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Dear readers,

We would like to inform you on issue 5 of our journal that contains the traditional sections.

Clinical studies are presented in this issue by six publications. The section opens with an article by authors from India (K. Kumar et al.), who assessed the prognostic value of the plaster cast index and the three-point index in fractures of both forearm bones in children. The study included 55 patients. Having analyzed the results, the authors came to the conclusion that both indices are clinically useful tools for assessing the quality of plaster casting after closed reduction of forearm fractures in children and for predicting re-displacement in fractures of the distal forearm.

Evreinov et al. (Kurgan, Yekaterinburg) studied the main etiological factors and comorbid pathology in severe cerebral palsy in 170 children. Having assessed the results, the authors conclude that the main risk factors for the development of cerebral palsy in patients with severe motor impairments in GMFCS levels IV–V are associated with the pre- and intranatal periods. Comorbid pathology of patients with severe forms of cerebral palsy is due to severe brain damage and motor disorders that develop due to this damage.

The section continues with an article by authors from Vietnam (Khoa et al.), who studied the immediate functional results of hip arthroplasty for avascular necrosis of the femoral head and patient-related factors. The study involved 143 patients. The results of the study showed that total hip arthroplasty allows achieving good outcomes in patients with aseptic necrosis of the femoral head. The operation performed early before the onset of functional limb failure and timely and adequate treatment of concomitant diseases improve the results of total hip arthroplasty.

A team of authors from Moscow (Eremin et al.) present in their work the advantages of direct anterior approach (DAA) in combination with PENG block and lateral femoral cutaneous nerve block in hip arthroplasty. Having analyzed the results of treating 62 patients, the authors stress that low postoperative pain syndrome allows patients to be activated faster, thereby improving the outcomes of the early rehabilitation period. The use of PENG block and LCFN block in arthroplasty through DAA has clinical efficacy in the first 24 hours, contributing to the acceleration of postoperative recovery of patients.

The clinical, functional and neuropsychological status of 448 patients admitted for joint replacement was studied by authors from Kaliningrad (Dzhigkaev et al.). Almost all patients had changes in leukocyte indices, showing the presence of an inflammatory process associated with the underlying disease, osteoarthritis. Mitochondrial dysfunction and aging of the immune system contribute to the formation of the "proinflammatory status". The cognitive impairment is associated with age status and the presence of comorbid pathology, primarily cardiovascular diseases. Distress and anxiety is associated with an emotional response to surgical intervention.

Shipitsyna et Spirkina (Kurgan) show the results of studying the antibacterial effect of a semiconductor laser on the bacteria S. Aureus and P. Aeruginosa. The authors note that the effectiveness of PDT depends on the type of microorganism, the anatomical location of the infection site, as well as the properties of the photosensitizer and the laser used. Different susceptibility of bacteria to photodynamic effects was observed and depended on the structure of the cell wall.

Experimental studies in the issue are presented by Stogov et al. (Kurgan, Yekaterinburg, Tomsk), who studied the effect of zinc-containing calcium-phosphate coating on osseointegration of transcutaneous implants for limb prosthetics. A set of studies showed that the implant

with zinc-containing calcium-phosphate coating has signs of improved integration in contrast to the product without coating. The absence of serious adverse reactions to the tested products indicates acceptable tolerability and safety of its use.

The Case Reports section describes clinical cases of lateral corticotomy for impaired consolidation of extra-articular fractures of the proximal femur in a 66-year-old patient (Shafigulin et al., Kazan), arthroplasty of the talus head in the treatment of Müller-Weiss disease in three patients (Skrebtsov et al., Moscow) and treatment of periprosthetic infection and repair of Paprosky type 2C cavitary defects at the stage of installation of an articulating spacer (Rozhkov et al., Kurgan).

Four literature reviews that conclude the issue cover current approaches to temporary osteosynthesis of the tibia in the treatment of multiple and combined injuries (Khodzhanov et al., Tashkent, Uzbekistan), surgical correction of post-traumatic flexion contractures of the joints of three-phalangeal fingers of the hand (Abdiba et al., St. Petersburg), arthroplasty of the proximal interphalangeal joint of the hand (Fedotov et al., Cheboksary) and optimization of revision arthroplasty (Minasov et al., Ufa).

We hope that you find the content of this issue interesting and it will be useful in your daily 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
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Use of cast index and three-point index in paediatric both bone forearm fractures: a prospective study

K. Kumar[1], Ch. Katariya[1], M. Jindal[1]✉, P. Gupta[2]

[1] Kalpana Chawala Government Medical College, Karnal, India
[2] Guru Gobind Singh Medical College, Faridkot, India

Corresponding author: Mohit Jindal, drmohitjindalortho@gmail.com

Abstract

Introduction The majority of paediatric both bone forearm fractures are treated with manipulative reductions and casting; loss of reduction is one of the most commonly reported complications.

We **aimed** to assess the role of cast index and 3-point index as predictor of outcome of a successful closed reduction in distal both bones forearm fractures.

Materials and methods This prospective observational study was conducted at the Department of Orthopedics, Kalpana Chawala Government Medical College inKarnal to assess the role of cast index and 3-point index as predictor of outcome of a successful closed reduction in distal both bones forearm fractures. In the present study, patients under 16 years irrespective of sex with distal both bones forearm fractures, managed by closed reduction and casting were included.

Results In the present study, 55 patients were included. Fracture reduction failure was observed in 32.7 % of the patients. Both three-point index and cast index were found to be significantly higher in patients with reduction failure. It was observed that at 2 weeks Area under curve (ROC Curve) for Cast index and Three point index was 0.72 and 0.85 respectively. At 4 weeks, Area under curve for Cast index and Three point index was 0.77 and 0.84 respectively and at 6 weeks 0.74 and 0.86 respectively. Thus, in the present study, CI and 3PI had similar predictability for fracture reduction failure.

Conclusion The three-point index and cast index are clinically useful tools to assess the quality of cast molding following closed reduction of pediatric forearm fractures and to predict re-displacement in distal forearm fractures.

Keywords: forearm fracture, casting, cast index, three-point index, VAS score

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INTRODUCTION

Forearm fractures account for 17.8 % of all fractures in pediatric age [1]. Joeris et al. found forearm fractures to be significantly more frequent in school age children (65 %) and adolescents (63 %) compared to infants (42 %) and preschool children (50 %) [2]. Both forearm bones were fractured in 50.1 % of cases of forearm injuries and there were significantly more males than females injured (63.6 % versus 36.4 %) [3]. The majority of the childhood diaphyseal forearm fractures are treated with manipulative reductions and loss of reduction was one of the most commonly reported complications [4]. Various indexing for assessment of reduction were described: cast index, padding index, Canterbury index, gap index and three-point index.The cast index (CI) is a simple and quick method of predicting the re-displacement after cast application in radius and ulna fractures in paediatric patients, particularly distal radius fractures [5]. Alemdaroglu et al. described the three-point index (TPI) in adult and paediatric radius distal end fractures and reported that the significance of the index in predicting the loss of reduction was higher than all other indices [6]. Therefore, in this study, we aimed to assess the role of cast index and three-point index as predictors of outcome of a successful closed reduction in distal both-bone forearm fractures.

MATERIALS AND METHODS

This prospective observational study was conducted at the Department of Orthopedics of Kalpana Chawla Government Medical College, Karnal, India from December 2022 to June 2024. Ethical committee clearance was taken. Informed written consent was taken from all the parents/care providers of patients included in the study. The inclusion criteria were patients under 16 years of age irrespective of sex with distal both-bone forearm fractures, managed by closed reduction and casting with acceptable reduction, pediatric patients presenting within a week of fracture. The exclusion criteria were patients with open fractures, polytrauma, vascular compromise, poor skin condition, allergy to POP, isolated radial or ulnar fractures, systemic disease (Bone metabolic disease). A total of 55 patients fulfilling the inclusion criteria were studied. All fractures were manipulated to anatomical position for close reduction under X-ray image intensification before the application of an above elbow plaster cast using Plaster of Paris with forearm in neutral position and elbow kept at 90 degrees flexion. A uniform layer of padding was applied throughout with a 50 % overlap between successive wraps. The manipulation and casting was done by orthopaedic surgeons; patients were followed up at the Kalpana Chawla Government Medical College. The principles of good forearm casting technique, i.e. interosseous molding, supracondylar molding, appropriate padding (ensuring at least two layers of padding material, with extra padding over bony prominences), evenly distributed cast material, straight ulnar border and flat posterior humeral borders, and three-point molding, were ensured. Reduction was assessed on check radiographs in standard AP and lateral views. Quality of reduction was assessed and casting indices (cast index and three-point index) of the patient were calculated at this stage. The cast index (CI) was calculated on the basis of the cast geometry at the fracture site: cast index = inner diameter of the cast at fracture site in the lateral view/ inner diameter of the fracture cast at fracture site in the AP view as shown in Figure 1. An ideal CI will be taken to be 0.8 or less.

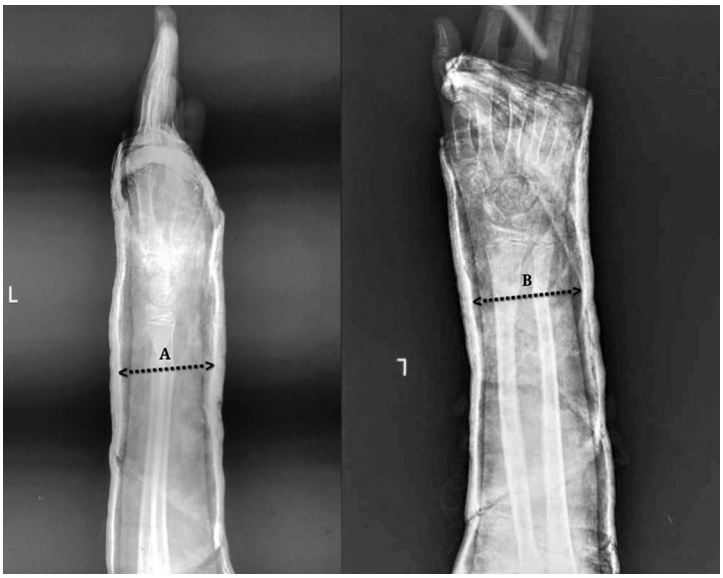

Fig. 1 X-ray of the forearm capturing the wrist joint, lateral and anteroposterior views showing CI calculation. CI = A / B, A — internal anteroposterior diameter of cast excluding padding, B — internal mediolateral diameter of cast excluding padding

The three-point index was assessed as shown below in Figure 2. The three-point index considered the gap at the fracture site as well as the gaps that are proximal and distal to the fracture itself. It was calculated with a complex formula. The narrowest distal radial gap at radiocarpal or proximal carpal joint + the narrowest ulnar gap within 1 cm of the fracture site + the narrowest radial gap within the area between 3 and 7 cm proximal to the fracture line) / transverse width of bone contact between proximal and distal fragments on AP + (the narrowest distal dorsal gap at radiocarpal or proximal carpal joint + the narrowest volar gap within 1 cm of the fracture site + the narrowest dorsal gap within the area between 3 and 7 cm proximal to the fracture line)/transverse width of contact between proximal and distal fragments on lateral radiograph and the cut-off was < 0.8.

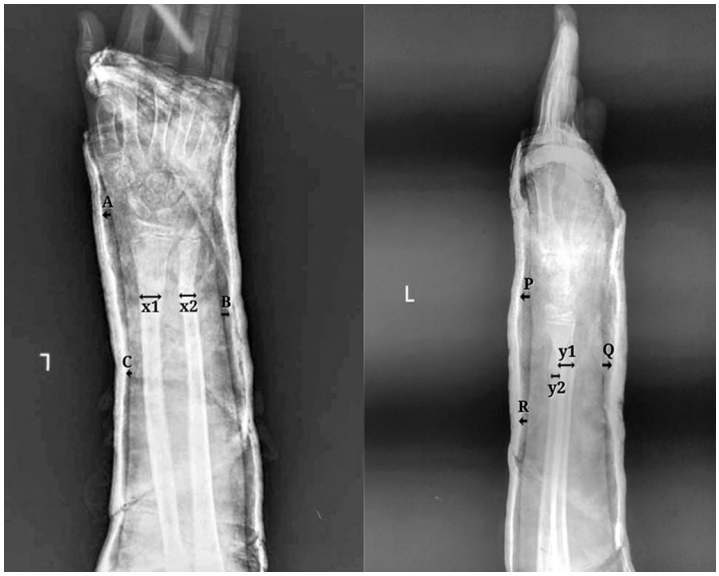

Fig. 2 Three-point index:
(1) Anteroposterior (AP) radiograph, showing measurement of distal radial gap (A), fracture site ulnar gap (B) and proximal radial gap (padding thickness) (C), sum of which was divided by sum of coronal reduced distance of radius (x1) and ulna (x2). (2) Lateral radiograph, showing measurement of distal dorsal gap (P), fracture site volar gap (Q) and proximal radial gap (R), sum of which was divided by sum of sagittal reduced distance of radius (y1) and ulna (y2). Results of calculations of AP and lateral radiographs are added to find the three-point index
(A + B + C) / (x1 + x2) + (P + Q + R) / (y1 + y2)

The reduction was deemed satisfactory by the surgeon when there was no evidence of displacement (< 5 mm) on both planes and angulation was corrected to near anatomical position (< 5°). The decision to re-manipulate was based on standard guidelines [7] (re-angulation of more than 20°). Fractures that re-displaced significantly were re-manipulated or fixed internally. All patients were followed up at 2 weeks, 4 weeks and 6 weeks.

Statistical analysis

The Statistical analysis included profiling of patients on different demographic, laboratory and clinical parameters. Descriptive analysis of quantitative parameters was expressed as mean and standard deviation. Ordinal data were expressed as absolute number and percentage. Comparison was done between patients with and without failure of fracture reduction. Cross tables were generated and chi square test was used for testing of associations and student t-test was used for comparison of quantitative parameters. A *p*-value < 0.05 is considered statistically significant. All analysis was done using SPSS software, version 24.0.

RESULTS

Fifty-five patients were included in the study. Fracture reduction failure was observed in 32.7 % of the patients (Table 1).

In the present study, 16.4 % of patients were under 5 years of age, 47.3 % were aged between 5 to 10 years and 36.4 % were aged between 10 and 15 years. Mean age of the patients was 9.2 ± 2.6 years (range, 4 to 15 years). Age distribution was not significantly different between patients with and without fracture reduction failure (*p*-value = 0.76).

Boys were 81.8 % of the study population. Gender distribution was not significantly different between patients with and without fracture reduction failure (*p*-value = 0.34).

Mean three-point index immediately after reduction was 0.79 ± 0.01 and 0.80 ± 0.01 among those without and with reduction failure, *p*-value = 0.26. Further follow-up indices follow at 2 weeks among those without and with reduction failure were (0.81 ± 0.01 vs 0.79 ± 0.01, *p*-value < 0.05),

at 4 weeks among those without and with reduction failure (0.81 ± 0.02 vs 0.78 ± 0.02, *p*-value < 0.05), and at 6 weeks among those without and with reduction failure (0.82 ± 0.04 vs 0.77 ± 0.02, *p*-value < 0.05); mean TPI was significantly higher in those with reduction failure as compared to those without failure (Table 2).

It was observed that immediately after reduction among those without and with failure, 22.2 % and 45.9 % had three-point index < 0.8, and at subsequent follow-ups at 2 weeks (16.7 % vs 59.5 %, *p*-value < 0.05) at 4 weeks (27.8 % vs 89.2 %, *p*-value < 0.01) and 6 weeks (44.4 % vs 94.6 %, *p*-value < 0.01); there was a significantly lower proportion of patients who had three-point index < 0.8 among those with reduction failure as compared to those without reduction failure (Table 3).

Table 2

Comparison of mean three-point index between patients with and without fracture reduction failure

Three-point index	No Failure		Failure		*p*-value*
	Mean	SD	Mean	SD	
Immediately after reduction	0.79	0.01	0.80	0.01	0.26
2 weeks	0.79	0.01	0.81	0.01	< 0.05
4 weeks	0.78	0.02	0.81	0.02	< 0.05
6 weeks	0.77	0.02	0.82	0.04	< 0.05

* — analysed using independent t test.

Table 3

Comparison of three-point index between patients with and without fracture reduction failure

Follow-up	Three-Point Index	No Failure		Failure		Total		*p*-value*
		N	%	N	%	N	%	
Immediately after reduction	< 0.8	17	45.90	4	22.20	21	38.20	0.89
	> 0.8	20	54.10	14	77.80	34	61.80	
2 weeks	< 0.8	22	59.50	3	16.70	25	45.50	< 0.05
	> 0.8	15	40.50	15	83.30	30	54.50	
4 weeks	< 0.8	33	89.20	5	27.80	38	69.10	< 0.01
	> 0.8	4	10.80	13	72.20	17	30.90	
6 weeks	< 0.8	35	94.60	8	44.40	43	78.20	< 0.01
	> 0.8	2	5.40	10	55.60	12	21.80	
Total		37	100	18	100	55	100	

* — analysed using chi-square test.

Mean CI immediately after reduction was 0.80 ± 0.01 and 0.81 ± 0.01 among those with and without reduction failure, respectively (*p*-value = 0.07). Further follow-up indices were at 2 weeks (0.80 ± 0.01 vs 0.79 ± 0.01, *p*-value < 0.01), at 4 weeks (0.81 ± 0.02 vs 0.78 ± 0.01, *p*-value < 0.05), and at 6 weeks (0.82 ± 0.04 vs 0.78 ± 0.02, *p*-value < 0.05); mean CI was significantly higher in those with reduction failure as compared to those without failure (Table 4).

Table 4

Comparison of mean cast index between patients with and without fracture reduction failure

Cast Index	No Failure		Failure		*p*-value*
	Mean	SD	Mean	SD	
Immediately after reduction	0.80	0.01	0.81	0.01	0.07
2 weeks	0.79	0.01	0.80	0.01	< 0.01
4 weeks	0.78	0.01	0.81	0.02	< 0.05
6 weeks	0.78	0.02	0.82	0.04	< 0.05

* — analysed using independent t test.

It was observed that immediately after reduction, those without and with failure, 27.8 % and 40.5 % respectively, had cast index < 0.8 and at subsequent follow-ups the rate was at 2 weeks (33.3 % vs 67.6 %, *p*-value < 0.05), at 4 weeks (44.4 % vs 94.6 %, *p*-value < 0.01) and at 6 weeks (44.4 % vs 94.6 %, *p*-value < 0.01); there was a significantly lower proportion of patients who had cast index < 0.8 among those with reduction failure as compared to those without reduction failure (Table 5).

Table 5

Comparison of cast index between patients with and without fracture reduction failure

Follow-up	Cast Index	No Failure		Failure		Total		*p*-value*
		N	%	N	%	N	%	
Immediately after reduction	< 0.8	15	40.50	5	27.80	20	36.40	0.35
	> 0.8	22	59.50	13	72.20	35	63.60	
2 weeks	< 0.8	25	67.60	6	33.30	31	56.40	< 0.05
	> 0.8	12	32.40	12	66.70	24	43.60	
4 weeks	< 0.8	35	94.60	8	44.40	43	78.20	< 0.01
	> 0.8	2	5.40	10	55.60	12	21.80	
6 weeks	< 0.8	35	94.60	8	44.40	43	78.20	< 0.01
	> 0.8	2	5.40	10	55.60	12	21.80	
Total		37	100	18	100	55	100	

* — analysed using chi-square test.

Mean pain score according to VAS (Visual Analog Scale) immediately after reduction was 6.7 ± 0.5 and 6.8 ± 0.6, *p*-value 0.31 among those with and without reduction failure, respectively. At further follow ups it was at 2 weeks (5.5 ± 0.9 vs 4.9 ± 0.5, *p*-value < 0.05), at 4 weeks (3.8 ± 1.3 vs 2.5 ± 0.7, *p*-value < 0.01), and at 6 weeks (2.5 ± 1.2 vs 1.4 ± 0.6, *p*-value < 0.05); mean VAS score was significantly higher in those with reduction failure as compared to those without failure (Table 6).

Table 6

Comparison of mean pain VAS score between patients with and without fracture reduction failure

VAS	No Failure		Failure		*p*-value*
	Mean	SD	Mean	SD	
Immediately after reduction	6.7	0.5	6.8	0.6	0.31
2 weeks	4.9	0.6	5.5	0.9	< 0.05
4 weeks	2.5	0.7	3.8	1.3	< 0.01
6 weeks	1.4	0.6	2.5	1.2	< 0.05

* — analysed using independent t test.

It was observed that at 2 weeks the area under curve (AUC) for cast index and three-point index was 0.72 and 0.85, respectively. At 4 weeks, the area under curve for cast index and three-point index was 0.77 and 0.84, respectively, and at 6 weeks it was 0.74 and 0.86, respectively (Table 7, Fig. 3).

Thus, in the present study, CI and TPI had similar predictability for fracture reduction failure.

