of the first toe is a key component of human gait biomechanics). Skin lesions were observed in 69 % of patients who had painful keratoses on the plantar surface of the foot at the head of the first metatarsal resulting from the short ray. Granberry et al. reported osteophytes at the 1 MCP joint. Radiological examination showed osteophytes formed around the implant in 53 % of patients [32].

Metal implants

Metal hemiendoprostheses were developed to eliminate excessive resection of the articular surface and shorten the first ray with use of silicone implants [33]. In 1986, Swanson developed a titanium hemi-implant that was used to replace the articular surface of the main phalanx (Fig. 2a). In 1987, Townley modified the implant that was manufactured using an alloy of cobalt and chromium (Fig. 2b). It had a thin xiphoid rod that required no additional processing of the bone marrow canal. The implant included a thin head that would limit the resection of the proximal phalanx and maintain soft tissues attached. The implants are manufactured by Wright Medical in five sizes (from 0 to 4). Phalangeal half-implants did not fully reduce pain and improve joint mobility, since the degenerative head of the first metatarsal had not been primarily treated. Subsequently, the grinding procedure of the head of the first metatarsal became mandatory with use of this implant model [34].

In 2009, Konkel et al. reported a retrospective review of 33 patients with arthritis of the 1 MTP who received hemiendoprostheses. The average follow-up period was 6 years. Relapse of dorsal osteophyte growth was detected in patients with early signs of arthritis grade three. Postoperative foot and ankle condition measured with the American Orthopedic Foot and Ankle Society Score (AOFAS) used in the USA [18] was 67.

The HemiCAP first-generation System (Arthrosurface Inc, Franklin, MA, USA) was developed for arthroplasty of metatarsal head in 1998 (Fig. 2c). HemiCap is a two-part tapered metatarsal head metallic implant that incorporates a titanium alloy fixation component connected via taper to the cobalt chromium alloy articular contoured component [35].

In 2012, Arthrosurface developed a second generation HemiCap DF (Dorsal Flange) implant for the first metatarsal head (Fig. 2d). The HemiCAP prosthesis was adapted to include a dorsal flange. This might improve the range of dorsiflexion not seen with the traditional model. The implant's dorsal flange is oriented to cover the dorsal aspect of the metatarsal head and to prevent subsequent osteophyte formation after implantation [36].

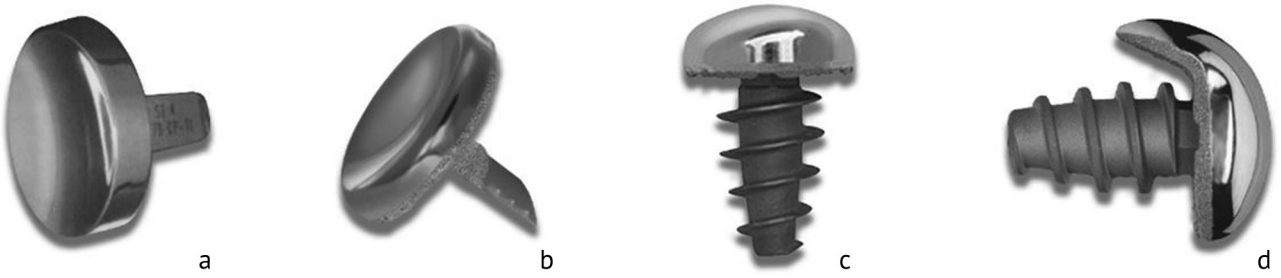

Fig. 2 Appearance of metal hemiendoprostheses of the 1 MTP: (*a*) hemi-implant fabricated by Swanson to replace the head of the first metatarsal and manufactured by Wright Medical, Tennessee, USA, 1986; (*b*) hemi-implant designed by Townley to replace the head of the first metatarsal and manufactured by Wright Medical, Tennessee, USA, 1986; (*c*) HemiCAP first-generation System (Arthrosurface Inc, Franklin, MA, USA) used to replace the head of the first metatarsal; (*d*) HemiCAP second-generation hemi-implant to replace the head of the first metatarsal, Arthrosurface Inc., Franklin, Massachusetts, USA, 2012 [37]