Table 7

Prediction of fracture reduction failure based on three-point index and cast index

Test Result Variable	Area under curve	Std. Error	Asymptotic 95 % Confidence Interval	
			Lower Bound	Upper Bound
Cast index 2 WKS	0.72	0.084	0.561	0.888
Three-point index 2 WKS	0.85	0.054	0.743	0.956
Cast index 4 WKS	0.77	0.075	0.624	0.917
Three-point index 4 WKS	0.84	0.057	0.732	0.957
Cast index 6 WKS	0.84	0.057	0.734	0.96
Three-point index 6 WKS	0.86	0.051	0.76	0.959

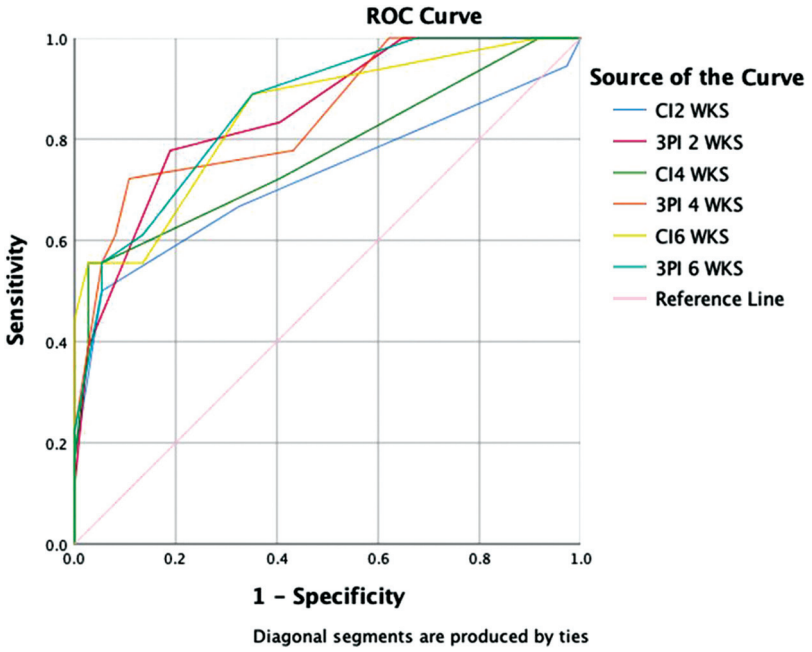

Fig. 3 Prediction of fracture reduction failure based on three-point index and cast index

DISCUSSION

Fracture reduction failure rate

In 55 patients of the study, fracture reduction failure was observed in 32.7 % which was similar to the finding observed in the study done by Alagöz et al. The study investigated the factors affecting the loss of reduction in pediatric diaphyseal forearm fractures and compared the three-point index (TPI) with the cast index, padding index, Canterbury index and gap index. In their study, 52 out of 159 patients (32.7 %) experienced loss of reduction during the follow-up [8]. Other studies showed different results in comparison to our study. Ajmera et al. assessed the rate of re-displacement in pediatric forearm fractures treated by cast by calculating the cast index. In their study, re-displacement was seen in 10 % of the cases [9]. In the study by Sipani et al., out of 69 distal forearm fractures 7 (10 %) were re-displaced and were re-manipulated [10]. Ravier et al. assessed which index is the most reliable in assessing cast adequacy in preventing re-displacements in a pediatric population. They reported loss of reduction in 54.8 % of the fractures [11].

The failure rates depend upon a number of factors which are beyond our scope of study. R. Arora et al. analyzed the role of risk factors and above casting indices in predicting significant re-displacement of pediatric forearm fractures treated by closed reduction and cast. In their study, thirteen (11.5 %) patients had significant re-displacement; all of them required re-manipulation [12].

Three-point index

It was observed that the mean three-point index immediately after reduction was 0.79 ± 0.01 and 0.80 ± 0.01 among those without and with reduction failure, respectively, p-value = 0.26 and at further follow ups at 2 weeks (0.81 ± 0.01 vs 0.79 ± 0.01, p-value < 0.05), 4 weeks (0.81 ± 0.02 vs 0.78 ± 0.02, p-value < 0.05), and 6 weeks (0.82 ± 0.04 vs 0.77 ± 0.02, p-value < 0.05); mean three-point index was significantly higher in those with reduction failure as compared to those without failure.

Our findings were similar to the studies done by Kharbamon et al., Alagöz et al., Iltar et al., Arora et al., which also concluded that if the three-point index is more than 0.8 than there was requirement of re-manipulation.

In the study by Kharbamon et al., the three-point index changed insignificantly from 0.81 ± 0.08 at first week post-operatively to 0.77 ± 0.18 six weeks post-operatively [13].

In the study by Alagöz et al., 78.8 % of those with loss of reduction had three-point index ⩾ 0.8, while only 15.9 % among those without loss of reduction had the three-point index ⩾ 0.8. This association was statistically significant (*p*-value < 0.01). Although the accuracy of the three-point index was higher than the other parameters, the authors concluded that no parameter alone could provide a definite prediction [8].

In their study, Iltar et al. compared the three-point index with the cast, padding, and Canterbury indices and reported that three point index's sensitivity and specificity were higher than all other indices [14].

In a recent study, Asadollahi et al. found that cast, padding, gap and three-point indices all have a strong correlation with re-displacement [15].

Cast index

The cut-off level of cast index as given by Sheikh et al. [16] was 0.77 for re-displacement and 0.92 for second procedure by Debnath et al. [17], whereas in our study this level was 0.8. The probable reason for this difference may be the difference in padding material used by us compared to their study. Bohm et al. found no difference in re-displacement rates of below elbow versus above elbow casts based on cast index above or below 0.70 [18]. Sheikh et al. hypothesized that cast index of less than 0.8 is more difficult to achieve in the proximal forearm but that this does not necessarily adversely affect the risk of fracture re-displacement.

This is based on the fact that the proximal forearm has more soft tissue as compared with the distal forearm and therefore a cast that is more elliptical in cross section is less likely. However, a less elliptical proximal forearm cast (i.e., one with a higher cast index) may still provide adequate three-point fixation. Though not investigated in the present study, weight of the children also has an effect on the cast index. The study by Kamat et al. concluded that in addition to obesity, excessive padding and soft tissue swelling could allow re- displacement [19]. Similar observations were made by Malviya et al. who suggested that in young normally chubby children there is very little control over this otherwise useful tool [20].

In the present study, mean cast index immediately after reduction was 0.80 ± 0.01 and 0.81 ± 0.01 among those with and without reduction failure, *p*-value = 0.07. Further follow ups at 2 weeks (0.80 ± 0.01 vs 0.79 ± 0.01, *p*-value < 0.01), 4 weeks (0.81 ± 0.02 vs 0.78 ± 0.01, *p*-value < 0.05), and 6 weeks (0.82 ± 0.04 vs 0.78 ± 0.02, *p*-value < 0.05), showed that the mean cast index was significantly higher in those with reduction failure as compared to those without failure.

Shaw et al. reported that the mean cast index of the re-displacement group was 0.84, which significantly differs (p < 0.001) from the control group at 0.68 [21]. In another study by Agarwala et al., the mean cast index was 0.72 for distal forearm fractures. Mean cast index in displaced distal fractures was calculated to be 0.85. Mean cast index for un-displaced distal fractures was 0.7. Out of 83 distal forearm fractures 9 were re-displaced and were re-manipulated while 4 (out of 9) had to undergo operative treatment [22]. In the study by Ajmera et al., the mean cast index in the proximal, middle and distal forearm was 0.92, 0.86 and 0.80 respectively. Re-displacement was seen in only 3 (10 %) cases with cast index of 0.75, 0.97 and 1.004 and the mean cast index in these re-displacement cases was 0.908 (range 0.75 to 1.004). The change in cast index at 2, 4 and 6 weeks was not significantly different. Re-displacement was in one case of distal forearm fracture and two cases were of middle forearm fracture. This showed that the re-displacement rate is not associated with the level of fractures, but is directly proportional to cast index: the higher is the cast index, the higher is the chance of re-displacement [9].

VAS pain score

In the present study, mean VAS score immediately after reduction was 6.7 ± 0.5 and 6.8 ± 0.6, *p*-value 0.31 among those with and without reduction failure. Further follow ups at 2 weeks (5.5 ± 0.9 vs 4.9 ± 0.5, *p*-value < 0.05), 4 weeks (3.8 ± 1.3 vs 2.5 ± 0.7, *p*-value < 0.01), and 6 weeks (2.5 ± 1.2 vs 1.4 ± 0.6, *p*-value < 0.05) showed that the mean VAS score was significantly higher in those with reduction failure as compared to those without failure.

To the best of our knowledge, no previous study has assessed pain after successful closed reduction in distal both-bone forearm fractures.

Limitations

There are a few limitations of our study: We could not observe the patients for a longer period of time to know re-modelling in the long term. We did not take in to consideration the severity of fracture, type of anesthesia used (conscious sedation versus General Anesthesia) and the fracture configuration while assessing the outcomes. We also did not collect information about anthropometric parameters like child weight and diameter of the forearm.

CONCLUSION

Based on the results of our study, we conclude that both three-point index and cast index were found to be significantly higher in patients with reduction failure. Based on the area under curve, cast index and three-point index had similar predictability for fracture and reduction failure. Pain was significantly higher in patients with reduction failure. Thus, the three-point index and cast index are clinically useful tools to assess the quality of cast molding following closed reduction of pediatric forearm fractures and to predict re-displacement in distal forearm fractures.

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Information about the authors:

Kuljit Kumar — Professor, Department of Orthopedics, koolguy0062008@gmail.com, https://orcid.org/0009-0007-6462-4102;

Chetan Katariya — DNB Resident, Department of Orthopedics, katariyachetan96@gmail.com;

Mohit Jindal — Associate Professor, Department of Orthopedics, drmohitjindalortho@gmail.com, https://orcid.org/0000-0002-1699-456X;

Pranav Gupta — Assistant Professor, Department of Orthopedics, pranavchd88@gmail.com.

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Main etiological factors and comorbid pathology in severe cerebral palsy

V.V. Evreinov[1]✉, T.A. Zhirova[2], Ya.V. Zueva[1]

[1] Ilizarov National Medical Research Centre for Traumatology and Orthopedics, Kurgan, Russian Federation
[2] Ural Institute of Traumatology and orthopedics named after V.D. Chaklin, Ekaterinburg, Russian Federation

Corresponding author: Vadim V. Evreinov, Evreinov2020@mail.ru

Abstract

Introduction The largest number of factors contributing to the development of cerebral palsy (CP) relate to the pre- and intranatal periods. Premature birth and low birth weight are the most important predictors of cerebral palsy and are associated with persistent brain and motor disorders.

Purpose To evaluate the main etiological factors of severe cerebral palsy and comorbid pathology in children with severe motor disorders.

Material and methods A retrospective observational study included 170 patients with severe forms of cerebral palsy, divided into two groups (85 subjects each) depending on motor disorders: GMFCS IV, GMFCS V. Perinatal risk factors for severe cerebral palsy were assessed, correlations between perinatal risk factors for expressed movement disorders and height/weight indicators, comorbid pathology in children at the time of admission to the trauma and orthopaedic hospital.

Results Prenatal risk factors were responsible for the development of cerebral palsy in children in 71 % of cases. In the GMFCS IV group, gestational age had an inverse correlation with preterm birth (R = –0.53; R2 = 28 %). In the GMFCS V group, disorders caused by a shorter gestational age were interrelated with the duration of the antenatal period (R = –0.79; R2 = 62 %), and also directly correlated with delivery by cesarean section (R = 0.58; R2 = 34 %). Among the comorbid pathologies, eye diseases and psychological development disorders were most often detected.

Discussion Low height/weight parameters of patients were due to comorbid pathology, rather than phenotypic constitutional features. Inverse correlation between the disorders caused by the gestational age, low birth weight and duration of pregnancy, risk of developing respiratory disorders, and a direct correlation with cesarean section seem logical. Severe conmobid diseases were more frequently diagnosed in patients with GMFCS V, indicating more extensive perinatal catastrophes in the central nervous system and the relationship between the developed pathology and severe motor disorders.

Conclusions The main risk factors for the development of cerebral palsy in patients with severe GMFCS IV–V motor impairments are associated with the pre- and intranatal periods. Comorbid pathology of patients with severe forms of cerebral palsy is caused by severe brain damage and movement disorders that have developed against this background.

Keywords: etiological factors, comorbid pathology, children, cerebral palsy

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INTRODUCTION

The most common etiological factors contributing to the development of severe spastic forms of cerebral palsy (CP) are asphyxia, hemorrhagic or ischemic stroke, infections, central nervous system (CNS) malformations, and birth trauma [1, 2]. Premature birth (23–27 weeks of gestation) and low birth weight (less than 2500 g) are the most important predictors of CP, combined with persistent brain defects (cystic or cavum-like), severe movement disorders, dysphagia, neonatal seizures, and respiratory failure [2–4]. Maternal diseases (21–30.5 %) before conception (systemic diseases, use of psychotropic drugs, etc.) and during pregnancy (transient hypothyroxinemia, gestational diabetes, uterine bleeding, preeclampsia, etc.) also increase the risk of developing cerebral palsy in the child [5, 6].

Low height/weight parameters of patients with severe motor disorders due to cerebral palsy, detected at birth, persist with age, become most noticeable in adolescents and can reach z-scores lower than –2 [2]. In addition, such children are more often diagnosed with epilepsy (35–62 %), mental retardation (40–70 %), mental disorders (more than 50 %), dysarthria (40 %), visual impairment (from 40 to 75 %), hearing loss (4–13 %), oropharyngeal dysphagia (40–90 %), malnutrition (60–90 %), diseases of the genitourinary system (up to 60 %), chronic pain syndrome (32–74 %) [7, 8].

Thus, understanding the etiological causes of cerebral palsy allows for pre-pregnancy preparation of women for pregnancy, potential primary prevention of neurological disorders in newborns, while the understanding of probable comorbidities enables to plan early therapy for children with cerebral palsy, determine a rehabilitation strategy and a plan for social integration of such patients.

Purpose To evaluate the main etiological factors of severe cerebral palsy and comorbid pathology in children with severe motor disorders.

MATERIAL AND METHODS

A retrospective observational study included 170 patients (60 girls and 110 boys) with severe cerebral palsy, spastic dislocations (subluxations) of the femurs, in which reconstructive or palliative interventions on the hip joints were performed.

The work was carried out at the Ilizarov National Medical Research Center of Traumatology and Orthopaedics in the period from October 2021 to January 2024.

Inclusion criteria were:

— Age range: 5–17 years old;

— Severe CP (GMFCS IV–V);

— Uni– or bilateral spastic dislocation (subluxation) of the femur;

— Reconstructive or palliative interventions on the hip joint.

The patients were divided into two groups of 85 subjects each (30 girls and 55 boys) in accordance with the Gross Motor Function Classification System (GMFCS) of movement disorders. Children with severe motor impairments, unable to control body position and move without the help of parents (guardians), were assigned to functional level V (GMFCS V group), while patients who used technical rehabilitation devices for movement and could sit independently in a wheelchair were assigned to level IV (GMFCS IV group) [9].

Age and height/weight characteristics of the patient groups are presented in the Table1.

Table 1

Age and height/weight parameters of patients in the groups, Me [Q1; Q3]

Parameter		GMFCS IV group	GMFCS V group	*P*
Age	Gestational age, months	31 [28; 32]	31 [28; 36]	0.06
	At time of surgical intervention, years	9 [6; 11]	9 [7; 11]	0.47
Weight, kg	At birth	1.5 [1.3; 1.8]	1.7 [1.3; 2.7]	0.04
	At admission to hospital	22 [17; 29]	18 [15; 23]	0.001
Height, cm	At birth	41 [39; 43]	41 [36; 48]	0.13
	At admission to hospital	*122 (16)	*120 (16)	0.34
Quetelet Index, kg/m^2	At birth	9.4 [8.4; 10.8]	10.1 [9.1; 11.6]	0.03
	At admission to hospital	15.5 [13.9; 17.7]	13.3 [12.4; 15.1]	< 0.001

Notes: Me — median; [Q1; Q3] — interquartile range; * — mean values and standard deviation (SD)

In the GMFCS IV group, spastic diplegia (Little's disease) was detected in 57 (67 %) patients, spastic tetraplegia in 28 (33 %) patients, while in the GMFCS V group it was 16 (19 %) and 69 (81 %) patients, respectively ($p < 0.001$) [10].

The severity of dysphagia was assessed according to the EDACS (Eating and Drinking Ability Classification System), which determines the ability to take food and liquid in everyday life [11]. In the GMFCS IV group, 24 (28 %) children were classified as level I, 36 (42 %) as level II, 25 (29 %) as level III, 2 (2 %) as level IV, while in the GMFCS V group: 12 (14 %), 19 (22 %), 38 (45 %), 16 (19 %), respectively, and were significantly different ($p < 0.001$).

Evaluation criteria:

— Perinatal risk factors for severe cerebral palsy;

— Correlations between perinatal risk factors for cerebral palsy, severe motor disorders according to GMFCS, and children's height and weight indicators;

— Comorbid pathology at the time of admission to the trauma and orthopaedic hospital.

Statistical processing of the material was performed using the Stat Plus 7 program. When the numerical values were subject to the Gaussian distribution criteria (Kolmogorov – Smirnov / Lilliefors), quantitative characteristics were described using the mean and standard deviation (SD). In cases where the assessed indicators did not meet the parameters of normal distribution, the median (Me) and interquartile range [Q1; Q3] were calculated. One-way analysis of variance or the nonparametric Mann – Whitney U-test were used to compare the groups. The χ^2 criterion was used to compare proportions. In all cases, the significance level α, at which the null hypothesis was rejected, was taken to be 0.05. The presence of a relationship between variables was determined by the pairwise linear correlation coefficient (R), and the strength of the relationship was determined by the Chaddock scale. The proportion of variance was estimated by the determination coefficient (R^2). The study was approved by the institutional ethics committee (protocol No. 2 (70) dated October 21, 2021) and was conducted in accordance with the ethical standards set out in the Declaration of Helsinki.

RESULTS

Prenatal risk factors were responsible for the development of cerebral palsy in 71 % of cases, while intranatal factors were responsible for 21 % and postnatal factors were responsible for 8 % of cases. The main predictors of intrauterine cerebral palsy included surgical or spontaneous abortions in the mother's history, bleeding and anemia during pregnancy, gestosis, sexually transmitted infections (STIs), pelvic anomalies, and fetal pathologies. The most significant etiologic factors during labor were short gestational age and birth weight, cesarean section, and respiratory and cardiovascular disorders in the newborn. Factors that could lead to brain damage of the newborn in the extrauterine period were sepsis and hemolytic disease (Table 2).

Table 2

Perinatal risk factors for CP in the groups

Risk factors for CP (ICD10)	Group				*P*
	GMFCS IV, *n* = 85		GMFCS V, *n* = 85		
	Number	%	Number	%	
Prenatal					
Coagulation disorders (D68)	3	3.5	0		0.08
History of pregnancy with an abortive outcome (O00–O08)	41	48.2	36	42.3	0.44
Edema, proteinuria and hypertensive disorders during pregnancy (O10–O16)	35	41.2	45	52.9	0.12
Bleeding in early pregnancy (O20)	49	57.6	45	52.9	0.53
Urinary tract infection during pregnancy (O23)	9	10.5	12	14.1	0.48
Multiple pregnancy (O30)	14	16.5	5	5.9	0.02
Malpresentation of the fetus (O32)	1	1.2	6	7	0.05
Established or suspected maternal pelvic anomaly (O34)	14	16.5	11	12.9	0.51
Established or suspected pathological conditions of the fetus (O36)	14	16.5	10	11.7	0.37
Polyhydramnios (O40)	6	7	0		0.01
Disorders of the amniotic fluid and fetal membranes (O41)	6	7	6	7	1
Placenta previa (O44)	2	2.4	6	7	0.14
Premature placental abruption (O45)	17	20	15	17.6	0.69
Infectious and parasitic diseases of the mother complicating pregnancy (O98)	11	12.9	14	16.5	0.51
Anemia complicating pregnancy (O99.0)	16	18.8	19	22.3	0.57
Diseases of the endocrine system, nutritional disorders and metabolic disorders that complicate pregnancy (O99.2)	3	3.5	7	8.2	0.19
Intrauterine hypoxia (P20)	13	15.3	6	7	0.08
Respiratory diseases complicating pregnancy (O99.5)	17	20	8	9.4	0.05
Restoration and preservation of reproductive function (Z31)	8	9.4	1	1.2	0.01
Problems related to the mother's lifestyle (Z72)	1	1.2	2	2.4	0.56
Intranatal					
Premature rupture of membranes, onset of labor after 24 hours of anhydrous period (O42.1)	13	15.3	11	12.9	0.66
Preterm labor and delivery (O60)	81	95.3	68	80	0.00
Delivery by caesarean section, with forceps or with the use of a vacuum extractor (O81–O82)	64	75.3	66	77.6	0.71
Disorders associated with shortened gestation and low birth weight (P07)	80	94.1	64	75.3	< 0.001
Respiratory and cardiovascular disorders characteristic of the perinatal period (P21–P29)	77	90.6	82	96.5	0.12
Intracranial nontraumatic hemorrhage in the fetus and newborn (P52)	24	28.2	19	22.3	0.37
Postnatal					
Bacterial sepsis of the newborn (P36)	7	8.2	6	7	0.77
Hemolytic disease of the fetus and newborn (P55)	1	1.2	1	1.2	1

Based on the correlation analysis, a moderate inverse relationship was found between the severity of motor disorders according to GMFCS and the body mass index at the time of admission to the trauma and orthopaedic hospital (R = –0.32). The coefficient of determination (R2) of the dependent variable

(BMI) was 10 %. The strength of the relationship according to Chaddock among perinatal risk factors for cerebral palsy and major motor disorders was either absent or very weak. Also, no relationship was registered in both groups between the Quetelet index (BMI) at birth and the BMI upon admission to the Ilizarov Center.

In the GMFCS IV group, the gestational age was directly correlated (R = 0.59; R2 = 35 %) with the birth weight index and had an inverse correlation with preterm birth (R = –0.53; R2 = 28 %), the risk of developing respiratory and cardiovascular disorders in the neonatal period (R = –0.43; R2 = 18 %) (Table 3). In the GMFCS V group, disorders due to shortened gestational age and low birth weight were interconnected with the duration of the antenatal period (R = –0.79; R2 = 62 %), and also directly correlated with cesarean section (R = 0.58; R2 = 34 %) (Table 4).

Table 3

Correlation coefficients of parameters in group GMFCS IV, *n* = 85

Parameters	O60	P07	P21–P29	Gestational age, months	BMI at birth, kg/m^2
Preterm labor and delivery (O60)	1				
Disorders related to short gestation and low birth weight (P07)	0.43	1			
Respiratory and cardiovascular disorders specific to the perinatal period (P21–P29)	0.24	0.23	1		
Gestational age, months	–0.53	–0.35	–0.43	1	
BMI at birth, kg/m^2	–0.52	–0.51	–0.19	0.59	1

Table 4

Correlation coefficients of parameters in group GMFCS V, *n* = 85

Parameters	O32	O36	O40	O60	O81–82	P07	P20	Gestational age, weeks	BMI at birth, kg/m^2
Malpresentation of the fetus (O32)	1								
Established or suspected pathological conditions of the fetus (O36)	–0.03	1							
Polyhydramnios (O40)	–0.05	– 0.02	1						
Preterm labor and delivery (O60)	0.03	–0.08	0.50	1					
Delivery by caesarean section, with forceps or with vacuum extraction (O81–82)	0.13	0.06	–0.05	0.27	1				
Disorders related to short gestation and low birth weight (P07)	0.16	0.07	–0.16	0.15	0.58	1			
Intrauterine hypoxia (P20)	0.42	0.49	–0.04	–0.02	0.12	0.14	1		
Gestational age, months	–0.21	0.12	0.16	–0.20	–0.55	–0.79	–0.09	1	
BMI at birth, kg/m^2	–0.19	–0.05	–0.07	–0.10	–0.28	–0.29	–0.13	0.40	1

In the compared groups, among the comorbid pathologies, eye diseases and disorders of psychological development were identified; in patients with extremely severe motor disorders (GMFCS level V), diseases of the genitourinary, nervous (epilepsy, hydrocephalus, etc.), endocrine systems, nutritional disorders and metabolic disorders were most often diagnosed (Table 5).

Table 5

Comorbid pathology in the groups of patients

Коморбидная патология	Group				*P*
	GMFCS IV, *n* = 85		GMFCS V, *n* = 85		
	Abs. number	%	Abs. number	%	
Diseases of the eye and its adnexa	72	84.7	66	77.4	0.24
Diseases of the skin and subcutaneous tissue	1	1.2	1	1.2	1
Diseases of the blood, hematopoietic organs and certain disorders involving the immune mechanism	3	3.6	3	3.6	1
Diseases of the genitourinary system	26	30.6	56	65.8	< 0.001
Diseases of nervous system	38	44.7	52	61.2	0.03
Diseases of respiratory organs	10	11.7	10	11.7	1
Diseases of the digestive system	22	25.8	55	64.7	< 0.001
Diseases of blood circulation system	10	25.9	15	17.6	0.27
Diseases of the endocrine system, nutritional disorders and metabolic disorders	48	56.5	67	78.8	0.004
Congenital anomalies, deformities and chromosomal disorders	8	9.4	14	16.5	0.17
Disorders of psychological development	76	89.4	75	88.2	0.8

DISCUSSION

In our study, most of the risk factors associated with the likelihood of cerebral palsy in a child were related to the period of embryonic development that is consistent with large studies in this area [12–15]. Hypoxic-ischemic damage to neurons and intracranial hemorrhages caused the formation of epileptic foci in the brain, severe intellectual disorders, spastic diplegia and tetraplegia, pseudobulbar disorders, and oropharyngeal dysphagia. Along with this, low height/weight parameters of patients in the groups, diagnosed at birth and persisting with age, were probably due to comorbid pathology, severe motor limitations, low nutrient intake, energy deficiency, metabolic disorders, and not phenotypic constitutional features [16–21].

Premature birth is often promoted by acute inflammatory diseases of the female pelvic organs, a history of abortions, and a postoperative scar on the uterus [22, 23]. In such cases, obstetricians and gynecologists use surgical methods of delivery to reduce neonatal mortality [24]. In a newborn, due to morphologically immature lungs, gas exchange may be impaired, metabolic acidosis, and respiratory failure may develop, which may lead to hypoxic ischemia of the myocardium and brain of the child [25–27]. Thus, the inverse correlation revealed in our work between disorders caused by the gestational age, low birth weight, and the duration of pregnancy, premature birth, the risk of respiratory and cardiovascular disorders and a direct correlation with cesarean section delivery seems logical.

According to the US Centers for Disease Control, the mortality rate of infants born at 22–24 weeks of gestation is 64 %, and neurological disorders are detected in 43 % of cases among survivors [25, 28]. Extremely premature infants have white matter lesions in the form of periventricular leukomalacia or consequences of hemorrhages in 80 % of cases, while full-term infants have a gray matter defect [12, 15]. Thus, bilateral spastic forms of cerebral palsy were recorded in 31.4 % of cases, mental retardation with IQ < 50 in 32.1 % of cases, and severe eye vision impairment in 12.3 % of cases [15, 29, 30]. In our study, cerebral vision impairment and retinopathy of premature children were the main eye diseases in children with severe limitations of motor functions [31]. Psychological disorders were also established with equal frequency, which indicates damage to similar parts of the brain. At the same time, diseases of the genitourinary, digestive, endocrine systems, nutritional

disorders and metabolic disorders, hydrocephalus, epilepsy were more often diagnosed in patients with GMFCS V, which indicates more large-scale perinatal catastrophes that occurred in the central nervous system, as well as the relations between the pathology developed and pronounced motor disorders.

CONCLUSION

The main risk factors for the development of cerebral palsy in patients with severe motor impairments GMFCS IV–V are associated with the pre– and intranatal periods.

Comorbid pathology in patients with severe cerebral palsy is caused by severe brain damage and motor disorders that have developed due to it.

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Information about the authors:

Vadim V. Evreinov — Candidate of Medical Sciences, anesthesiologist-reanimatologist, Evreinov2020@mail.ru, https://orcid.org/0000-0002-0964-2718;

Tatyana A. Zhirova — Doctor of Medical Sciences, methodologist, Satokenia70@gmail.com, https://orcid.org/0000-0001-6911-0812;

Yana V. Zueva — orthopaedic surgeon, black_boom@mail.ru, https://orcid.org/0009-0008-0491-2070.

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Short-term functional outcome of total hip arthroplasty for avascular necrosis of femoral head and influence of patient-related factors

Khoa V. Vu[1], Quang Nguyen[2], Lan T.P. Luong[3], Thieu Q. Nguyen[4], Loi B. Cao[5], Anh T. Le[6]✉

[1] Orthopaedic and Outpatient Clinic, Vietnam-Germany Friendship Hospital, Ha Noi, Vietnam
[2] Ha Tinh TTH Hospital, Ha Tinh, Vietnam
[3] University of Medicine & Pharmacy, Vietnam National University, Ha Noi, Vietnam
[4] National Institute of Malariology, Parasitology, and Entomology (NIMPE), Ha Noi, Vietnam
[5] National Institute of Malariology, Parasitology and Entomology, Ha Noi, Vietnam
[6] Vietnam Military Medical University, Ha Noi, Vietnam

Corresponding author: Anh T. Le, anh_lt@vmmu.edu.vn

Abstract

Introduction Avascular necrosis of the femoral head (ANFH) is a phenomenon vascular supply disruption lead to death of bone cells around the femoral head. The disease is a severe health issue all over the world. Within 2 years about 80 % to 85 % of symptomatic cases will result in collapse of the femoral head. Recovery of hip function after total hip arthroplasty (THA) may be influenced by many factors that vary among different racial/ethnic groups. Most findings in this field have been from Western developed nations, and not much information from developing Asian countries is available.

This study **aimed** to determine the six-month functional outcome and patient–related factors that predict functional recovery in patients with avascular necrosis of the femoral head (ANFH) undertaking total hip arthroplasty (THA).

Methods Between January 2022 and December 2023 there were 143 patients participating in this prospective study. Demographic, medical history and clinical findings were collected from their medical records. The six-month functional outcome was evaluated using the Harris hip score (HHS). The mean age of the participants was 55.90 ± 11.49 years, and the majority (86.7 %) were male. Most patients had excellent (43.4 %) or good outcome (51.7 %).

Discussion Our study had some limitations: the length of the follow-up after surgery is short (6 months), that hospital-related factors like the type and volume of the hospital have not been analyzed. Nonetheless, previous observations suggest that most of the improvement in physical function occurs during the first six months following surgery and remains the same for a long time. However, our sample has typical demographic and clinical characteristics of patients with THA for ANFH, suggesting that determinants of the 6-month functional outcome in the current study could apply to other patients undergoing this surgery.

Results The determinants of excellent outcome were a higher preoperative HHS (odds ratio (OR): 4.369, 95 % confidence interval (CI) =1.854 – 10.299; $p < 0.001$) and absence of comorbidity (OR: 2.440, 95 % CI = 1.071 – 5.557, $p = 0.034$). No demographic (age, gender, body mass index), medical history (using of steroids, alcohol consumption or smoking), or any other clinical parameter (stage or side of the affected hip, time until surgery) had a significant influence on functional outcome.

Conclusion Earlier surgery during functional decline and better management of comorbidity may help improve THA outcomes for patients with avascular necrosis of the femoral head.

Keywords: total hip arthroplasty, avascular necrosis of femoral head, functional recovery, Harris hip score, Vietnam

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INTRODUCTION

Avascular necrosis of the femoral head (ANFH) is a phenomenon vascular supply disruption lead to death of bone cells around the femoral head [1, 2]. The disease is a severe health issue all over the world. In the United States, about 10,000 to 20,000 new cases are reported each year [1]. In Japan, the mean ageadjusted incidence rate is 2.51 cases per 100,000 person-years [3]. The natural history of ANFH is progression to collapse of the hips [2]. Within 2 years about 80 % to 85 % of symptomatic cases will result in collapse of the femoral head [4]. When ANFH has reached this advanced stage, total hip arthroplasty (THA) is the treatment of choice and there are no other suggested procedures [2]. Click or tap here to enter text.. One of the most important outcomes of THA is function recovery which may be influenced by many factors [2]. These factors may vary in different racial/ethnic groups [5]. However, most findings in this field have been from Western developed nations, and not much information from developing Asian countries is available [6–8].

Vietnam is a developing country in South East Asia. The prevalence of ANFH in Vietnam remains unknown, but it is expected to be high due to the high rates of alcohol consumption or smoking, well-known risk factors of the disease [6–8]. Compared to those from developed countries, Vietnamese patients may have different demographic, clinical characteristics as well as anatomical parameters of the hip joint [11, 12]. Consequently, the outcome and factors correlated to the functional outcome of THA may be different from those in developed countries. There have been some preliminary works on results of THA in Vietnam [13], but little is known about factors that may have influence the functional outcome. Therefore, we carried out this research to determine functional outcomes and patient-related factors that predict functional results of THA for ANFH in Vietnamese patients.

MATERIAL AND METHODS

This prospective survey was conducted in a general hospital, Ha Tinh TTH hospital, between January 2022 and December 2023. It received ethical clearance from the review board of TTH hospital (18/QD-TTH). Written informed consent was obtained from all patients or their legal representatives after receiving an explanation of the study. This study is part of a thesis work for the degree of Doctor of Philosophy in Health Studies at the National Institute of Malariology, Parasitology, and Entomology (NIMPE) of Vietnam.

The inclusion criteria were patients with advanced ANFH, ARCO stages III or IV (ARCO, Association Research Circulation Osseous), who underwent primary cementless THA. Patients who were not medically fit for surgery or had a history of THA for more than 12 weeks were excluded. Patients' information including demographic (gender, age, body mass index (BMI), medical history (use of steroids, alcohol consumption or smoking), and clinical data (time of pain onset, the side and stages of hips affected, the preoperative function, comorbidity) were collected using a case record form. Comorbidities listed in this analysis included cancer, cardiac disease, endocrine disease (diabetes mellitus, thyroid disease), cardiovascular disease, gastrointestinal disease, hematologic disease, hepatobiliary disease, infectious disease, neurological disease, respiratory disease, joint disease, sciatica or chronic back problem as described elsewhere [7, 8].

A conventional protocol was applied to all participants. All comorbidities were treated before the surgery. In patients with both hips affected, staged bilateral THA was performed at an interval of 6–12 weeks. After the surgery, rehabilitation specialists instructed all patients to perform functional rehabilitation. The pre-operative and 6-month functional outcome was evaluated using Harris hip score (HHS).

Definition

Patients were categorized as underweight (< 18.5), normal weight (18.5–23), overweight and obesity (⩾ 23) based on Asian criteria for BMI (kg/m2) [14]. The time of pain to THA < 24 months was considered early surgery and >= 24 months was late [15]. The functional outcome was rated as excellent for HHS of 90–100 points, good for 80–90 points, fair for 70–79 points, and poor for lower than 60 [15]. For continuous variables such as age and preoperative HHS that did not have predefined cutoff values, the mean values were used as the cut point.

Data analysis

Statistical analysis was performed using SPSS statistical software version 16.0. Continuous variables were reported as means and standard deviations (SD) while frequencies and percentages were used to express categorical variables. To find out the factors predicting the excellent functional outcome Pearson's chi-square tests and, when appropriate, Fisher exact tests were used for univariate analysis. The independent variables with a significant association from univariate analysis were entered into a multivariable linear regression model. The p-value lower than 0.05 was considered significant in all analyses.

RESULTS

There were 143 patients with a median age of 55.90 years (range, 28–85 years) included in the study. Most of the patients (80.4 %) were between 41 and 70 years old. Among the participants, 4.27 % had one comorbidity. Sciatica (11.89 %), hypertension (11.19 %), and diabetes mellitus (DM; 4.90 %) were the most frequent comorbidities. Regarding the operation, 89.7 % of the patients underwent unilateral THA, and 68.5 % of them had early surgery.

The mean HHS observed at 6-month post-surgery was 89.22 %. Most patients (95.1 %) had excellent or good outcome (Table 2).

Table 1

Baseline data of the study population (*n* = 143)

	Parameter	Value (N, %, CI 95 % or mean ± SD)
Demographics factors		
	Age (years)	55.90 ± 11.49
	Min – max	28 – 85
Gender	Male	124 (86.7)
	Female	19 (13.3)
BMI	Underweight	11 (7.69)
	Normal weight	93 (65.03)
	Overweight and obese	39 (27.28)
Medical history	Steroid use	102 (71.3 %)
	Alcohol abuse	104 (72.72)
	Smoke	95 (66.43)
Clinical data		
	Comorbidity*	49 (34.27)
	Time to surgery (months)	18.59 ± 15.38 (1 – 72)
	Early management	98 (68.5)
	Late manegement	45 (31.5)
Type of treatment	Unilateral THA	114 (89.7)
	Bilateral THA	29 (20.3)
Stage on MRI	III	69 (48.3)
	IV	74 (51.7)
	HHS	51.22 ± 3.39 (40 – 64)

* Morbidity: sciatica 17 (11.89 %), hypertension 18 (11.19 %), diabetes mellitus 7 (4.90 %), gout 5 (3.50 %), liver disease 5 (3.5 %), chronic obstructive pulmonary disease 1 (0.7 %), polyarthritis 2 (1.4 %), thyroid carcinoma 1 (0.7 %).

Table 2

Physical function at 6 months after total hip replacement (*n* = 143)

	Number/points	Percent
Excellent	62	43.4
Good	74	51.7
Fair	4	2.8
Poor	3	2.1
HHS (mean ± SD)	89.22	6.06
Min-max	66	100

The univariate analysis showed that age, concomitant morbidity, waiting time for surgery and pre-operative HHS significantly correlated with functional outcome. However, only higher pre-operative HHS (odds ratio (OR): 4.369, 95 % confidence interval (1.854 – 10.299); $p < 0.001$) and absence of comorbidity (OR: 2.440, 95 % CI = 1.071 – 5.557, $p = 0.034$) were the factors predicting excellent function on multivariate analysis. No significant association was found between other parameters and functional recovery (Table 3).

Table 3

Factors predicting excellent functional outcome at 6 months after total hip replacement ($n = 143$)

Factors		Univariate analysis		Multivariate analysis	
		OR (CI 95 %)	*p*	OR (CI 95 %)	*p*
Demographics factors					
	Age group*	2.266 (1.154 – 4.452)	0.019	2.050 (0.960 – 4.378)	0.064
	Gender†	1.366 (0.504 – 3.704)	0.624		
	BMI‡	1.089 (0.543 – 2.182)	0.861		
Medical history	Steroid use	1.562 (0.753 – 3.239)	0.265		
	Alcohol	0.653 (0.306 – 1.396)	0.344		
	Smoke	0.792 (0.391 – 1.604)	0.593		
Clinical findings	Stage‖	1.596 (0.820 – 3.106)	0.181		
	Time to surgery¶	3.957 (1.765 – 8.867)	< 0.001	2.249 (0.882 – 5.736)	0.090
	Type of surgery#	0.779 (0.344 – 1.765)	0.675		
	Pre-operative HHS**	5.483 (2.576 – 11.667)	< 0.001	4.369 (1.854 – 10.299)	< 0.001
	Comorbidity††	2.267 (1.093 – 4.702)	0.033	2.440 (1.071 – 5.557)	0.034

*, Age (⩽ 55 vs > 55 years); †, Gender: female vs. male; ‡, Underweight and normal ones compared to overweight patients, patients with normal BMI was the reference group; ‖, ARCO stages III vs. IV; ¶, early management compared to late management; #, unilateral THA vs bilateral THA; **, 50 vs. > 50 HHS; ††, patients without comorbidity vs. with comorbidity

DISCUSSION

Baseline characteristics

The present study was conducted at a general hospital in Ha Tinh province, a province in central Vietnam. The mean age of our sample was 55.90 years, and most patients were male (81.9 %) which agrees with distribution of age and gender in patients with ANFH [17, 18]. The average preoperative HHS was 51.22 (range, 40 – 64). In previous studies, THA is usually indicated for patients with HHS lower than 40 [18, 19]. However, others report THA for patients with an HHS of more than fifty as in our study [20, 21].

Functional outcome

The first aim of the current study was to investigate the functional outcome of primary THA in patients with AFHN in a Vietnamese cohort. Like many previous studies, our results demonstrate that THA had good outcomes with more than 90 % of patients rated as excellent or good recovery [19, 22]. The average post-operative HHS in our study (89.26) was also in the range of postoperative scores previously reported (from 85 to 93) [18, 19].

Factors predicting functional outcome

The second aim of the current study was to identify factors that may predict excellent functional outcomes after THA for the treatment of ANFH. This study corroborates many previous studies showing no association between demographic parameters including age, gender, weight status and the functional outcome [20, 23]. Age and gender are patient-related factors that are useful for clinicians to determine the appropriate type of surgery [24]. It has been suggested that the optimal age for THA is about 60 to 75 years [25], but many investigators have found that the operation has good outcomes regardless of patients' age [26, 27]. Similarly, the lack of association between weight status and THA outcome in our sample follow the trend previously described [28, 29]. It is generally accepted that THA should not be withheld from patients who are overweight or obese [30, 31].

Regarding medical history variables, our results concur with studies suggesting that use of steroids, alcohol consumption and smoking have no influence on the functional outcome of THA [6, 32, 33]. Use of steroids is considered the leading cause of atraumatic ANFH [1]. In addition, patients with ANFH are more likely to be exposed to corticosteroid use [34]. Steroid use may result in a high rate of complications and reoperation of THA [35]. Nevertheless, functional outcome is similar to patients with no history of using steroids [35, 36]. Alcohol abuse is another common risk factor for atraumatic AVN, especially in younger patients [37, 38]. However, Johannson et al. (2011) found that alcohol abuse is not associated with poor THA outcomes [6].

Among the clinical findings, pre-operative HHS and comorbidity were independently associated with six-month functional recovery of our patients (Table 3). The strong association between pre-operative HHS and functional recovery has been addressed in many studies [21, 23, 31, 32]. Röder et al. (2007) reported a significant relationship between higher pre- and post-operative walking capacity and range of hip flexion when analyzing data from 12,925 patients (13,766 total hip arthroplasties) registered in the International Documentation and Evaluation System European between 1967 and 2002 [39]. In a recent review, the preoperative function is the determinant of THA outcomes with the highest amount of evidence [40]. Likewise, the association between comorbidity and THA outcome in our patients is supported by several earlier observations [8, 41, 42]. A recent review shows a significant negative association between comorbidity and functional outcome in patients undertaking THA in almost all studies under review (11/13 studies) [40].

In the present study, the influence of other clinical variables including the stage of the disease, the time to THA and the side of the affected hip on functional outcome is not significant. Yang et al. (2023) found that patients with ARCO stage III had a significantly shorter operative time, hospital stay length, and reduced intraoperative bleeding volume [25]. Still, there were no significant differences in postoperative HHS ($p = 0.062$) compared with patients with ARCO stage IV [25]. Jones et al. (2001) have shown that time until surgery did not affect function at 6 months among patients with THA [42]. The literature review shows that bipolar THA has similar results to unipolar THA [43]. In other words, evidence in our study suggests that earlier operation in the disease process and better management of comorbidity should be implemented to improve THA outcomes in patients with advanced ANFH [7, 41. 44].

Limitation

Our study had some limitations. Firstly, the length of the follow-up after surgery is short (6 months). Nonetheless, previous observations suggest that most of the improvement in physical function occurs during the first six months following surgery [8] and remains the same for a long time [17, 44]. The second limitation is that hospital-related factors like the type and volume of the hospital have not been analyzed. However, our sample has typical demographic and clinical characteristics of patients with THA for ANFH, suggesting that determinants of the 6-month functional outcome in the current study could apply to other patients undergoing this surgery.

CONCLUSION

This study suggests that total hip arthroplasty for the treatment of avascular necrosis of the femoral head in Vietnam has good outcome. There is a significant association between pre-operative function and comorbidity and functional outcome. This data may be useful both for providing a precise prognosis and a more adequate intervention strategy, e.g. early operation in the course of functional decline and better management of comorbidity for patients with this debilitating disease.

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Information about the authors:

Khoa V. Vu — MD, bskhoavd@gmail.com;

Quang Nguyen — MD, quangnguyendr@gmail.com;

Lan T. P. Luong — MD, phuonglanlt.ump@vnu.edu.vn;

Thieu Q. Nguyen — MD, PhD, thieunq@gmail.com;

Loi B. Cao — MD, PhD, Associate Professor;

Anh T. Le — PhD, MD, Associate Professor, anh_lt@vmmu.edu.vn, https://orcid.org/0000-0002-4919-1739.

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Rapid recovery after total hip arthroplasty: direct anterior approach combined with PENG block and lateral cutaneous femoral nerve block

I.K. Eremin[1], A.A. Daniliyants[2]✉, N.A. Ermakova[1], U.A. Baysarov[1], Z.M. Molarishvili[1], N.A. Semenov[1], N.V. Zagorodniy[2,3]

[1] Fomin Michurinsky Clinic, Moscow, Russian Federation
[2] Patrice Lumumba Peoples' Friendship University of Russia, Moscow, Russian Federation
[3] National Medical Research Center of Traumatology and Orthopedics named after. N.N. Priorov, Moscow, Russian Federation

Corresponding author: Armen A. Daniliyants, armendts@mail.ru

Abstract

Introduction The "gold" standard for the treatment of late stages of coxarthrosis is total hip arthroplasty. Direct anterior approach (DAA) refers to minimally invasive surgical interventions in orthopaedics. Extended anesthetic measures in combination with low-traumatic surgical techniques may reduce postoperative pain and accelerate patient's recovery.