In 2021, Jørsboe et al. reported a review of 116 patients with hallux rigidus treated with the first- and second-generation HemiCap implants. At 2 years, 4 years and 6 years, the implant survival was 87 %, 83 % and 74 %, respectively. At the mean five-year follow-up, 47 patients had dorsiflexion of 45°. Functional results measured with AOFAS scored 77.2 ± 2.8 and Visual Analogue Scale (VAS) score was 2.0 ± 1.6 [38]. With the growing popularity of two-rod silicone implants, a "revolution" took place in the creation of two-component unconstrained implants. Silicone implants failed due to excessive wear and tight design. With greater understanding of the biomechanical parameters of the 1 MTP joint, there is a need for a design that would address weight-bearing characteristics, sliding, and multidirectional joint motion. The 1 MTP joint is a hinge joint, and with the proximal phalanx being flexed at an angle of greater than 30°, its axis in the horizontal plane shifts

to the dorsal side. Dual-stemmed silicone implants were not adjusted to the normal physiological range of motion, abnormal loads applied to the implant eventually led to its failure [39]. In 1985, Zeichner attempted to construct a ball-shaped implant from existing materials at the time in order to avoid the piston-type kinematics effect characteristic of hinged implants and create a prosthesis with a variable axis [40]. In 1989, Merkle and Sculco developed an implant made of titanium alloy and high-density polyethylene and used polymethyl methacrylate bone cement for its fixation. Their design did not include an intramedullary stem on the metatarsal component. Two implants were removed due to the high loosening rate (54.5 %). The authors concluded that cemented 1 MTP joint replacement did not provide satisfactory results and recommended further research to improve fixation techniques [41].

In 1989, Koenig developed a two-piece system for replacing 1 MTP joint, similar to that used for knee replacements. The metatarsal head component had an intramedullary rod and was made of titanium alloy. It included a plantar surface reproducing the condyles of the metatarsal head for articulation with the load-bearing sesamoid bones. The phalangeal component was made of ultra-high molecular weight polyethylene with an intramedullary rod, and both components were placed using the press-fit method [42]. A similar Total Toe System is produced by Biomet (USA, Warsaw) and characterized by entirely polyethylene or titanium phalangeal components. Plasma spraying of both stems is performed to improve integration into the medullary canal (Fig. 3a) [43].

In 1991, Koenig followed up 18 patients at 18 months after surgery, examined radiographs to measure the intermetatarsal angle, hallux abduction angle, first metatarsal length, and implant alignment. Adequate alignment and complete osseointegration were seen in 7 cases. The full range of motion in the 1 MTP was regained in 12 cases, and a revision was required in one case with metallosis detected. In 1996, Koenig and Horwitz published a study of 61 patients over a 5-year postoperative period. Excellent results were obtained in 80.5 % of patients, and poor outcomes of varying degrees were noted in 10 % of cases [44].

In 1991, Orthopedic Bio-systems developed the Bioaction Great Toe System implant. The implant has a metatarsal component made of cobalt-chrome and a phalangeal component made of titanium and a polyethylene insert. The design is manufactured by Osteomed. Pulavarti et al. reported 77 % of patient satisfaction, while 23 % showed radiographic evidence of implant loosening and subsidence [45]. A new total implant, the Movement Great Toe System, manufactured in the USA (Integra, New Jersey) entered the market in 2019 (Fig. 3b). The anatomically shaped components have a cobalt-chromium articular surface. Titanium plasma spraying was used for the posterior surface of the implant to improve osseointegration. The design of the stem of the implant differs from other models on the market. Cylindrical stem with four ribs provides improved fixation and anti-rotation stability. The metatarsal component has a dorsal flange to prevent re-formation of osteophytes. The proximal phalanx component contains suture holes on the plantar portion of the implant to allow reattachment of the flexor apparatus in case of injury. The endoprosthesis was first implanted in January 2018 and is available in four sizes [46].

In 2016, Johnson reviewed 35 patients with arthrosis of the 1 MTP 2 years after arthroplasty performed using the Movement Great Toe System. He found that 82 % of patients were satisfied with the results evaluated with PASCOM, and 62.9 % were free from pain when using shoes. The average range of motion was 57.6° in dorsiflexion and 10.5° in plantar flexion. There were no radiological signs of loosening of the implant components [47].

Ceramic implants

In 1994, Moje Ceramic Implants (Petersperg, Germany) introduced zirconium ceramic implants for the 1 MTP joint. The metatarsal component is hemispherical in shape and the phalangeal component is concave. The original design included two titanium positioning screws for the metatarsal and phalangeal components and a press fit method was employed with the design (Fig. 3c).