The **purpose** of the study was to compare the rate of recovery of patients after hip arthroplasty using DAA in combination with PENG block, lateral cutaneous femoral nerve (LCFN) block and without extended anesthetic measures.

Materials and methods A prospective randomized comparative clinical study was performed, which involved 62 patients divided into two groups: the study one (n = 29) and the control one (n = 33). In both groups, arthroplasty was performed using DAA. Patients of the study group underwent PENG block and LCFN block. The patients in the control group did not receive extended anesthesia. The evaluation criteria were pain assessment using the visual analogue scale (VAS), administration of painkillers, patient's mobility and the length of hospital stay.

Results The VAS score for pain in the study group were lower than in the control group after 6 hours — 3.7 (3.4; 4.1) and 4.3 (4.2; 4.8); 24 hours after surgery — 3.5 (3.3; 3.6) and 4.1 (3.9; 4.5) (p < 0.001). After 48 hours, the indices were comparable: 3.5 (3.1; 4.1) and 3.7 (3.6; 3.9) (p = 0.19). The rate of requests for pain relief in the first 24 hours was lower in the study group than in the control group: 2 (1; 2) and 3 (2; 3) cases (p = 0.003). The results of the manual muscle test after 6 hours and 24 hours were comparable (p > 0.05). The time interval between the end of the operation and the first walking on crutches was shorter in the study group — 3.1 hours (2.9; 3.4) and 3.98 hours (3.8; 4.2) (p < 0.001). The length of hospital stay was shorter in the study group: 1.5 (1.2; 2) and 2.5 (2; 3) days (p < 0.001).

Discussion Lower postoperative pain allows faster activation of patients, thus improving the results of the early rehabilitation period.

Conclusion The use of PENG block and LCFN block in arthroplasty with the use of DAA has clinical effectiveness in the first 24 hours, and helps to accelerate the postoperative recovery of patients.

Keywords: hip arthroplasty, direct anterior approach, lateral cutaneous femoral nerve block, PENG-block, extended anesthetic management

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INTRODUCTION

According to the literature, the incidence of coxarthrosis in the world population has been steadily increasing [1]. Aging, overweight and genetic predisposition are the most important factors in the development of degenerative processes in large joints of the lower extremities [2, 3]. Nelson A found that by the age of 85, one in four patients has a pronounced clinical picture of osteoarthritis in the hip joint (HJ), significantly worsening the patient's quality of life [4].

The "gold" standard for treating late stages of coxarthrosis is hip arthroplasty. According to Sloan et al., by year 2030, the annual number of such operations in the United States will reach 635 thousand [5]. At the same time, leading orthopaedists strive to improve the techniques of surgical interventions. Direct anterior approach may significantly reduce postoperative pain, speed up the start of rehabilitation, and reduce the length of the patient's stay in the hospital [6–8].

Postoperative pain syndrome is a common problem that slows down the rehabilitation process and patients often require the administration of opioid analgesics, which can contribute to the development of delirium, cause respiratory depression, constipation and urinary retention [9–11]. Against this background, regional methods of pain relief may reduce the recovery time and decrease the intensity of nociceptive impulses from the surgical intervention area [12]. The simplest and at the same time effective method of conduction anesthesia in hip arthroplasty is the blockade of the pericapsular group of nerves of the hip (PENG-block) [13–17]. This method of analgesia is commonly used in arthroscopy, primary and revision hip arthroplasty [18, 19]. Based on the fact that the blockade of the indicated nerves does not solve the problem of pain in the area of the postoperative wound, a number of researchers proposed to block the lateral cutaneous femoral nerve (LCFN), which is responsible for the sensitive innervation of the skin of its anterolateral region [20]. Later, it was proposed to combine the PENG-block and LCFN blockade in order to achieve a deeper analgesic effect [21].

Thus, the assessment of the practical effectiveness of these methods in hip arthroplasty prompted us to conduct this study.

The **purpose** of the study was to compare the recovery rate of patients after hip arthroplasty using direct anterior approach in combination with PENG block, lateral cutaneous femoral nerve block, and without extended anesthesia.

MATERIAL AND METHODS

Study design A prospective randomized comparative clinical study was performed. A total of 62 patients (28 men and 34 women) participated in the study, divided into 2 groups: the study (n = 29) and the control (n = 33) groups.

Inclusion criteria Primary patient selection was carried out according to the following inclusion criteria:

— male and female gender, age range from 18 to 85 years old;
— established diagnosis of idiopathic stage II–III coxarthrosis according to the classification of NS Kosinskaya; post-traumatic coxarthrosis without fracture of the anterior/posterior column;

dysplastic coxarthrosis in stage 1–2 according to the classification of J. Crowe; aseptic necrosis of the femoral head stage 3–5 according to the classification of Steinberg.

Final selection of patients for inclusion in the study was done following *exclusion criteria*:

— previous surgical treatment of the hip joint;

— defects of the femur such as destruction or absence of the medullary canal of the femur, making it impossible to correctly install the femoral component;

— chronic inflammation of any location requiring surgical debridement;

— anemia of any severity.

Study conditions The study was conducted at the department of traumatology and orthopaedics of the Fomin Clinic for one year (from January 2023 to January 2024). All subjects were randomized using a random number generator and assigned to either the main or control group. Randomization was performed by an independent investigator. Subsequently, all procedures were performed by one group of surgeons and one anaesthesiology team.

Surgical methods Patients of the study group underwent arthroplasty through a direct anterior approach (DAA) in combination with PENG block and LCFN block. Extended anaesthesia was performed in the following order: spinal anesthesia, PENG block, LCFN block. Patients of the control group underwent arthroplasty through the direct anterior approach without extended anesthesia. The technique of arthroplasty through DAA is described in detail by the authors of the study [22].

All patients received premedication in the following volume: cefazolin — 2 g diluted in 20 ml of 0.9 % NaCL intravenously; omez — 40 mg intravenously; tranexamic acid — 15 mg/kg intravenously; latran — 4 mg intravenously; dexamethasone — 8 mg intravenously; midazolam — 100 mcg/kg intravenously.

Methods of result evaluation The main criterion was pain severity in the postoperative period. Pain was assessed using the visual analog scale (VAS) on the day of hospitalization, as well as 6, 24, and 48 hours postsurgery.

The following indicators were also used as criteria for assessing the clinical effectiveness of the operation:

1) intake of pain-killers (ketorol, single dose — 0.3 mg/kg);

2) patient's mobility state:

- time to first walking with crutches, defined as the period between the end of surgery and the first time the patient was able to walk with crutches under the supervision of a physician;
- in patients who underwent regional blocks, the presence of quadriceps motor block was assessed using a manual muscle test, evaluated as:

  0 — absent contraction and movement of the muscle;

  1 — weak muscular contraction;

  2 — movements are performed only in the horizontal state;

3 — the patient is able to lift the limb independently, but without artificial resistance from the doctor;

4 — full range of motion, the patient is able to lift the limb with little resistance;

5 — normal mean statistic muscle power;

3) hospital stay since admission till discharge.

Criteria for patient's discharge from the hospital:

— readiness to return to everyday life: ability to dress independently, get out of bed, sit and get up from a chair/toilet, independent care of oneself, walk 70 m with crutches, pain level according to VAS lower than 3 points;

— correct position of the implant components in the postoperative checking radiograph;

— absence of ECG rhythm disturbances and pathological changes;

— CBC values within reference range;

Complications A complication was defined as any unexpected event occurring during the entire surgical procedure or in the postoperative period, manifested by a local or systemic response that may prolong the patient's hospital stay or impair hip joint function.

Statistical methods Statistical analysis was performed using Jamovi 2.4.11. Quantitative indicators were assessed for compliance with the normal distribution using the Shapiro – Wilk test. Since all the studied characteristics in both groups had a distribution different from normal, quantitative data were described using the median (Me) and interquartile range. Categorical data were described using absolute values and percentages. Comparison of two groups by a quantitative indicator whose distribution differed from normal was performed using the Mann – Whitney U test. Comparison of two groups by a qualitative indicator whose distribution differed from normal was performed using the Spearman chi-square test. Differences were considered reliable at statistical significance $p \leqslant 0.05$.

RESULTS

The study did not reveal statistical differences between the two groups in regard to gender, age, BMI, and distribution of the sides of the intervention (Table 1). Thus, the absence of statistical differences in the studied groups allows for their further analysis.

VAS pain scores in the patients who received extended anaesthesia were lower than in the control group at 6 and 24 hours after surgery ($p < 0.001$). However, after 48 hours, the pain scores were comparable ($p = 0.213$) (Table 2).

Table 1

Baseline characteristics of patients who participated in the study

Parameter	Study group ($n = 29$)	Control group ($n = 33$)	p
Age, years	64 (58; 68)	66 (64; 72)	0.074*
BMI	32.4 (29.8; 34.1)	30.8 (28.9; 33.5)	0.413*
Affected side (right/left), abs	16/13	15/18	0.961**
Gender (M/F), abs	13/16	15/18	0.961**

Note: method used: * — Mann – Whitney U test; ** — Spearman's chi-square test

Table 2

VAS score for pain in the groups after 6, 24 and 48 hours

Group	VAS score, Me (Q1; Q3)		
	after 6 h	After 24 h	after 48 h
Study group	3.7 (3.4; 4.1)	3.5 (3.3; 3.6)	3.5 (3.1; 4.1)
Control	4.3 (4.2; 4.8)	4.1 (3.9; 4.5)	3.7 (3.6; 3.9)

Note: method used: median (Me) and interquartile range (Q1; Q3).

The total number of patients' requests for pain relief during the first 24 hours after arthroplasty was lower in the study group — 2 (1; 2) cases, compared to the control group — 3 (2; 3) cases ($p = 0.003$).

No postoperative motor blockade of the quadriceps femoris was recorded in either group. The results of the manual muscle test after surgery were comparable: after 6 hours — 3 (2.5; 3) and 3 (2; 3), after 24 hours — 5 (4.5; 5) and 5 (4; 5) in the study and control groups, respectively ($p > 0.05$).

The time interval between the end of the operation and the first walking on crutches was shorter in the study group compared to the control group: 3.1 hours (2.9; 3.4) and 3.98 hours (3.8; 4.2), respectively ($p < 0.001$).

The length of hospital stay was shorter in the study group compared to the control group: 1.5 (1.2; 2) days and 2.5 (2; 3) days, respectively ($p < 0.001$).

In both groups, no complications associated with extended regional anaesthesia or THA performance through the DAA were recorded. In neither group was it necessary to prescribe opioid analgesics.

DISCUSSION

We believe that the longer analgesic effect in patients of the study group was due to the peripheral block of the sensory branches of the femoral and obturator nerves innervating the hip joint capsule. At the same time, during the study, it became clear that after 48 hours, afferent impulses of this group of nerves restore, and the analgesic effect ceases. The advantage of this technique compared to other existing regional blockades of this area is the absence of a motor block of the quadriceps muscle of the thigh, which is also confirmed in this work. The results obtained are consistent with the literature data and the conclusions of randomized clinical trials conducted by Pascarella et al., Hu et al. and Zheng et al. [9, 23–28].

Low pain levels immediately after surgery allow patients to be out of bed faster, thereby reducing the time interval between the end of surgery and the first walking on crutches. We believe that rapid mobilization of patients after THA has a positive effect on both the early postoperative rehabilitation period and the patient's satisfaction with surgical treatment. The ability of patients to stand up independently, move around with crutches, and take care of themselves in the first hours after surgery reduces the need for urinary catheters and allows the use of diapers, which reduces the risk of genitourinary infection. Another advantage of an active early rehabilitation period is the absence of the need to prescribe compression stockings and elastic bandages to patients without concomitant cardiovascular pathology.

In our study, we found that the length of hospital stay of patients in the study group was one day

shorter than that of the patients in the comparison group. This is due to the fact that low pain syndrome and rapid postoperative recovery of patients allowed them to achieve the discharge criteria after THA described by Wainwright et al [29] more quickly.

Our work revealed a decrease in the rate of taking nonsteroidal anti-inflammatory drugs in the first 24 hours after surgery in the patients of the study group, which is due to the continuing analgesic effect of the regional anesthesia. Results comparable to those obtained by us were demonstrated in a randomized clinical trial conducted by Liang et al [30].

CONCLUSION

The study allows us to conclude that the use of PENG-block in combination with the LCFN block during hip arthroplasty through the DAA has a clinical advantage in the first 24 hours of the postoperative period compared to the performance of THA through the DAA without extended anaesthesia. The obtained data allow us to consider the use of extended anaesthesia in THA through the DAA as an additional way to achieve a faster postoperative recovery of patients.

Conflict of interest *The authors declare no obvious or potential conflicts of interest related to the publication of this study.*

Funding *The authors declare no external funding for the study.*

Ethical statement *All manipulations performed in the study involving people complied with the standards of the local ethics committee, as well as the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Formal consent from the local ethics committee is not required for this type of study.*

Informed voluntary consent *was obtained.*

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Information about the authors:

Ivan K. Eremin — orthopaedic surgeon, eremindoctor@yandex.ru, https://orcid.org/0000-0002-0992-0706;

Armen A. Daniliyants — resident, armendts@mail.ru, https://orcid.org/0000-0001-6692-0975;

Natalya A. Ermakova — anesthesiologist-reanimatologist, Head of the Department, dr.anesthesiaandreevna@gmail.com, https://orcid.org/0009-0001-6084-0082;

Usman A. Baysarov — orthopaedic surgeon, maas_zn@mail.ru, https://orcid.org/0009-0003-9434-8736;

Zurab M. Molarishvili — orthopaedic surgeon, zurab2mail.ru@gmail.com, https://orcid.org/0009-0006-8436-8575;

Nikita A. Semenov — orthopaedic surgeon, senikitaal@gmail.com, https://orcid.org/0009-0006-5818-9063;

Nikolay V. Zagorodniy — Doctor of Medical Sciences, Professor, Corresponding Member of the Russian Academy of Sciences, Head of the Department, zagorodniy51@mail.ru, https://orcid.org/0000-0002-6736-9772.

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Clinical, functional and neuropsychological status of joint replacement patients

A.H. Dzhigkaev[1,2], A.M. Tynterova[2], I.I. Kozenkov[2], E.V. Khaibulin[2], E.V. Trofimova[2], K.Yu. Popadin[2], K.V. Gunbin[2], A.G. Goncharov[2]✉

[1] Federal Center for High Medical Technologies, Kaliningrad, Russian Federation
[2] Immanuel Kant Baltic Federal University, Kaliningrad, Russian Federation

Corresponding author: Andrey G. Goncharov, agoncharov59@mail.ru

Abstract

Introduction The number of hip and knee replacement surgeries is increasing annually in Russia and worldwide. The majority of patients receiving joint arthroplasties are elderly women.

The **objective** was to assess the clinical, functional and neuropsychological status of patients undergoing total knee or hip replacement.

Material and methods The study included 448 patients admitted for elective surgery of total knee or hip replacement at the Department of Traumatology and Orthopedics of the Federal Center for High Medical Technologies (CHMT, Kaliningrad Region). Anthropometric parameters of the patients were measured, the medical history and concomitant diseases recorded. Common blood count and biochemistry test were evaluated preoperatively. Neuropsychological examination included assessment of cognitive and executive functions, levels of distress, depression, anxiety and somatization.

Results Almost all patients studied were found to have varying degrees of obesity. A typical combination of concomitant pathology in volunteers was stage 2 hypertension, risk degree 2–3, and chronic gastritis in remission. Half of the volunteers showed moderate and high levels of distress, depression, anxiety and somatization. A significant number of volunteers showed moderate to high levels of cognitive decline. Age- and sex-related blood counts were slightly different from the normal ranges for a CBC and biochemistry. Changes in leukocyte count were detected.

Discussion Leukocyte counts indicated the osteoarthritis induced inflammatory process in most patients. Mitochondrial dysfunction and aging of the immune system contributed to the "proinflammatory status." The high rate of cognitive impairment in volunteers was associated with age and comorbidity, cardiovascular conditions, in particular. Distress and anxiety were associated with emotional reactions to surgery.

Conclusion The factors reported can affect the duration and course of rehabilitation. The "pro-inflammatory status" of patients can complicate the healing of a postoperative wound. Neuropsychological disorders noted during postoperative rehabilitation can have a significant impact on physical recovery, social and professional adaptation.

Keywords: orthopedics, osteoarthritis, joint replacement, clinical, functional and neuropsychological status of patients

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INTRODUCTION

Osteoarthritis (OA) is a group of heterogeneous polyetiological diseases of the joints and one of the major causes of disability in elderly. The prevalence of osteoarthritis (OA) increases with age and the disease is diagnosed in adults over the age of 85 years of age in 85–90 % [1]. As osteoporosis, OA is classified as an age-associated disease. OA primarily affects articular cartilage and involves the entire joint, including the subchondral bone, synovial membrane, menisci and periarticular structures. The pathogenesis of primary gonarthrosis/coxarthrosis is associated with chronic, age-associated inflammation, leading to the accumulated injury in organs and tissues [2]. Mitochondrial dysfunction developing with age and leading to caspase-1-dependent production of pro-inflammatory interleukins-1β (IL-1β) and 18 (IL-18) contributes to the "pro-inflammatory status" of patients [3]. Anti-inflammatory therapy aimed at stabilizing the degenerative process can be practical in the early stages of OA [4, 5]. Surgical methods are used to treat patients with the condition when anti-inflammatory therapy for OA fails. Total replacement of the knee or hip joints is commonly used in the terminal stage of arthrosis. More than 2 million (in the Russian Federation about 150 thousand) operations are performed annually worldwide and the procedures are expected to increase in the future [6]. Joint replacement surgeries are normally performed for elderly and the majority are women. With the high social role of OA associated with disability, the projected increase in the number of joint replacement surgeries, and specific gender and age of patients, it is important to explore clinical, socio-psychological and cognitive status of candidates for surgical joint replacement. The data may improve management of the patients and rehabilitation.

The **objective** of the study was to evaluate clinical, functional and neuropsychological status of patients admitted for total knee or hip replacement.

MATERIAL AND METHODS

Cohort of patients

The study included 448 patients diagnosed with post-traumatic or primary grade 3 gonarthrosis/coxarthrosis. The diagnosis was based on complaints, clinical manifestations and radiological findings. The surgical intervention was performed using a standard technique of TKA with PMMA-based bone cements. Hip joint implants fixation was dependent on age, bone density and individual structural features of the acetabulum and femoral canal and produced using three techniques. Smith & Nephew (USA), Zimmer (USA) TKA replacement systems were used for the patients. Smith & Nephew (USA), Zimmer (USA), Aesculap (Germany) replacement systems were employed for hip procedures. Surgeries were performed using combined epidural anesthesia (neuraxial anesthesia). The postoperative period was uneventful with no complications recorded. Patients were discharged from the hospital after 7 or 8 days.

The mean age of the patients was 64.77 ± 10.29 years. There were 46.13 % of patients aged 65 years and younger and 53.87 % aged over 65. The examinees were volunteers aged from 50 to 70 years (59.73 %). There were 68.88 % female and 31.12 % male patients.

Methods of investigation

Patients were measured for height, weight, blood pressure, heart rate and respiration in the department, and the concomitant diseases and professional status recorded in the medical history. Muscle strength was measured using standard methods with a digital hand dynamometer MEGEON 34090 with 0.1 kg precision.

Preoperative laboratory findings included CBC and biochemistry blood count. Leukocyte count was additionally tested in the patients [7]:

1) SIRI (Systemic Inflammation Response Index) = abs. number of neutrophils × abs. monocyte count ÷ abs. lymphocyte count;
2) SII (Systemic Inflammation Index) = neutrophil count × platelet count ÷ lymphocyte count;
3) AISI (Aggregate Inflammation Systemic Index) = neutrophil count × monocyte count × platelet count ÷ lymphocyte count;
4) IIR (Immunoreactivity Index). When using the immunoreactivity index (IIR Index), the sum of % eosinophils and % blood lymphocytes is measured and divided by the number of % monocytes;
5) Leukocyte intoxication index (LII) according to V.K. Ostrovsky = (number of myelocytes in % + young neutrophils in % + band neutrophils in % + segmented neutrophils in % + plasma cells in %) / (monocytes in % + number of lymphocytes % + eosinophils in %+ basophils in %));
6) Allergy index (AI) = (lymphocyte count in % +10 × (eosinophil count in % +1)) / (neutrophil count in % + monocyte count in +basophil count in %).

A neuropsychological study to explore cognitive function was produced after 4–6 days of surgery. The overall score of cognitive decline was verified in accordance with the Montreal Cognitive Assessment (MoCA). Episodic memory was examined by repetition of 10 words (Luria test). The word-color interference technique was used to assess executive function with the Stroop test. Language function was examined using MoCA subscales (tests for repetition of two syntactically complex sentences, verbal fluency) and assessment of semantic information processing (idiom comprehension). A test for studying subject gnosis (Boston Naming Test) was used to measure confrontation naming ability. Constructive praxis (test of drawing 4 geometric figures) and ideational praxis (performing complex movements including a series of simple actions) was performed to assess praxis. The Bourdon Test was used to explore the level of attention. To objectify cognitive function, the patients underwent a neurophysiological evaluation of the amplitude and latency of acoustic endogenous evoked potentials (EP), P300 from symmetrical areas of the left and right hemispheres of the cerebral cortex in the frontal and central leads.

Topical representation of P300 (hippocampus, parietal, superior temporal and lateral orbitofrontal cortex) facilitated assessment of the redistribution of attention, the amount of working memory involved, executive function, cognitive “flexibility” in the “stimulus-task-response” chain, control of motor response to external stimuli.

The Encephalan-131-03 hardware complex was usedTo amplify and average the EP. The level of distress, depression, anxiety and somatization was assessed using the Four-Dimensional Symptom Questionnaire (4DSQ).

Statistical analysis

Statistical processing of the data was produced using the standard application package SPSS Statistics V23.0 for Windows, Pandas and SciPy libraries. Quantitative parameters were assessed for compliance with normal distribution using the Kolmogorov–Smirnov test. Quantitative parameters with a normal distribution were described using arithmetic means (M) and standard deviations (SD), variables with a non-normal distribution were described using median values, the 1st and 3rd quartiles (Q1, Q3). The Spearman rank correlation coefficient was used to assess relationships between leukocyte indices.

RESULTS

Social and psychological characteristics of the study group

About 80 % of the volunteers were of retirement age and approximately 50 % continued their working career. In terms of the severity and intensity of working conditions, all types of professional activities of the volunteers were within the 1st (optimal) and 2nd (acceptable) classes of the labor process. Sixty-seven percent of the individuals were engaged in physical labor (earlier or at the time of the study), which implies an increased muscular load on the musculoskeletal system.

Persons engaged in physical labor could be structured as those preoccupied with mechanized labor (agricultural machine operators, drivers, welders, turners, equipment maintenance specialists) — 26 %, semi-automatic and automatic production (conveyor production workers) — 17 %, agricultural production workers (field farmers, greenhouse workers) — 24 %. Patients engaged in intellectual work (33 % of the study group) can be structured as: operators involved in managing technological processes and machines — 8 %, managers, teachers and university professors, accountants, salespeople — 12 %, creative workers (musicians, architects, designers, constructors) — 2 %, medical workers (doctors, nursing staff) — 11 %. Almost all subjects reported greater psycho-emotional stress during their working activities, which was confirmed by the results of neuropsychological testing in the present study. Analysis of the 4DSQ parameters revealed distress of high level in 16.67 % (> 20 points), moderate level (10–20 points) in 34.83 %, low level in the rest of the patients. A high level of depression (> 5 points) was identified in 13.22 % of patients, moderate level of depression (2–5 points) seen in 41.0 % of cases. Anxiety was registered in 51.32 % of patients and rated as a moderate level (8–12 points). Assessment of somatization revealed a high level (> 20 points) in 11.0 % of patients, and a moderate level (10–20 points) in 31.43 %.

Assessment of cognitive functions in volunteers of the study group

Cognitive impairment in the study cohort of patients was characterized by manifestations of moderate cognitive impairment (MoCA: 20–25 points) in 170 (37.91 %) patients. A cognitive function decreased to the level of dementia (MoCA < 20 points) was noted in 4.7 % of patients over the age of 65 years. Extensive neuropsychological testing demonstrated a predominant decrease in mnestic, regulatory and neurodynamic functions. Diagnosis of auditory-verbal memory (repetition of 10 words without interference) revealed a decrease in memory in 201 (44.93 %) patients to (6.28 ± 1.20) points (normally 7–10 words). The Stroop test revealed a reduced low level of executive function in 301 (67.24 %) patients to (11.34 ± 3.50) points (maximum 20 points). Speech function, mainly affecting aspects of speech fluency, was reduced in 115 (25.74 %) patients to (2.32 ± 2.6) points (normal 3 points), mainly in the patients older 65 years. Decrease in the semantic information processing to (2.5 ± 2.4) points (normal — 3 points) in 11.8 % of cases and perception to (22.61 ± 1.30) points (maximum value — 24 points) 14.35 % of patients was observed in patients over 65 years of age with overall MoCA cognitive decline <22 points. Constructive praxis was reduced to 4.3 points in 116 (25.93 %) patients which corresponded to inadequate copying of one figure out of four on average. Ideation praxis was reduced to 4.4 points in 102 (22.82 %) patients, which reflected failure to comply with one of the five proposed instructions. Attention was reduced in 43.99 % of patients and corresponded to 4.05 points (normal 5 points). A greater increase in latency of the P300 cognitive evoked potential, beyond the normal range (> 450 ms) was observed in the central (C3–A1) and frontal (F4–A2) leads in 53.4 % of patients with cognitive decline.

Concomitant diseases in volunteers of the study group

Concomitant conditions were identified in volunteers. Concomitant diseases were not recorded in medical histories of 67 (14.96 %) individuals out of 448 in addition to the main diagnosis of the knee or hip arthrosis). Blood circulation conditions were most common to include hypertension of varying

degrees and risk (75 %), coronary heart disease (14 %), varicose veins of the lower extremities (56 %), etc. Cardiovascular pathologies were recorded in 243 (54.2 %) patients. The second common comorbidities (53.8 % of patients) were related to the digestive system identified in 240 (53.6 %) patients. Various forms of gastritis were common among the diagnoses of this group of conditions (all patients underwent gastroscopy was produced for all patients prior to admission to the clinic). Diseases of the endocrine system, nutritional disorders and metabolic disorders were noted in 68 (17.8 %) patients, of which 46 (12.1 %) patients suffered from type 2 diabetes mellitus, 9 (2.2 %) from type 1 diabetes mellitus, 13 (3.5 %) patients had other endocrine pathologies. 24 patients (5.36 %) had a history of neoplasms (breast tumors, gastrointestinal polyps, etc.). 4.69 % of volunteers had genitourinary diseases, musculoskeletal diseases were recorded in 16 patients (3.58 %). Isolated cases of infectious diseases were identified in 9 (2.4 %) patients with chronic infectious hepatitis and respiratory diseases in remission. Some patients had diseases of the nervous system, blood diseases and ophthalmological diseases. Stage 2 hypertension, risk degree 2–3, and chronic gastritis in remission was the most typical combination of concomitant pathology in the volunteers.

Anthropometry

Almost all patients in the study group (more than 91.2 %) were diagnosed with varying degrees of obesity. The mean body mass index (BMI) measured 32.66 ± 2.54, which significantly exceeds the recommended normal values (*N* = 1.85–25.0). The excess weight has an impact on the cardiovascular and the musculoskeletal systems (primarily the knee and hip joints). Adipose tissue is a source of pro-inflammatory cytokines and can aggravate the course of the underlying disease [8]. The mean muscle strength of volunteers measured (47.42 ± 11.78) kg for men and (23.15 ± 7.29) kg for women, which corresponded to the standard indicators for residents of Russia (43.4 ± 11.1) kg (M), (27.6 ± 6.1) kg (W). Patients aged over 65 years showed the mean measurements being within the range for men (41.41 ± 10.57) kg, and for women (20.99 ± 6.67) kg, that were within the age norm (37.8 ± 10.0) and (24.8 ± 5.8) (in men and women, respectively). Among elderly patients, 7.4 % of men and 23.95 % of women had muscle strength levels below the "threshold values" (24 kg for men, 17 kg for women) [9]. Blood pressure was higher by 7–8 % on admission in 24.5 % of patients and measured 140–155 mm Hg. The frequency of respiratory movements and heart contractions were within the physiological norm and amounted to 14–18 breaths per minute, respectively. and 68–82 heart beats per minute.

Blood groups and CBC

The presence of one blood group or another in volunteers practically coincides with data on the distribution of blood groups among Russian citizens (https://dop-mosreg.ru/rasprostranennost-gruppy-krovi-v-rossii). In our series, 17.1 % had a negative Rh factor which was higher than the average statistical data for the Russian Federation (13.96 %). A note: 21.1 % residents of the Kaliningrad region have a negative Rh factor (data from the State Budgetary Healthcare Institution "Blood Transfusion Station of the Kaliningrad Region").

CBC slightly deviated from the indicators generally accepted for the gender and the age. Therefore, we attempted to conduct a comparative assessment based on "new" markers of systemic inflammation, which were essentially indices, calculated indicators of systemic inflammation (SIRI, AISI, SII, IIR), as well as hematological markers based on leukocyte counts and the subtypes (IA, LII). These indices can be calculated as part of CBC with a leukocyte formula, which makes them financially accessible in routine clinical practice and they are easily feasible. In recent years, it has been shown that these indices can accurately predict poor prognosis in patients with a wide variety of pathologies compared to hematological markers based on leukocyte counts and the subtypes (neutrophils, lymphocytes and monocytes) [10–15].

The median value of the systemic inflammatory response index (SIRI) in the study group was 0.68 units (Q1 of 0.46, Q3 of 1.03). Only 28.34 % of the individuals had this index being within the normal limits of 0.4–0.6 units; 14.06 % had the index below 0.4 units, and all other patients (57.6 %) had the index significantly exceeding the recommended values. Calculation of the cumulative systemic inflammation index (AISI) showed median of 170.95, Q1 of 109.23 and Q3 of 280.81. AISI exceeded the normative values (51.10–125.57 units) in 67.05 % of volunteers. AISI was within the physiological norm in 28.8 % of patients and below it in 4.15 %. The systemic inflammation index (SII) in the study cohort showed median of 414.67, Q1 — 304.86, Q3 — 551.49. Standard values are 450–890 units and SII was within these limits in 28.11 % of volunteers. SII was above the normal values in 31.11 %, and the rest (40.76 %) had it below the lower limit of the norm. Normal values of the leukocyte intoxication index (LII), calculated as modified according to V.K. Ostrovsky, range from 1.0 to 1.6 units. A mild degree of endogenous intoxication corresponds to (2.8 ± 0.64) units, a moderate degree of (4.3 ± 1.5) units, a severe degree of (8.1 ± 0.34) units. The majority of patients (82.2 %) had mild or moderate intoxication, and 13.6 % had severe intoxication.

The index of immunoreactivity (IIR) showed median of 5.56, Q1 of 4.07, Q3 of 7.23. An increased IIR can be interpreted as an increase in immunological activity. The immunoreactivity index is normally 18.1–37.4; it was significantly reduced in the majority of patients (75.35 %). IIR was normal in 21.89 %, increased values were seen in 2.76 % of volunteers. These results are comparable with data on the allergenic index (AI). Eosinophil and lymphocyte counts increase in 56–86 % of cases during allergic reactions. Analysis of the blood count will allow you to derive an index to identify an allergic reaction, AI. AI fluctuations range from 0.68 to 1.08 in normal people and increase to 2.37–2.97 in patients with various forms of allergic reactions. In our series, the majority of patients had a reduced AI (median of 1.08, Q1 of 0.85, Q3 of 1.45), which was clinically confirmed by rare complaints about manifestations of the allergic syndrome. The median ESR in the volunteers measured 11.00 (Q1 of 7.00, Q3 of 20.00) and was within the age-sex limits of normative values.

Basic biochemical parameters in volunteers of the study group

A blood biochemistry test was performed for all patients on admission to the clinic in addition to CBC to assess functioning of internal organs. The level of creatinine was within the age-sex norm in almost all patients and averaged to (81.41 ± 21.82) μmol/l. The normal level of total bilirubin in adults is 3.4–17.1 μmol/l in women and 3.7–18.5 μmol/l in men. The mean bilirubin level in the study group measured (13.65 ± 6.69) μmol/l. Bilirubin level was higher in 18.2 % of patients and measured 30.5–40.6 μmol/l (median of 12.25, Q1 of 9.30, Q3 of 16.18). Similar results were obtained for transferases. The median of aspartate aminotransferase (AST) was 21.40 (Q1 of 17.10, Q3 of 27.95), the median of alanine aminotransferase (ALT) was 20.60 (Q1 of 16.00, Q3 of 28.85). Higher levels were observed in 10.7–14.84 % of volunteers. Some patients were diagnosed with type 2 diabetes mellitus and received therapy; only 15.5 % had elevated blood glucose levels measuring 10.0–12.5 mmol/l. The median was 5.65 mmol/l (Q1 of 5.20, Q3 of 6.39). The serum cholesterol level was mainly within the age norm measuring (5.80 ± 1.40) mmol/l,but 8.52 % of volunteers had hypercholesterolemia of more than 8.0 mmol/l. In general, the patients had no significant deviations in biochemical analysis and, accordingly, had no contraindications to surgical treatment.

DISCUSSION

Muscle strength measured during dynamometry can be below threshold values in some patients and can be a diagnostic criterion for sarcopenia [16] and are associated with an increased risk of death, primarily from cardiovascular diseases [9, 17, 18, 19]. The biochemical panel is important

due to the fact that surgical intervention is preceded by a preparation period (sometimes a long period) to include courses of therapy, physiotherapy, rehabilitation measures aimed at remission of comorbid diseases to be followed by THA/TKA surgery. The question of using leukocyte counts as indicators of the severity and course of the inflammatory process in patients with OA remains controversial. On the one hand, the study demonstrated significance of the markers associated with reference values of CBC. On the other hand, leukocyte count can be influenced by a long-term, sometimes uncontrolled, use of NSAIDs and the concomitant diseases associated with chronic inflammation including diabetes mellitus, obesity and some gastrointestinal diseases. In the study group, a decrease in the immune reactivity index was associated with high intoxication index and low AI values, possibly, due to significant doses of NSAID used for pain relief. The parameters are closely related to each other and are directly or inversely related. The strength of the connection on the Chaddock scale ranges from "noticeable" to "very high" ($p < 0.05$).

In general, the assessment of leukocyte indices indicated to a "pro-inflammatory status" in the volunteers and was characterized by increased production of pro-inflammatory cytokines. The levels of acute phase proteins, prostaglandins and coagulation factors increased to a lesser extent. At least three closely related groups of factors participate in the formation of the condition: mitochondrial dysfunction associated primarily with impaired mitophagy processes, chronic emotional stress, age-related inflammatory imbalance of the immune system. The age-related inflammatory status of the immune system can be explained by the fact that, the immune response with the inflammatory reaction as major protective mechanism becomes excessive during life. The changes are associated with chronic stimulation of the immune system, viruses and bacteria, altered microbiota, increased senescent cells, degradation products of the intercellular matrix and accumulation of adipose tissue with age leading to increased production of proinflammatory cytokines [20]. Age-associated mitochondrial dysfunction makes a significant contribution to the "proinflammatory status." It results in a disruption in the mitophagy process, the utilization of defective mitochondria. Incomplete removal of damaged mitochondria leads to hyperactivation of inflammatory signaling pathways and to chronic systemic inflammation and inflammatory diseases [21]. Mitochondrial dysfunction was explored previously on a small sample of volunteers (n=48 people) by the number of copies of the mitochondrial genome in postmitotic muscle cells.

Our series demonstrated that the critical threshold of mtDNA heteroplasmy was exceeded in a third of muscle samples, at which a pathological phenotype with noticeable biochemical abnormalities became dominant in the functioning of the oxidative phosphorylation system (OXPHOS) [22]. Chronic emotional stress, which is characterized by phase changes in the immune system contributes to the formation of a pro-inflammatory status. The production of anti-inflammatory cytokines (IL-10 and IL-13, TGF-β) increases at the initial stages due to decreased secretion of the pro-inflammatory group of cytokines (IL-1β, IL-6, TNF-α and IFN-γ). Then a mechanism of increased expression of inflammatory cytokine genes is launched after restructured activity of the nuclear cytoplasmic protein "kappa-B" (contained in T-lymphocytes, monocytes/macrophages) [23, 24]. Long-term (chronic) influence of stress factors leads to disruption of the homeostatic connection between the neuroendocrine and immune systems and to the development of a "pro-inflammatory status" [25, 26, 27]. In our case, impaired productivity due to significantly limited mobility and chronic pain was long-term stress factors. This was confirmed by manifestations of distress of varying severity diagnosed in the volunteers and was consistent with the studies reporting psycho-emotional disorders in patients with chronic pain of various etiologies [28, 29].

Cognitive deficit was characterized by moderate impairments in a third of patients and dementia in 4.7 % of cases, which corresponds to data from population studies demonstrating the prevalence of dementia of 6 % among people over 60 years of age and non-dementia disorders observed in 12 to 41 % [30, 31]. The wide representation of cognitive impairment in our series was associated with a number of reasons. First, the cognitive phenotype with predominantly impaired memory and regulatory functions is directly related to age (53.8 % of patients over 65 years of age) and is mediated by morphological and functional changes in the brain structures of elderly patients [32]. Secondly, comorbid pathology is important and was represented by endocrine (17.99 %) and cardiovascular (55.81 %) diseases as potential predictors of cognitive impairment, predominantly of a vascular nature with the manifestation of dysregulatory syndrome and decreased attention [33]. A psychoemotional disorder, characterized by a moderate level of affective disorders, somatization and distress was an important factor in the development and progression of cognitive deficits in half of the patients. Distress and anxiety are common in patients and associated with the preoperative emotional response and are reflected in the testing of cognitive flexibility and attention. The prevalence of speech, perceptual and semantic disorders, memory loss in elderly reflects the degenerative component of aging, characteristic of Alzheimer's disease and neurodegeneration [34, 35]. Larger cohort studies and standard neuroimaging examinations are needed to verify cognitive impairment of a degenerative or mixed nature. Lengthened P300 wave, along with the clinical phenotype of cognitive decline allows us to consider the parameters of P300 latency and amplitude as an objectifying method for assessing cognitive functions. Successful restoration of the function of the operated knee or hip joint relies on the quality of rehabilitation. Some factors reported may affect the duration and course of the recovery process. The factors include late adulthood and concomitant pathology, excess weight and greater weight on the operated joint, "pro-inflammatory status", characterized by the predominant serum pro-inflammatory cytokines, the presence of distress and cognitive impairment in some patients.

Rehabilitation for the volunteers should include preoperative preparation for rehabilitation and several stages of postoperative recovery. The main goal of the first (preoperative) stage is to improve blood circulation in the affected joint, increase muscle tone of the lower limbs, because many patients suffer from venous disorders of the lower limbs. Our patients spend an average of one day in the hospital before surgery and underwent appropriate physiotherapeutic procedures. Postoperative rehabilitation includes three stages with the duration of a year. At the first stage, the main task is to relieve pain and arrest infection. The new markers of systemic inflammation tested in this series were useful in predicting infection post surgery in individuals with surgical pathology [36, 37, 38, 39]. Their use requires further in-depth research, since the indices are calculated on the basis of CBC. The second and third stages of rehabilitation included postoperative physiotherapy, massage and kinesitherapy aimed at restoration of the joint function motivating the patient to actively participate in the rehabilitation process in order to return to a normal lifestyle. In recent years numerous studies exploring the impact of cognitive and psycho-emotional disorders on the postoperative functional motivational status of the patient reported a negative impact of such outcomes as depression, decline in motivation, distress, regulatory and mnestic dysfunction on the prognosis of restoration of the patient's physical condition, employment and social adaptation [40, 41, 42].

A high proportion of volunteers with impaired cognitive function and distress was observed in our series, and screening for cognitive and psycho-emotional disorders became an integral part of the preoperative preparation of patients and part of an elective surgical intervention. Neurophysiological and neuropsychological examination allowed us to assess the risk of persistent postoperative

cognitive disorders. The knowledge of the preoperative neuropsychological status can contribute to an accurate prediction of the risk of severe cognitive disorders at a short and long term. Verified cognitive and psychoemotional disorders upon admission of a patient for planned surgical treatment will allow optimizing postoperative rehabilitation methods and expanding the scope of recovery potential. The role of dynamometry and leukocyte counts revealed in the series is essential for planning studies aimed at verifying markers of systemic inflammation and muscle dysfunction in patients with osteoarthritis. The generated database will be further compared and analyzed with the results of assessing the level of heteroplasmy in mitochondrial DNA in the muscle tissue of our volunteers. The findings can be used to diagnose pathologies of elderly and for healthy aging.

CONCLUSION

Selective assessment of the clinical, functional and neuropsychological aspects of patients admitted for total knee or hip replacement allowed for identifying the major indicators that can effect the success of the postoperative rehabilitation in elderly patients. Those were dynamometry parameters below threshold values, excess body weight, decreased neuropsychological functions and a “pro-inflammatory status”.

Verified markers of various modalities, along with comorbid pathology, will allow us to formulate optimal diagnostic and therapeutic strategies for managing patients post surgery. Identified factors such as depression, distress and cognitive deficits, which would narrow the scope of recovery potential require the services of neuropsychological specialists to be involved in rehabilitation to correct the patient’s psychosomatic condition post surgery.

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Information about the authors:

Akhsarbek H. Dzhigkaev — Candidate of Medical Sciences, Head of Department, Associate Professor, dzigkaev.ah@kldcardio.ru, https://orcid.org/0009-0009-1637-1803, SPIN: 4072-9811;

Anastasia M. Tynterova — Candidate of Medical Sciences, Associate Professor of the Department, antynterova@mail.ru, https://orcid.org/0000-0003-1743-4713, SPIN: 2999-5812;

Ivan I. Kozenkov — Junior Researcher, ikozenkov@kantiana.ru, https://orcid.org/0000-0003-4706-4653, SPIN: 7377-2178;

Eldar V. Khaibulin — Research Assistant, khaibulin.98@mail.ru, https://orcid.org/0009-0009-8454-3734;

Elena V. Trofimova — Post-graduate student, Junior Researcher, trofim0va_elena@vk.com, https://orcid.org/0009-0003-9286-4374, SPIN: 3391-5198;

Konstantin Yu. Popadin — Candidate of Biological Sciences, Senior Researcher, konstantinpopadin@gmail.com, https://orcid.org/0000-0002-2117-6086, SPIN: 3029-4740;

Konstantin V. Gunbin — Candidate of Biological Sciences, Senior Researcher, genkvg@gmail.com, https://orcid.org/0000-0003-1851-8169, SPIN: 6638-9367;

Andrey G. Goncharov — Candidate of Medical Sciences, Senior Researcher, agoncharov59@mail.ru, https://orcid.org/0000-0001-6967-8838, SPIN: 7159-0402.

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Antibacterial effect of semiconductor laser radiation against the strains of *S. aureus* and *P. aeruginosa*, leading pathogens in osteomyelitis

I.V. Shipitsyna✉, **E.S. Spirkina**

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

Corresponding author: Irina V. Shipitsyna, ivschimik@mail.ru

Abstract

Introduction The study of the antibacterial effect of photodynamic therapy against the leading pathogens of chronic osteomyelitis is one of the promising directions today.

Purpose of the work was to evaluate the antibacterial effect against the strains of *Staphylococcus aureus* and *Pseudomonas aeruginosa* with the ALOD-01 laser system in the presence of photodithazine.

Materials and methods The object of the study was 24-hour archival cultures of gram-positive and gram-negative microorganisms belonging to two taxa: *Staphylococcus aureus* (25923), *Pseudomonas aeruginosa* (27853). The antibacterial effect after the exposure to laser radiation in the presence of photodithazine on the microbial cells of the studied cultures was assessed by the absence of microorganism growth in the area of the light beam.

Results Laser exposure in combination with photodithazine (concentration 0.5–1.0 mg/ml) on *S. aureus* for two minutes at 200–300 J achieved a bactericidal effect in the beam area. A bactericidal effect on the entire surface of the Petri dish was achieved with light exposure of 400 J for 5 minutes and a photodithazine concentration of 1.0 mg/ml. Laser exposure for 2 minutes in the presence of photodithazine at a concentration of 0.5 mg/ml and 1 mg/ml did not have an antibacterial effect on *P. aeruginosa* strains. Continuous growth of microorganisms was observed on the dish. Increasing the light dose and exposure time contributed to a decrease in the growth of microbial cells. A bactericidal effect was obtained only in the center of the dish in treating the bacterial suspension with photodithazine at a concentration of 5 mg/ml.