The implant is plasma sprayed with apatite and fosterite crystals to improve osseointegration and has very good biocompatibility and excellent wear resistance [48, 49].

In 2020, Nagy et al. reported 30 patients treated with a ceramic total implant of the first metatarsophalangeal joint. The mean follow-up period was 81 ± 27 months. after surgery, the average range of passive motion of the joint was 32° dorsiflexion, the mean AOFAS scored 84. 24 patients (84 %) were satisfied with the result. The radiographs revealed a change in the angle of inclination of the implant and migration of the proximal or distal components. Complications included one case of wound infection. Revision was performed in 5 cases (16 %) due to loosening, migration, subluxation or destruction of the implant stem. The survival rate of implants was 92 % at 5 years, 85 % at 7 years, and 78 % at 9 years [50].

Fig. 3 Appearance of total implants of the 1 MTP joint: (*a*) Total Toe System implants manufactured by Biomet, Warsaw, USA, 1989; (*b*) Movement Great Toe System implants manufactured by Integra, New Jersey, USA, 2019; (*c*) ceramic implants from Moje Ceramic Implants, Petersburg, Germany, 2004 [51]

Hydrogel implants

A new polyvinyl alcohol hydrogel implant (CARTIVA, Georgia, USA) received FDA approval in July 2016 (Fig. 4) and was tested in the UK and Canada. Both studies showed promising results before entering the US market. The implant was made of polyvinyl alcohol hydrogel and acted as a spacer between the first metatarsal and the base of the proximal phalanx. As non-toxic and non-carcinogenic polymer polyvinyl alcohol is used in contact lenses and food packaging materials. In terms of its ability to resist stress, it has an ultimate tensile strength at a pressure of 17 MPa comparable to human cartilage and a similar water content [52, 53].

Fig. 4 Hydrogel implant of the 1 MTP made of polyvinyl alcohol (CARTIVA, Georgia, USA, 2016) [54]

In 2018, Baumhauer et al. prospectively compared a synthetic hydrogel implant and arthrodesis in terms of safety and effectiveness (arthrodesis of the first metatarsophalangeal joint is used to treat severe degrees of arthrosis). Upon completion of 24 months. study in both groups of patients who underwent both endoprosthetics with a Cartiva hydrogel implant and arthrodesis, a significant decrease in pain intensity was noted on the VAS scale. Subsequent secondary surgeries occurred in 11 % implant patients and was equivalent to the reoperation rate in the first metatarsophalangeal joint arthrodesis group (12 %). The hydrogel implant maintained function and dorsiflexion (mean 29.7°). Radiological comparisons did not reveal loosening or destruction of the implant, although two patients developed a periosteal cyst in the proximal phalanx [55, 56].

Lee et al. explored 90 patients hallux rigidus treated with hydrogel implant. The mean VAS score was 4.0 and AOFAS measured 64 points. On postoperative plain radiographs, implant subsidence was observed 60 % at 4 weeks after surgery and 90 % at the final follow-up. Fifty percent (5/10) showed radiologic lucency around the implant. Bone resorption around the implant was radiologically detected in 50 % of patients [57, 58].

Overall, hydrogel implants have a promising future. Major upgrade of hydrogel implant design is essential for prevention of implant migration.

CONCLUSION

The use of silicone implants provided satisfactory functional outcomes in 72 % of cases evaluated with PASCOM. The study of MTP joint arthroplasties performed with Swanson double-stemmed great toe implants with titanium grommets showed most favorable outcomes among silastic implants. The rate of survival for metallic hemi-great toe implants was 74 % and the HemiCap DF implant scored 77 on the AOFAS scale. The use of total metal implants provided 82 % satisfactory results evaluated with PASCOM after placement of the Movement Great Toe System implant. Patients treated with Moje Ceramic total implants were satisfied in 85 % of cases. The use of hydrogel implants resulted in 50 % poor outcomes. Total first MTP joint replacement arthroplasties have been developed over the last six decades with advances in technology facilitating progressive changes in materials and surgical technique. New generation implants have a more durable design, anatomical shape, improved osseointegration, and are made from the most wear-resistant materials. These advances have resulted in greater patient satisfaction and implant longevity. The rate of revision surgeries after total first MTP joint replacement is decreasing and is comparable to the rate of re-operations after arthrodesis. However, the complication rate remains high after first MTP joint replacement. This indicates the need for continued research and further work to improve implants for effective and easier use.

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