Discussion The effectiveness of PDT depends on the type of microorganisms, the anatomical location of the infection site, as well as the properties of the photosensitizer and the laser used. Depending on the structure of the cell wall, different susceptibility of bacteria to photodynamic effects is observed.

Conclusion *S. aureus* strains can be successfully photoinactivated using photodithazine. For *P. aeruginosa* strains, it was not possible to find a regime in which microbial cell growth was absent throughout the dish. The photodynamic reaction occurs only when adequate doses of light energy act on the photosentisizer in the presence of oxygen in the medium, while the photodynamic damage is local and the bactericidal effect is limited by the zone of light exposure.

Keywords: photodynamic therapy, photodithazine, chronic osteomyelitis, antimicrobial effect

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INTRODUCTION

The generally accepted method of treating chronic osteomyelitis is surgical. However, according to a number of authors, poor results in the treatment of patients with bone and joint pathology complicated by purulent infection are observed in 25–30 % of patients, relapses of the disease develop in 25–68 % of cases [1–4].

Bacterial infection plays a major role in the development of chronic osteomyelitis. Upon admission to hospital, gram-positive microorganisms, mainly *Staphylococcus aureus*, are most often isolated from the wounds of patients with chronic osteomyelitis. The joining of hospital microflora (*Pseudomonas aeruginosa, Enterobacter cloacae, Klebsiella pneumoniae*, and others) during treatment aggravates the course of the pathological process [4]. Standard antibacterial therapy is not always able to achieve complete elimination of the pathogen from the focus. In this regard, the search for new methods and means to achieve positive results in the treatment of this category of patients continues.

Currently, the photodynamic therapy (PDT) has been widely used in clinical practice. It is based on the use of photosensitizers (PS) and low-frequency laser radiation [5–8]. Singlet oxygen and free radicals are formed in microbial cells, which have a toxic effect on them [6]. The method is minimally invasive and non-toxic to healthy cells, which allows it to be used in various fields of medicine: oncology, gynecology, otolaryngology, and others. [9–22].

Since the most common agents of the wound microflora in patients with chronic osteomyelitis are *S. aureus* and *P. aeruginosa*, the study of the possibilities of using PDT as an alternative method to standard antibiotic therapy in the treatment of this category of patients can be considered relevant.

Purpose: to evaluate the antibacterial effect of ALOD-01 laser radiation in the presence of photoditazine against the strains of Staphylococcus aureus and Pseudomonas aeruginosa.

MATERIAL AND METHODS

The material for the study was 24-hour archival cultures of gram-positive and gram-negative microorganisms belonging to two taxa: *Staphylococcus aureus (No 25923), Pseudomonas aeruginosa (No 27853)*.

The experiment was conducted in two stages. In the first stage, the effect of light radiation using the ALOD-01 laser system (ALKOM Medica, Russia) (wavelength (λ) 660 nm, output power up to 3 W) on the viability of microbial cells in the absence of the drug was assessed. For this purpose, the surface of nutrient agar (Müller-Hinton Agar) in Petri dishes seeded with a lawn of 24-hour old cultures of the studied microorganisms with a certain concentration of microbial cells per 1 ml of meat-peptone broth (MPB) was exposed to a semiconductor laser for a time determined by the experiment. The parameters of laser radiation and the initial concentrations of cultures of the microorganisms are presented in Table 1. The result was assessed after 24 hours by the presence or absence of growth in the area of laser exposure.

At the second stage, a solution of photosensitizer (PS) with a known concentration was added to the suspension of 24-hourh cultures of the studied microorganisms. After 30 minutes, a lawn was made on the surface of the nutrient agar (Muller-Hinton Agar) and exposed to a semiconductor laser

light for a period of time determined by the experiment with specified radiation parameters (Table 2). Photoditzhaine is a second-generation photosensitizer intended for fluorescence diagnostics (FD) and PDT of malignant tumors.

Table 1

Laser radiation parameters

Time of exposure (t), min	Height of light guide (h), cm	Power of radiation (P), W	Targeted beam, %	Light dosage, J	Concentration of microbial cells per 1 ml	Volume of introduced suspension (V), ml
2	18	1.7	25	200	5×10^7	50
2	18	2.4	25	300	5×10^7	50
5	18	2.5	90	400	2×10^7	20
5	5	2.5	90	400	1×10^6	20

Table 2

Characteristics of study stages

Photodithazine concentration, mg/ml	Time of exposure (t), min	Volume ratio (V)	Light dosage, J	Height (h), cm	Radiation power (P), W	Targeted beam, %	Volume of introduced suspension (V), mcl	Concentration of microbial cells per 1 ml
0.5	2	1:1	300	18	1.7	25	50	5×10^7
1.0	2	1:1	200	18	2.4	25	50	5×10^7
1.0	2	1:1	200	18	1.7	25	50	5×10^7
1.0	5	1:1	300	5	2.5	90	50	2×10^7
1.0	5	1:1	400	18	2.5	90	50	1×10^6
1.0	5	1:2	400	18	2.5	90	50	1×10^6
1.0	5	1:3	400	18	2.5	90	50	1×10^6
5.0	5	1:3	400	5	2.5	90	50	1×10^6
1.0	5	1:3	400	5	2.5	90	50	1×10^6

The analysis of the obtained data was carried out with Gnumeric 1.12.17 software.

RESULTS

The light of the laser system targeted hon microbial cells of the studied cultures witout photoditazine did not have a bactericidal effect. Continuous growth of microorganisms was observed on Petri dishes (Table 3).

Exposure to laser light of *S. aureus* combined with photoditazine (concentration 0.5–1.0 mg/ml) for 2 min. at 200–300 J, achieved a bactericidal effect n the beam action zone (Table 4). The laser action was local. A slight growth of microbial cells was observed along the edges of the dish. A bactericidal effect on the entire surface of the Petri dish was achieved with a light exposure of 400 J for 5 min and a PS concentration of 1.0 mg/ml.

Table 3

Effect of the ALOD-01 semiconductor laser on microbial cells in the absence of PS

Laser effect without photodithazine	Time (t), min	Light dosage, J	Height (h), cm	Power (P), W	Targeted beam, %	Volume of introduced suspension (V), mcl	CFU/ml (MFar)	Results	
								S. aureus	*P. aeruginosa*
L –, PS –	–	–	–	–	–	50	0.5	Continuous growth	
L +, PS –	2	200	18	1.7	25	50	0.5		
L +, PS –	2	300	18	2.4	25	50	0.5		
L +, PS –	5	400	18	2.5	90	20	0.2		
L +, PS –	5	400	5	2.5	90	20	0.01		

Note: L — laser, PS — photosensitizer

Table 4

Effect of the ALOD-01 semiconductor laser radiation on archival cultures of *S. aureus* in the presence of photoditazine

Laser effect with photodithazine	Time (t), min	Light dosage, J	Height (h), cm	Power (P), W	Targeted beam, %	Suspension volume (V), mcl	CFU/ml (MFar)	Result
L+, PS+ 0.5 mg/ml (1:1)	2	200	18	1.7	25	50	0.5	No growth in the center, solitary colonies on the edges
L+, PS+ 1.0 mg/ml (1:1)	2	300	18	2.4	25	50	0.5	No growth in the zone of beam action, partial growth represented by several colonies
L+, PS+ 1.0 mg/ml(1:1)	2	200	18	1.7	25	50	0.5	
L+, PS+ 1.0 mg/ml (1:1)	5	300	5	2.5	90	50	0.02	
L+, PS+ 1.0 mg/ml (1:1)	5	400	18	2.5	90	50	0.01	Bactericidal effect

Note: L — laser, PS — photosensitizer

When the laser and photoditazine acted on microbial cultures of *P. aeruginosa*, the results were mixed depending on the radiation mode. Thus, laser exposure for two minutes in the presence of photoditazine at a concentration of 0.5 mg/ml and 1 mg/ml did not have any antibacterial effect. A continuous growth of microorganisms was observed on the dish. An increase in the light dose and exposure time contributed to a decrease in the growth of microbial cells (Table 5). A bactericidal effect was obtained in the center of the dish by treating the bacterial suspension with photodithazine at a concentration of 5 mg/ml. Single colonies were observed at the edges.

It was found that the ALOD-01 semiconductor laser exposure, regardless of the selected mode, did not have any antibacterial effect by itself. The use of the laser in combination with phhotoditazine significantly reduced the number of microbial cells, and in relation to *Staphylococcus aureus* strains contributed to a pronounced bactericidal effect (photoditazine concentration of 1.0 mg/ml and radiation dose of 400 J, exposure time of 2 min). For *Pseudomonas aeruginosa* strains, it was not possible to find a mode in which microbial cell growth was absent throughout the dish. However, the use of photoditazine at the maximum concentration (5 mg/ml), laser exposure time of 5 min and radiation dose of 400 J contributed to the pointed death of the microorganisms.

Table 5

Impact of the ALOD-01 semiconductor laser on archival cultures *P. aeruginosa* in the presence of photodithamine

Laser exposure in the presence of photodithazine	Time (t), min	Energy quantity, J	Height (h), cm	Power (P), W	Targeted beam, %	Volume of introduced suspension(V), mcl	CFU /ml (MFar)	Result
L+, PS+ 0.5 mg/ml (1:1)	2	200	18	1,7	25	50	0.5	Continuous growth
L+, PS+ 1.0 mg/ml (1:1)	2	300	18	2,4	25	50	0.5	Partial growth inhibition in the center
L+, PS+ 1.0 mg/ml (1:1)	2	200	18	1,7	25	50	0.5	
L+, PS+ 1.0 mg/ml (1:1)	5	300	5	2,5	90	50	0.02	Significant growth inhibition in the area of the beam action
L+, PS+ 1.0 mg/ml (1:1)	5	400	18	2,5	90	50	0.01	No growth in the area of highest drug concentration (diameter 10 mm)
L+, PS+ 1.0 mg/ml (1:2)	5	400	18	2,5	90	50	0.01	Sterile zone, diameter 12 mm
L+, PS+ 1.0 mg/ml (1:3)	5	400	18	2,5	90	50	0.01	
L+, PS+ 1.0 mg/ml (1:3)	5	400	5	2,5	90	50	0.01	Partial growth, single colonies in the center, continuous growth at the edges
L+, PS+ 5.0 mg/ml (1:1)	5	400	5	2,5	90	50	0.01	Sterile zone in the center, single colonies at the edges

Note: L — laser, PS — photosensitizer

DISCUSSION

The current problem of the spread of antibiotic-resistant strains contributes to the search for new methods and drugs for the treatment of purulent infections. Currently, PDT is one of the promising areas [9, 12, 14–16, 20–24]. An important advantage of this method over antibiotic therapy is the absence of toxicity of photosensitizers in relation to healthy tissues [5, 12, 20].

It has been established that the effectiveness of PDT depends on the type of microorganism, the anatomical location of the infection site, as well as on the properties of the photosensitizer and the laser system used [8, 13–17, 24–30]. The mechanisms of the impact of laser radiation on bacterial strains have not been fully studied [5, 25]. The different susceptibility of gram-negative and gram-positive bacteria to photodynamic effects is associated with the structure of their cell walls. The peptidoglycan layer of the bacterial cell wall of S. aureus has a much higher permeability (namely, for antibiotics) than the outer membrane of gram-negative bacteria.

In one of the works, the authors studied the effect of laser exposure on the growth of methicillin-resistant Staphylococcus aureus along with the use of dimegine. It was shown that with an increase in the dose

of photoexposure, there was a bacteriostatic effect [31]. Other authors proved the effectiveness of PDT using photodithazine as a photosensitizer in the treatment of inflammatory joint diseases in children and adolescents [9]. Chepurnaya et al used PDT in the treatment of purulent diseases of the hand. The authors noted a noticeable healing of postoperative wounds in the patients treated with PDT [15]. A technique for combined antimicrobial photodynamic therapy in surgery of purulent wounds has also been developed and its effectiveness has been proven [8, 14, 16, 32].

CONCLUSION

The study showed that archival strains of *S. aureus* can be successfully photoinactivated using photodithazine. The photodynamic reaction occurs only when adequate doses of light energy act on photosensitizers in the presence of oxygen in the environment. The photodynamic damage is local in nature, and the bactericidal effect is limited to the zone of light exposure.

Conflict of interest *The authors declare that there are no conflicts of interests.*

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Information about authors:

Irina V. Shipitsyna — Candidate of Biological Sciences, leading researcher, ivschimik@mail.ru, https://orcid.org/0000-0003-2012-3115;

Elena S. Spirkina — junior researcher, spirkina.82@mail.ru, https://orcid.org/0000-0003-2506-2657.

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The effect of zinc-containing calcium phosphate coating on the osseointegration of transcutaneous implants for limb prosthetics

M.V. Stogov[1]✉, A.A. Emanov[1], V.P. Kuznetsov[1,2], E.G. Komarova[3], E.N. Gorbach[1], E.A. Kireeva[1], T.V. Tolkacheva[3], Yu.P. Sharkeev[3]

[1] Ilizarov National Medical Research Centre for Traumatology and Orthopedics, Kurgan, Russian Federation
[2] Ural Federal University named after. the first President of Russia B.N. Yeltsin, Ekaterinburg, Russian Federation
[3] Institute of Strength Physics and Materials Science of Siberian Branch of Russian Academy of Sciences, Tomsk, Russian Federation

Corresponding author: Maksim V. Stogov, stogo_off@list.ru

Abstract

Introduction Increasing the integration of transcutaneous implants is an important goal for their application in clinical practice.

The **purpose** of the work was to evaluate the osseointegration of transcutaneous titanium implants with calcium-phosphate coating containing zinc ions.

Materials and methods The studies were performed on 12 male rabbits, who underwent implantation of an original implant into the tibial stump. After implantation, a compression device was installed on the bone, maintaining a load of 3.5 N for 5 weeks. Duration of observation was 26 weeks. The animals were divided into two groups: a control group (n = 6) with an implant without coating and an experimental group (*n* = 6) with a zinc-substituted calcium-phosphate coated implant.

Results The implant fell out in one case in animals from the control group; no cases of implant loss were noted in the experimental group. It was revealed that the weight concentration of Ca and P in all zones of the bone-implant block of the animals in the experimental group significantly exceeded similar indicators in the control group. In the control group, long-term persistence of high levels of C-reactive protein was noted, which was not observed in the experimental group.

Discussion This series of studies has shown that an implant with a zinc-modified calcium-phosphate coating exhibited a more effective integration, in contrast to an uncoated product. The absence of serious adverse reactions to the tested products indicates acceptable tolerability and safety of its use.

Conclusion The implants with a zinc-modified calcium-phosphate coating showed signs of more effective osseointegration compared to the product without additional coating.

Keywords: prosthetics, transcutaneous implant, osseointegration, calcium-phosphate coating

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INTRODUCTION

Transcutaneous osseointegration prosthetics is a developing method of treating patients with limb loss [1, 2]. Currently, along with the two-stage prosthetics technology, a one-stage procedure has been developed [3, 4], which requires new solutions to improve the osseointegration of the implanted part, since the problem of implant stability in a one-stage process is crutial [5]. Previously, we showed that effective osseointegration of transcutaneous implants in a one-stage procedure can be achieved through the use of additional implant fixing devices in combination with the ability of these devices to provide mechanical compression of the implant [6]. Another option for implementing a one-stage accelerated osseointegration protocol is the use of Press-Fit implants [7].

However, such approaches are insufficient for optimal osseointegration of implants in a single-stage procedure. Therefore, there is a need to develop additional technologies that stimulate the integration process of transcutaneous implants, including by modifying the surface of the implanted part [8, 9]. Thus, one of the ways to improve osseointegration of implants is to apply a bioinert oxide or bioactive calcium-phosphate coating to its surface [10]. Among the methods of applying coatings to titanium-based implants, the microarc oxidation method should be highlighted, which allows impregnating additional essential microelements into the coating composition, providing positive effects for osteogenesis. A number of studies have demonstrated a positive effect on osseointegration processes of introducing zinc, strontium and silicon ions into the calcium-phosphate coating [11–13].

The **purpose** of the work was to evaluate the osseointegration of transcutaneous titanium implants with calcium-phosphate coating containing zinc ions.

MATERIAL AND METHODS

Implants In this study, we used implants made of Ti6Al4V alloy for prosthetics of tubular bone stumps [14] (Fig. 1 a). A zinc-containing calcium-phosphate (CP) coating (Zn-CP) was applied to the working surface of the implant using the arc oxidation method (Fig. 1 b). The implants were made of Ti6Al4V powder with an average particle size of 23.5 μm manufactured by Advanced Powders&Coatings Inc. (Canada) using the selective laser melting method on an EOS EOSINT M 280 3D printer (Germany). The coatings were applied to the implants using a Micro-Arc 3.0 semi-industrial system.

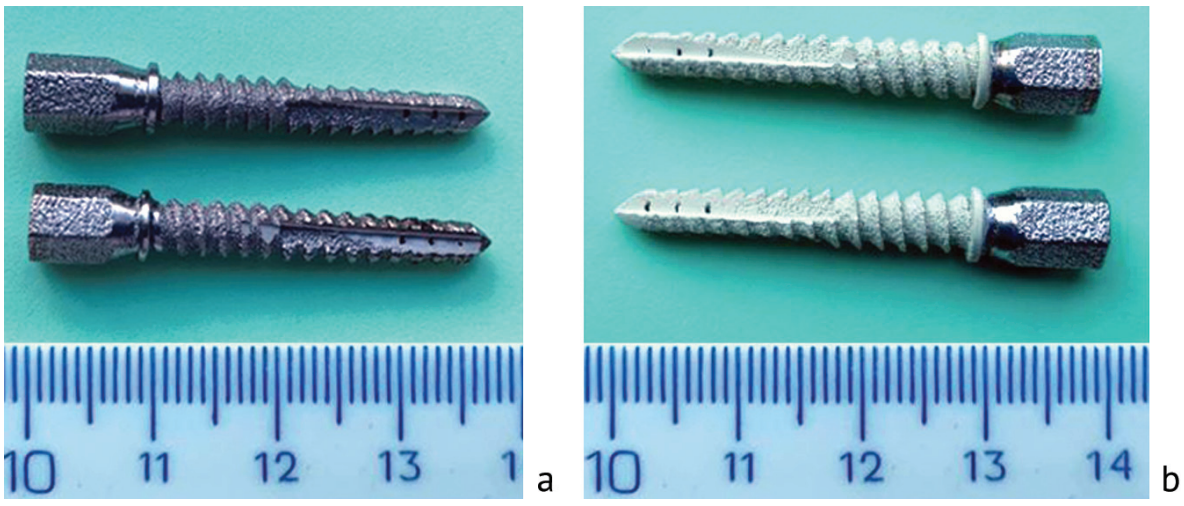

Fig. 1 Photos of implants: *a* without coating (control); *b* Zn-CP coated (experiment)

To apply the coatings, the implants were immersed in a bath with an electrolyte. The coatings were deposited in an electrolyte suspension of the following composition (wt %): H_3PO_4 — 27; $CaCO_3$ — 7; synthetic zinc-substituted hydroxyapatite (Zn-HA) ($Ca_{10}Zn_9(PO_4)_6(OH)_2$) — 5; the rest was distilled

water. Zn-HA in a nanocrystalline state with an average grain size of 30–50 μm was synthesized by a mechanochemical method at the Institute of Solid Body Chemistry and Mechanochemistry SB RAS [15]. The coating application parameters were: anode voltage — 200 V, pulse duration — 100 μs, pulse frequency — 50 Hz, treatment duration — 5 minutes. The coating thickness was determined using a Zubr digital micrometer (measurement accuracy of 1 μm). The coating mass was measured with CAS CAUX-220 analytical scales (measurement accuracy of 1 mg). The surface roughness was determined using a contact Profilometer-296 by the parameter Ra, as the root-mean-square deviation of the profile within the base length. The mass of the coatings formed on the implants was (29.3 ± 2.1) mg, the thickness was (33.5 ± 2.8) μm, and the roughness Ra was (2.3 ± 0.5) μm (Fig. 1 b). The morphology, structure, composition, and properties of the coatings were described in previous studies [11, 13].

All implants were delivered in individual packages, non-sterile. Before use, the implants were sterilized in a dry-heat oven at 180 °C for 1 hour. The maximum shelf life of the products before use was 6 months.

Study design in vivo The experiment was conducted on 12 male chinchilla rabbits aged 8 to 9 months, the average weight of the rabbits was (3.4 ± 0.2) kg. All rabbits underwent resection of the tibia at the border of the upper and middle thirds. After that, the bone marrow canal was processed with a drill; the implant was screwed into the stump of the tibia. The soft tissues were sutured layer by layer with internal sutures; a skin flap was formed in which an opening was made for the exit of a part of the implant to the outside. Then, a retaining compression device [16] with a fluoroplastic prosthesis was installed on the bone. The bone was subjected to a compression load of 3.5 N for 5 weeks. The observation continued 26 weeks. The animals were divided into two groups: group 1 (n = 6) animals had an uncoated product (control); group 2 (n = 6) animals had implants with zinc-substituted calcium-phosphate coating (experimental group). Clinical monitoring was carried out during the entire postoperative period. Attention was paid to the condition of the animals, thermometry, pulse, respiration, local status of the limb, condition of soft tissues, as well as postoperative wounds.

Regulating standards The study was performed in accordance with ISO 10993-1-2021. Medical devices. Biological evaluation of medical devices. Part 1: Risk management evaluation and testing; ISO 10993-6-2021. Medical devices. Biological evaluation of medical devices. Part 6: Local effects studies after implantation.

Ethical standards The study was conducted in compliance with the principles of humane treatment of laboratory animals in accordance with the requirements of the European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes and Directive 2010/63/EU of the European Parliament and of the Council of 22 September 2010 on the protection of animals used for scientific purposes. Prior to the start of the study, approval was obtained from the local ethics committee (protocol No. 1 (71) dated 28.04.2022).

Euthanasia Planned euthanasia was performed after muscle relaxation with a solution of 1 % diphenhydramine (0.02 mg/kg) and 2 % rometar (5 mg/kg), then a lethal dose of barbiturates was administered.

Radiographic, histological and biochemical studies were performed to determine the effectiveness of osseointegration.

Radiographic study A Compact X-ray machine (Italy) was used for radiographic study. X-ray examination of the involved limb was performed in craniocaudal and lateromedial views. Radiography was performed before and after surgery, at 5, 12, 26 weeks after implantation.

Histological study In euthanized animals, a layer-by-layer preparation of the soft tissues of the tibia stump with an intramedullary integrated implant was performed. The material was fixed in a 10 % solution of neutral formalin for at least 10 days. Then the bone-implantation block was sawed longitudinally, leaving the implant in one of the halves.

The bone fragment without the implanted product was demineralized in a mixture of formic and hydrochloric acid solutions, dehydrated in ethyl alcohol. After stages of impregnation in several portions of "liquid" 5 % celloidin, it was poured into thick 40 % celloidin and the blocks were compacted in chloroform.

Sections were prepared using a Reichard sledge microtome (Germany) and stained with hematoxylin and eosin, picro-fuchsin, and Masson's floating section method. Histological preparations were studied using an AxioScope.A1 stereomicroscope; digital images were obtained using an AxioCam ICc 5 digital camera.

The other part of the bone-implant block of the tibial stump was dehydrated, poured into camphene and dried in air until its complete sublimation. The dried preparations were sprayed with Pt in a special sprayer IB-6 (EICO, Japan).

Quantitative determination of the content of Ca and P (W, in weight %) in different areas of bone-implant blocks was performed by the method of energy-dispersive X-ray microanalysis using a BRUKER QUANTAX 200 — XFlash 6/10 spectrometer (Bruker Nano GmbH, Germany), complete with a scanning microscope (SEM) Zeiss EVO MA18 (Carl Zeiss Group, Germany). Analysis of quantitative indicators was carried out in the ESPRIT program (Bruker Nano GmbH, Germany).

Biochemical study included determination of the concentration of total protein, urea, creatinine, glucose, lactate, total calcium, inorganic phosphate, potassium, sodium, chlorides, C-reactive protein (CRP), as well as the activity of alkaline phosphatase (ALP) and tartrate-resistant (bone) isoenzyme of acid phosphatase (TrAP), creatine kinase, and transaminases in the blood serum. The studies were performed on an automatic biochemical analyzer Hitachi/BM 902 (Italy) using Vital Diagnostics and Vector-Best (Russia) reagent kits.

Statistical study The results in the tables are presented depending on the characteristics of the compared samples (normality was assessed using the Shapiro-Wilk criterion) either as the arithmetic mean and standard deviation (Xi ± SD), or as the median, 1–3 quartiles (Me, Q1–Q3). The procedure for statistically assessing the significance of differences in the parameters at the experimental stages with preoperative values was performed using the Wilcoxon W-test. The reliability of differences between the groups at the follow-up time-points was assessed using the nonparametric Mann-Whitney T-test. The minimum significance level (p) was taken to be 0.05.

RESULTS

Clinical monitoring of animals in the postoperative period showed that the condition of rabbits in all groups was satisfactory, there were no unplanned deaths. In the first three days, there was edema in the stump area in all the cases, and a decrease in appetite was noted. The dynamic function of the limb restored in all animals on the 4th–5th day after the operation. No soft tissue inflammation was noted. During the first week after dismantling the special device (6 weeks after implantation), implant loss was noted in one case in an animal of group 1, while there was no implant loss in the experimental group.

X-ray examination showed that in the animals of group 1, there were areas of resorption at the bone/implant junction 5 weeks after implantation, while in the animals of group 2, resoption signs were not detected (Fig. 2).

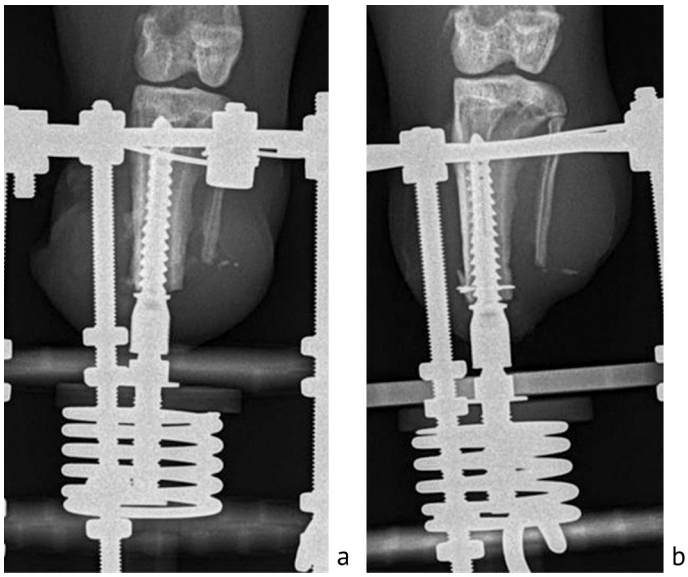

Fig. 2 Radiographs 5 weeks after implantation: *a* group 1; *b* group 2

After 12 weeks of implantation, signs of osseointegration were noted in both groups; resorption was not visualized, and minor periosteal layers were determined in the compaction stage (Fig. 3). At 26 weeks after implantation, complete organotypic reorganization of the bone in the peri-implant zone was noted (Fig. 4). However, in the animals of group 2, bone layers were in the compaction stage, located behind the limiting ring, which indicated an active bone integrative process at the bone-implant border (Fig. 4 b).

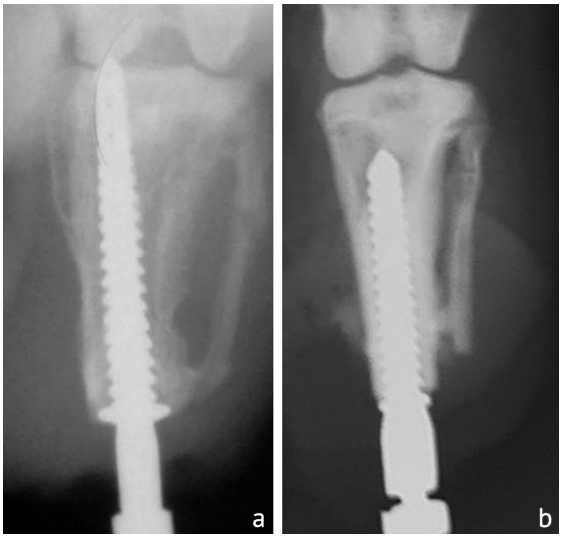

Fig. 3 Radiographs 12 weeks after implantation: *a* group 1; *b* group 2

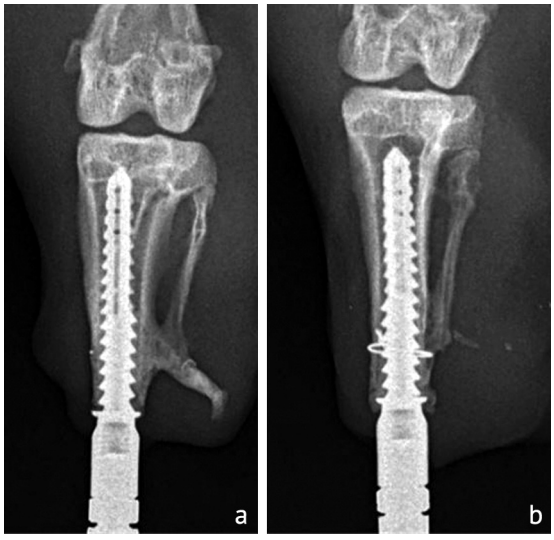

Fig. 2 Radiographs 26 weeks after implantation: *a* group 1; *b* group 2

Thus, in animals of group 2, the X-ray picture at all stages of the experiment revealed the presence of stability and the absence of resorption, what are positive signs of the osseointegration properties of the product.

Histological study In group 1, after 26 weeks of the experiment, a tight contact was observed between the implant surface and the bone tissue, and a single bone-implant block was formed. A continuous compact plate was preserved along the entire length of the bone stump. No pronounced periosteal stratifications were detected. In the distal and middle parts of the tibial stump, bone tissue ingrowth into the thread recesses of the implant was noted (Fig. 5).

Fig. 5 Bone-implant block formed in the animals of the control group by the 26th week of the study: *a* tibia of the rabbit with an intramedullary integrated implant (longitudinal cut); *b* longitudinal histotopographic section of the tibia of the rabbit after removal of the implant. Stained with picrofuchsin; magnification ×1.5

The histostructural characteristics of the tibial stump during the integration of theimplants in the experimental group after 26 weeks of the experiment revealed the preservation of the metaphyseal-epiphyseal part in the bed of the tibial stump and a continuous compact plate, which united with the surface of the implant in the metaepiphyseal region and in the proximal parts of the diaphysis with endosteally formed bone tissue of a medium lamella of trabecular structure. In the distal part, the compact plate tightly adjoined the implant. The presence of bone tissue was detected in the thread recesses of the implant (Fig. 6).

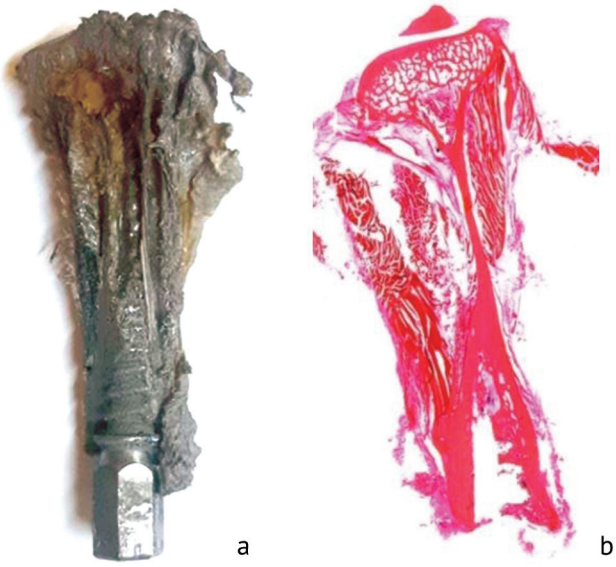

Fig. 6 Bone-implant block formed in the animals of the experimental group by the 26th week of the study: *a* tibia of the rabbit with an intramedullary integrated implant (longitudinal cut); *b* longitudinal histotopographic section of the tibia of the rabbit after removal of the implant. Stained with picrofuchsin; magnification ×1.5

Analysis of quantitative data on the content of osteotropic elements showed that after 26 weeks of the study in the substrate that formed on the surface of the implant in group 2 rabbits, calcium and phosphorus presence was significantly higher in all areas of the implant relative to the animals in the control group (Table 1).

Table 1

W (Ca) и W (P) in different parts of the tibial stump (Xi ± SD)

Study area	Ca, weight %		Phosphorus, weight %	
	Group 1	Group 2	Group 1	Group 2
Proximal	7.3 ± 0.4	15.1 ± 0.7*	3.6 ± 0.1	5.2 ± 0.3*
Middle	9.1 ± 0.3	15.3 ± 0.7*	4.6 ± 0.2	5.8 ± 0.2*
Distal	10.3 ± 0.3	13.2 ± 0.7*	4.5 ± 0.3	5.8 ± 0.4*
Intact animals	19.30 ± 0.91		8.12 ± 0.39	

Note: * — significant differences with group 1 (control) at $p < 0.05$

Thus, the histological study showed that the implant with a calcium-phosphate coating had more pronounced osteointegrative characteristics. In the distal part of the stump, an overgrowth of dense connective tissue was noted on the limiting ring structure and the structures of the implant preceding it, which contributed to the formation of an external barrier and prevented the development of intraosseous infection. A negative point is the imbibition of implant particles in the tissues bordering it.

Laboratory tests Changes in phosphatase activity and calcium and phosphate concentrations in the blood serum of experimental animals are presented in Table 2.

Table 2

Phosphatase activity, calcium and phosphate concentration in the blood serum of rabbits at the time-points (weeks) of the experiment, Me (Q1–Q3)

Week	Group	ALP, u/l	TrAP, u/l	Calcium, mmol/l	Phosphate, mmol/l
0	1	53 (48–63)	26 (22–26)	2.67 (2.61–2.70)	1.22 (1.14–1.34)
	2	54 (32–70)	28 (21–33)	2.69 (2.52–2.75)	1.34 (1.21–1.44)
3	1	42 (38–46)*	41 (35–42)*	2.78 (2.65–2.91)	1.31 (1.20–1.57)
	2	55 (47–63)^	29 (24–40)	2.75 (2.62–2.80)	1.14 (1.10–1.20)*
6	1	57 (49–69)	34 (29–38)*	2.65 (2.54–2.72)	1.34 (1.23–1.42)
	2	60 (53–65)	19 (17–21)*^	2.65 (2.60–2.71)	1.09 (1.07–1.18)*^
12	1	58 (45–66)	20 (16–28)	2.65 (2.57–2.73)	1.43 (1.42–1.45)
	2	46 (45–57)	24 (23–26)	2.51 (2.47–2.59)	1.04 (1.02–1.19)*^
26	1	61 (56–66)	20 (16–29)	2.71 (2.62–2.78)	1.39 (1.26–1.45)
	2	58 (42–63)	23 (22–28)	2.79 (2.55–2.83)	1.03 (0.98–1.14)*^

Note: * — differences with preoperative values (time-point 0), $p < 0.05$; ^ — differences with control group at $p < 0.05$.

It was found that in animals of group 1 (control), the activity of alkaline phosphatase relative to the preoperative level decreased at 3 weeks after implantation. In rabbits of group 2, an increase in the activity of alkaline phosphatase relative to the values before the operation was not noted, but alkaline phosphatase at 3 weeks was higher relative to the control group. The activity of TrAP at 3 and 6 weeks increased in the animals of the control group relative to the initial values. In group 2, a reliable decrease in the activity of TrAP at 6 weeks after implantation was noted both relative to the preoperative level and relative to the control group at that time. The concentration of total calcium in the blood serum of the experiment groups did not change statistically significantly either relative to the preoperative values or between the groups. In group 2, a decrease in the concentration of inorganic phosphate in the blood serum relative to the initial values and relative to the animals of the control group was noted at all stages of the experiment.

Significant differences in the dynamics of C-reactive protein (CRP) were noted (Table 3). Thus, significantly elevated CRP values in the control group (group 1) were observed up to week 26 of the experiment, and up to week 5 in group 2. In group 2, at week 26 of the experiment, a statistically significant decrease in lactate concentration was noted both relative to the initial, preoperative values, and relative to the values of the control group. Other biochemical parameters did not have reliable differences in both groups.

Table 3

Concentration of CRP and lactate in the blood serum of rabbits at the experimental time-points, Me (Q1–Q3)

Parameter	Group	Time-point (weeks) of the experiment				
		0	3	5	12	26
CRP mg/ml	1	0 (0–1)	13* (6–22)	10* (4–17)	2 (0–3)	4* (2–21)
	2	0 (0–1)	6* (2–14)	6* (5–10)	3 (0–4)	0 (0–2)
Lactate, mmol/l	1	9.5 (7.4–10.1)	10.4 (8.3–12.3)	9.0 (7.4–9.9)	8.8 (7.5–11.4)	10.5 (8.9–11.4)
	2	9.1 (7.5–10.8)	9.5 (7.8–10.2)	9.5 (8.1–10.0)	6.4 (4.9–7.8)	4.8*^ (2.7–7.5)

Note: * — differences with preoperative values (time-point 0), $p < 0.05$; ^ — differences with the control group at $p < 0.05$

DISCUSSION

One-stage osseointegration technology of transcutaneous implants is a promising method for solving bone prosthetics problems. A number of studies indicate that the transition to such a procedure helps improve the treatment results of target patients [17, 18]. The development of this version of transcutaneous osseointegration prosthetics technology lies in the direction of how to enhance osseointegration of the implant, ensuring its stability, resistance to infection and sufficient soft-tissue sealing around the outer part of the implant [19, 20].

Based on the available data, within the framework of the development of the methods of osseointegration stimulation, we evaluated a new implant for prosthetics of tubular bone stumps with a modified surface. It was found that the use of the implant with a Zn-containing CP-coating shows signs of improved integration in contrast to the product without such coating. Moreover, the implantation of the CP-coated product did not cause signs of rejection, intoxication (both local and systemic), systemic inflammatory reaction in the animals during the entire observation period. The absence of serious adverse reactions to the tested products allows us to conclude that all the studied implants have acceptable tolerability and safety.

Literature data on the assessment of the possibilities of increasing the integrative properties of implants with Zn-containing CP-coating are rather scarce. There is a work that also stresses the ability of such a coating to improve the osseointegration of metallic transcutaneous implants [21]. Nevertheless, the prospects of using such a coating are obvious, as evidenced by numerous data on improved osseointegration of CP-coated dental implants [22–24]. An additional factor in favor of using CP-coated products is that some studies indicate the ability of such coatings to reduce the inflammatory reaction and infection in the implantation zone [25, 26].

Further improvement of the osteointegrative characteristics of the developed product may be associated with an increase in the number of additional microelements in the composition of the CP-coating [27, 28], the use of implants with rapidly absorbable hydrogels loaded with antibiotics [29]. The possibility of applying biopolymer coatings to metal implants, especially to parts of the implant surface integrated with soft tissues [30], as well as the use of artificial polymers instead of titanium [31, 32] appears interesting.

It is obvious that the results we obtained have limitations in terms of the sample sizes of experimental animals. Extrapolation of the study results to clinical practice is possible, since the experimental model used is close to the clinical application model (single-stage prosthetics), including due to a sufficiently long observation period after implantation.

CONCLUSION

The use of implants with zinc-modified calcium-phosphate coating showed signs of more effective osseointegration compared to the product without additional coating. Such implants with a modified CP surface in the developed design, based on the obtained data on their effectiveness and safety, may be used for the tasks of prosthetics of small bone stumps in a single-stage prosthetics technology.

Conflict of interest *Not declared.*

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Information about the authors:

Maksim V. Stogov — Doctor of Biological Sciences, Associate Professor, Head of Department, stogo_off@list.ru, https://orcid.org/0000-0001-8516-8571;

Andrey A. Emanov — Candidate of Veterinary Sciences, Leading Researcher, a_eman@list.ru, https://orcid.org/0000-0003-2890-3597;

Viktor P. Kuznetsov — Doctor of Technical Sciences, Professor, Head of Laboratory, Professor of the Department, wpkuzn@mail.ru, https://orcid.org/0000-0001-8949-6345;

Ekaterina G. Komarova — Candidate of Technical Sciences, Researcher, katerina@ispms.ru, https://orcid.org/0000-0002-0903-6750;

Elena N. Gorbach — Candidate of Biological Sciences, Leading Researcher, gorbach.e@mail.ru, https://orcid.org/0000-0002-9516-7481;

Elena A. Kireeva — Candidate of Biological Sciences, Senior Researcher; ea_tkachuk@mail.ru, https://orcid.org/0000-0002-1006-5217;

Tatiana V. Tolkacheva — Leading Technologist, tolkacheva@ispms.ru; https://orcid.org/0000-0001-7125-484X;

Yurii P. Sharkeev — Doctor of Physical and Mathematical Sciences, Professor, Chief Researcher, sharkeev@ispms.ru, https://orcid.org/0000-0001-5037-245X.

Clinical case
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Lateral cortical notching for impaired healing of extra-articular proximal femur fractures (case report)

R.A. Shafigulin[2]✉, I.F. Akhtyamov[1], I.A. Aglyamov[2], A.A. Gornaev[2]

[1] Kazan State Medical University, Kazan, Russian Federation
[2] Republican Clinical Hospital, Kazan, Russian Federation

Corresponding author: Rashid A. Shafigulin, rashid 221@ yandex.ru

Abstract

Introduction Dynamization of the nail can be used to improve osteoreparation during intramedullary interlocking nailing (IIN). The procedure can be difficult to perform in some sub- and intertrochanteric femoral fractures due to anatomical and functional features.

The **objective** was to demonstrate a case of successful use of an original version of the lateral cortical notching (LCN) technique for dynamization of an intramedullary proximal nail in a patient with a nonunited subtrochanteric fracture.

Material and methods The treatment was performed for a 66-year-old patient with a non-united intertrochanteric fracture of the right femur complicated by the breakage of an intramedullary nail. The LCN technique was successfully used to dynamize the IM nail.

Results Radiological healing of the fracture and functional recovery of the patient were observed at a two-month follow-up. The absence of interfragmental compression in IIN could be caused by blocking of the sliding screw by the lateral cortical bone of the peripheral femur fragment. The complication could be prevented with LCN during primary osteosynthesis of the above fractures.

Discussion Based on scientific publications and our clinical experience, we assumed that LCN can be indicated for failed healing of intertrochanteric AO/OTA 31A3.1–3 fractures, type 3 Boyd and Griffin trochanteric fractures and all types of subtrochanteric fractures as graded by Seinsheimer with a vector of interfragmental compression to be created along the femur axis during cephalomedullary osteosynthesis. The case report showed the mechanism of impaired consolidation in some intertrochanteric and subtrochanteric fractures of the femur.

Conclusion The case report demonstrateed the successful use of the original version of the lateral cortical notching (LCN) technique for dynamization of an intramedullary proximal nail.

Keywords: subtrochanteric fracture, intramedullary nailing, lateral cortical notching

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INTRODUCTION

Treatment of proximal femur fractures can be associated with technical difficulties due to the anatomical and functional features and result in complications [1, 2]. Intramedullary nailing is an established treatment [3], however, despite the advanced technology and implant design, the method has limitations. Failure in fracture consolidation can lead to adverse events such as infection, loss of reduction, implant failure, etc. Pin dynamization is a standard method stimulating fracture consolidation with IM nail which involves removing the locking screw [4–10]. The technique can be impracticable in some extra-articular fractures. An original surgical technique of the lateral cortical notching (LCN) was offered to dynamize the pin during blocking intramedullary osteosynthesis (BIOS) and improve fracture consolidation. Analysis of literature sources in PubMed and Google Scholar indicated three foreign publications reporting the method applied in 9 cases that urged to present our own results.

The **objective** was to demonstrate a case of using original treatment using lateral corticotomy to dynamize an intramedullary proximal pin in a patient with a nonunited subtrochanteric fracture.

MATERIAL AND METHODS

We report the result of a patient treated at the trauma department No. 1 the Republican Clinical Hospital (Kazan). Victim S.,The 66-year-old man S. sustained a domestic injury in September 2021 from a fall from his own height. On the same day, he was admitted to the trauma department and diagnosed with a closed displaced intertrochanteric fracture of the right femur (AO/OTA 31A3.3; Boyd and Griffin type 3) (Fig. 1 a). The operation produced the next day included closed reduction, blocking intramedullary osteosynthesis of the subtrochanteric fracture of the left femur using a 10/360 DC pin in a dynamic way (Fig. 1 b, c).

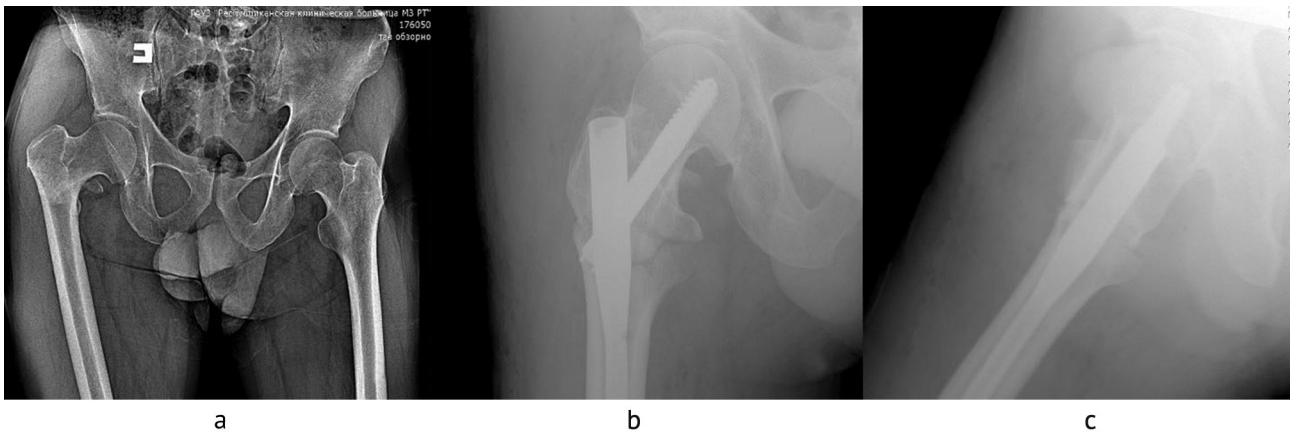

Fig 1 Radiographs of the fracture site: (*a*) AP view of the pelvis, showing intertrochanteric fracture of the right femur; (*b, c*) AP and axial views of the right hip joint, cephalomedullary osteosynthesis of the intertrochanteric fracture

The patient was verticalized at two days and began to ambulate using a walker. The postoperative period was uneventful. He was followed up at the emergency room at his place of residence. The patient was allowed to walk without additional support at 12 weeks. With fully restored limb function the patient experienced sharp pain in the right hip joint, lameness and gradual shortening

of the lower limb at nine months for which he sought medical help. Radiological examination of the hip joint was performed at the hospital. An AP view of the right hip showed a non-united intertrochanteric fracture and a broken intramedullary nail at the dynamic screw hole and the patient was readmitted to the hospital (Fig. 2 a). Although the distal blocking was performed in a dynamic way, the nail was not dynamized. The screws and broken nail were removed under regional anesthesia after appropriate examination. Broken fragments of the intramedullary nail were removed using an original technique developed in our clinic [11]. A conical Shants-type nail with cortical thread was screwed into the channel of the distal fragment of the broken pin with the impaction after removal of the proximal fragment. The nailing fragment was removed cranially after removal of the distal locking screws. Reduction was performed on an orthopedic table, and a new DC 10/360 proximal femoral nail was placed. The implant size was similar to the size of the previous one. The cervical screw was positioned in the previous channel to ease the procedure and trauma. The nail was locked using a dynamic method. Considering the fact that the outer end of the dynamic screw passed through the cortical layer of the peripheral fragment to prevent dynamization of the pin, the lateral corticotomy was performed under the dynamic screw (Fig. 2 b, c).

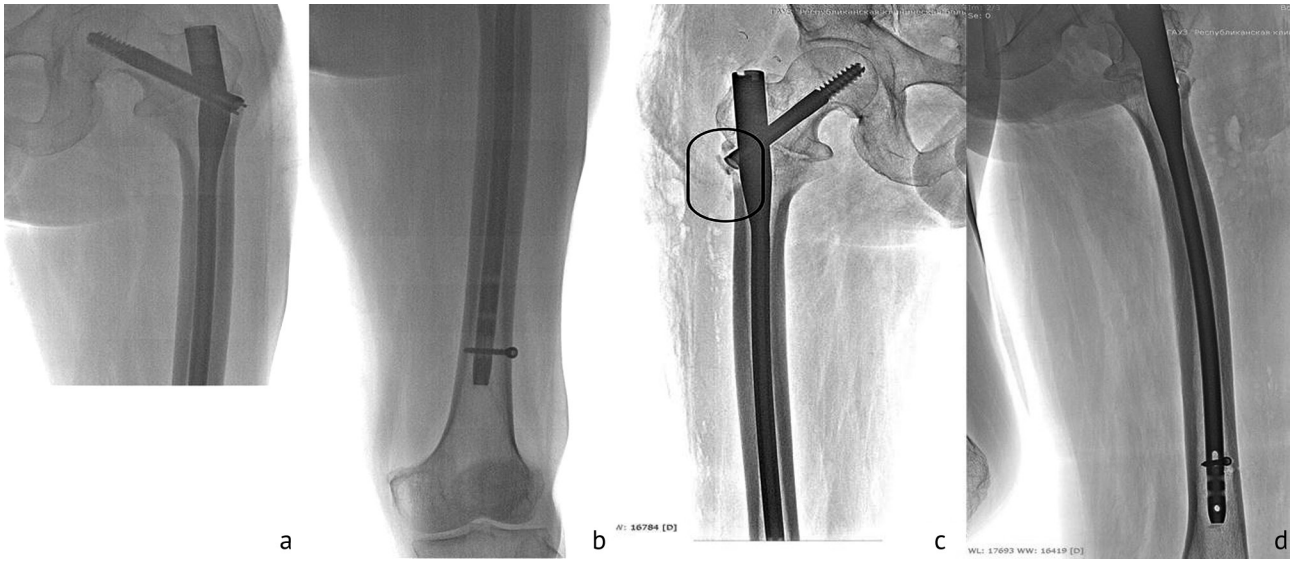

Fig. 2 Radiographs of the patient's hip joint showing (*a, b*) failed union of intertrochanteric fracture and deformed nail on preoperative AP view; (*c*) cephalomedullary reosteosynthesis of the intertrochanteric fracture, the lateral corticotomy of the femur under the entry point of the dynamic screw circled with an oval on the AP view; (*d*) cephalomedullary reosteosynthesis of the non-united intertrochanteric fracture of the femur on the axial view

In contrast to the original technique described in the literature, where a chisel with expanded surgical access is used to perform the corticotomy, we did not expand the surgical wound after dismantling the guide. The wire was placed along the channel of the dynamic screw, and a guide bushing made from a standard set of femoral pins was installed along onto the screw. A similar sleeve was placed parallel to the previous one and the wire was mounted in the lateral cortical layer of the femur using image intensifier. A corticotomy was performed using a drill along the wire to form a canal in the femoral neck. The next day the patient was verticalized and could walk using a cane. Postoperative period was uneventful and the patient was discharged from the hospital after five days to receive outpatient treatment.

RESULTS

The patient reported no complaints and could ambulate unassisted without additional devices at two-month follow-up and was radiologically diagnosed with healing intertrochanteric fracture of the right femur (Fig. 3 a). He had equal length of the lower limbs with no limitations in the range of motion in the joints of the target limb (Fig. 3 b, c).

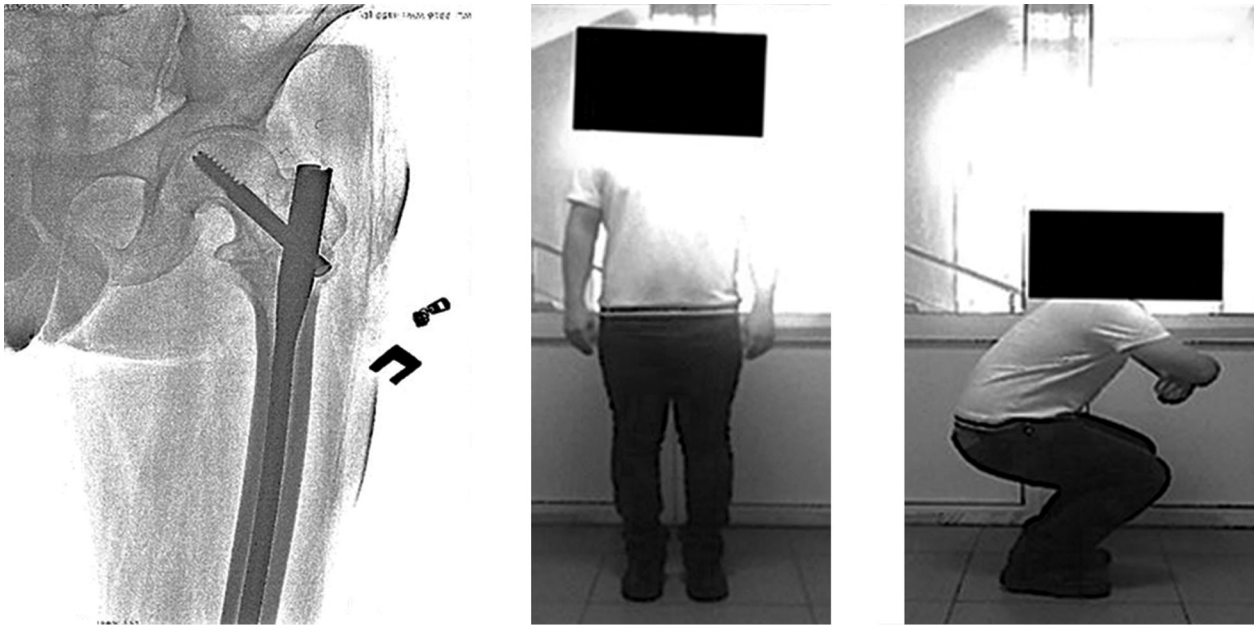

Fig. 3 The result of the treatment: (*a*) AP view of the hip joint showing healing intertrochanteric fracture fixed with a proximal femoral nail; (*b, c*) photo of the patient showing functional result with equal length of the lower limbs and range of motion restored in the joints of the lower limbs

Radiographs of the right femur were produced at 23 months of revision surgery (Fig. 4). The patient reported no complaints; the limb functions being completely restored with intertrochanteric fracture of the right femur consolidated.

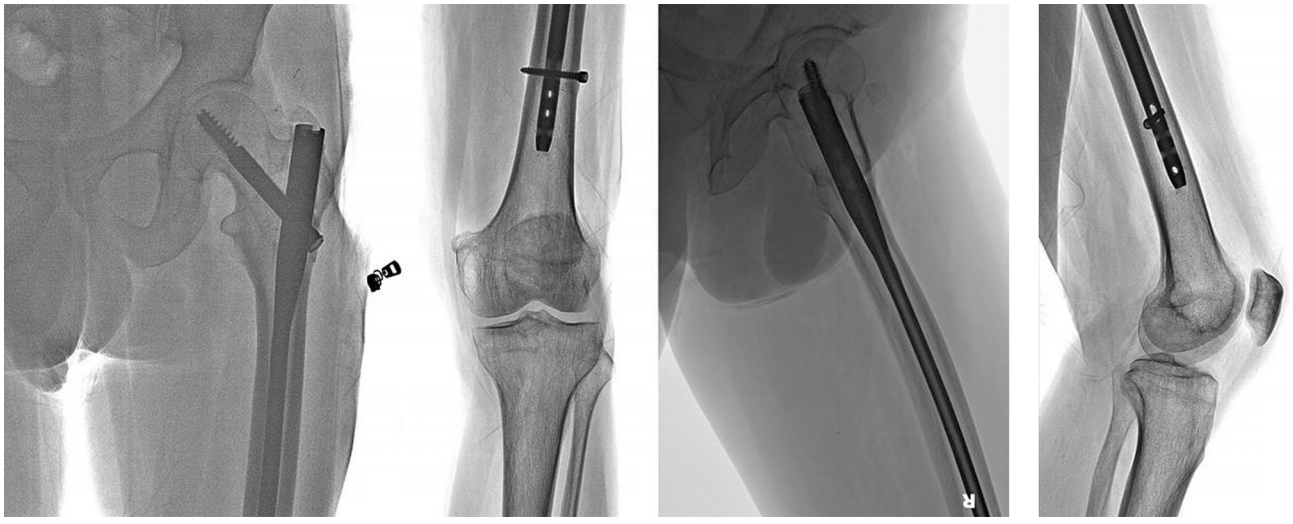

Fig. 4 The treatment resulted in the consolidated intertrochanteric fracture fixed with proximal femoral nail: (*a, b*) AP view of the femur; (*c, d*) lateral view

DISCUSSION

The first generations of intramedullary nails were characterized by blocking produced proximally and distally by a static method to provide additional stability and increase the rigidity of the bone-implant system. In some cases this led to imbalance between mechanical and biological factors of bone healing and impaired fracture consolidation [12]. Gross and Kempf developed the concept of intramedullary nail dynamization through removing a proximal or distal locking screw off the fracture turning a rigid system into a "flexible" one [13]. The concept was employed for constructs with a longitudinal hole for the nail blocking [14]. Now the nail dynamization technique is successfully used in orthopaedic practice. Failure to conform with this technology or anatomical changes in subtrochanteric fractures fixed with cephalomedullary constructs can result in impractical dynamization and a fatigue fracture of the nail [15–18]. The majority of extracapsular fractures of the proximal femur are treated with cephalomedullary constructs using the principle of a dynamic screw sliding along the axis of the femoral neck creating interfragmental compression. However, useful cephalomedullary constructs, originally designed for repair of transtrochanteric fractures, may fail to provide interfragmental compression for intertrochanteric fractures (AO/OTA 31A3.1–3; Boyd and Griffin type 3 trochanteric fractures) and for all types of subtrochanteric fractures according to the Seinsheimer classification with interfragmentary compression required along the axis of the femoral diaphysis to be provided by removing the locking screw, or initial fixation using a dynamic method avoiding the axis of the femoral neck. Biber et al. reported 8 cases of axial interfragmentary dynamization being complicated by the fact that the dynamic screw rested on the lateral cortical layer of the femur underlying the distal end [19]. This led to pain, implant instability, impaired fracture consolidation and to implant failure. It was caused by the sliding screw blocked by the lateral cortex of the distal peripheral femoral fragment. A biomechanically substantiated technique of lateral corticotomy was developed to dynamize the nail along the femoral axis and facilitate fracture healing. The authors offered and successfully implemented a surgical method with corticotomy of the lateral cortical layer right under the dynamic screw to block the nail using the dynamic method.

Biber et al. recommended to use this technique for patients who showed signs of impaired fracture consolidation and nail dynamization can be practical for interfragmental compression along the axis of the femoral diaphysis, without specifying specific nosologies of fractures. Tinner et al. reported a case of successful use of the technique in a patient with impaired consolidation of an intertrochanteric fracture, accompanied by breakage of the intramedullary pin [20]. Hinz et al. reported biomechanical effectiveness of the LCN in the dynamization of proximal femoral nails based on the finite element method with lateral corticotomy facilitating dynamization of the nail along the axis of the femoral shaft [21]. Based on the above publications and our own clinical practice, we suggested that the technique is useful for impaired consolidation of intertrochanteric fractures AO/OTA 31A3.1–3, type 3 trochanteric fractures as classified by Boyd and Griffin and all types of subtrochanteric fractures according to the Seinsheimer classification, i.e. fractures to be repaired with cephalomedullary osteosynthesis and interfragmental compression to be provided along the axis of the femur.

The clinical case showed the mechanism of impaired consolidation of intertrochanteric and subtrochanteric fractures of the femur reported by Biber et al. [19]. The dynamic (cervical) screw acts as a "spacer"passing through the central (femoral neck) and peripheral fragments (subtrochanteric region) preventing interfragmental compression along the axis of the femoral diaphysis and maintaining the diastasis between fragments with the distal blocking performed in a dynamic way. This results in failure of fracture healing with increased loading on the implant and breakage at the weakest point — the hole of the dynamic (cervical) screw — with a tendency to varus displacement of the central fragment. The lateral corticotomy performed under the dynamic (cervical) screw can help the "spacer" facilitating interfragmental compression along the axis of the femoral diaphysis and fracture consolidation. The assumption requires biomechanical justification, which we will try to present in future publications. Projecting the mechanism of fracture consolidation in our patient, we can assert the success of the technique. The construct collapsed because of nonunion despite the timely and high-quality cephalomedullary osteosynthesis performed according to indications. The failure was caused by the dynamic (cervical) screw blocked by the underlying lateral cortical layer which prevented interfragmental compression along the axis of the femoral diaphysis. A "spacer" effect maintained the existing diastasis between the fragments preventing fracture healing.

CONCLUSION

The clinical case presented demonstrated successful use of the lateral corticotomy technique for dynamization of the proximal femoral nail, its reproducibility and safety. Such an observation allows us to continue studying the relevant topic.

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

Funding *The patient's treatment was carried out within the framework of the state guarantee program for the provision of free medical care to citizens. The study was conducted without sponsorship.*

Compliance with ethical standards *The authors confirm that the rights of the patient who took part in the study were respected. Informed consent was obtained from all patients for being included in the study.*

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Information about the authors:

Rashid A. Shafigulin — Candidate of Medical Sciences, orthopaedic surgeon, rashid 221@ yandex.ru, https://orcid.org/0009-0008-6146-4470;

Ildar F. Akhtyamov — Doctor of Medical Sciences, Professor, Head of Department, yalta 60@mail.ru;

Ilnar A. Aglyamov — orthopaedic surgeon, aia3008@mail.ru;

Andrey A. Gornaev — orthopaedic surgeon.

Clinical case
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Talar head replacement for treatment of Müller – Weiss syndrome: three clinical cases

V.V. Skrebtsov[1]✉, V.G. Protsko[1,2], A.V. Skrebtsov[1], S.K. Tamoev[1]

[1] Yudin City Clinical Hospital, 115446, Moscow, Russian Federation
[2] Russian Peoples' Friendship University, 117198, Moscow, Russian Federation

Corresponding author: Vladimir V. Skrebtsov, Skrebtsov@mail.ru

Abstract

Introduction Müller – Weiss syndrome is a rare condition that is characterized by avascular necrosis of the navicular bone leading to severe foot deformity, pain disturbing activities of daily living. There is no generally accepted treatment for avascular necrosis of the scaphoid, and the available treatments have disadvantages, which necessitates the need for new options.

The **objective** was to present short-term results of three patients with osteonecrosis of the scaphoid and local necrosis of the talar head treated with ceramic talar head prosthesis, plastic surgery, metal osteosynthesis of the scaphoid and related surgical techniques.

Material and methods Three patients diagnosed with Müller – Weiss syndrome were treated with ceramic talar head replacement, autologous bone grafting and metal osteosynthesis of the scaphoid bone with accompanying surgical techniques. Severity of pain and the condition of patients were assessed with the VAS and AOFAS AH scores.

Results Short-term results showed consolidation at the site of metal osteosynthesis in all patients with no signs of instability of the talus hemiprosthesis. VAS and AOFAS AH scores indicated decrease in the pain and improved condition of the patients.

Discussion Hemiarthroplasty of the talar head combined with plastic surgery and restoration of a congruent joint surface of the scaphoid, and associated surgical techniques may become an effective alternative to existing treatments for patients with Müller – Weiss syndrome, with further study.

Conclusion The short-term findings showed that hemiarthroplasty was practical for restoration of the talonavicular mobility maintaining stable fixation of the talus.

Keywords: talonavicular joint, avascular necrosis, scaphoid bone, Müller – Weiss syndrome, joint replacement, ceramic implant

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INTRODUCTION

The talonavicular joint is part of the Chopart joint complex and is one of the key joints to ensure the foot function. It plays a significant role in the walking cycle distributing load vectors and is involved in pronation and supination of the foot [1]. Severe degenerative changes in the joints of the mid- and hindfoot can reduce the patient's quality of life affecting the foot function [2]. Osteonecrosis of the articular surfaces of the talonavicular joint is characterized by functional impairment. Osteonecrosis can be caused by post-traumatic conditions, rheumatoid arthritis and Keller's disease. Müller – Weiss syndrome is a rare disease that is characterized by ischaemic necrosis of the tarsal scaphoid [3]. Müller – Weiss disease is managed initially with conservative treatment that are not always effective [4]. Surgical options are reserved for severely destructed articular surfaces of the talonavicular joint [5, 6]. Arthrodesis of functionally important joints can result in poor functionality at a long term, in particular. An original endoprosthetic model of the talar head and a method for its implantation were offered to maintain the talonavicular function of severely deformed and destructed joint [7].

The **objective** was to present short-term results of three patients with osteonecrosis of the scaphoid and local necrosis of the talar head treated with ceramic talar head prosthesis, plastic surgery, metal osteosynthesis of the scaphoid and related surgical techniques.

MATERIAL AND METHODS

The study was performed in accordance with ethical principles for medical research involving human subjects stated in the Declaration of Helsinki developed by the World Medical Association as revised in 2013. The study received a favourable opinion from the relevant research ethics committee. The patients gave informed consent for publication of the findings without identification. Three patients diagnosed with Müller – Weiss syndrome were treated with ceramic talar head replacement, autologous bone grafting and metal osteosynthesis of the scaphoid bone with accompanying surgical techniques. Hemiprosthesis of the talar head is an original design developed in Russia and made of yttrium-stabilized zirconium oxide ceramics. The implant contains an articular head with a smooth articular surface and a four-lobed stem. Press-fit fixation occurs with the hemiendoprosthesis stem being self-jammed in the prepared canal of the talus. Weight-bearing radiography of the feet and multislice computed tomography (MSCT) were performed pre- and postoperatively to assess the objective condition of patients. VAS score and AOFAS AH score Severity of pain and the condition of patients were assessed with the VAS (visual analog pain scale) and AOFAS AH (American Orthopedic Foot and Ankle Society — Ankle Hindfoot Scale) scores preoperatively and at 12 months.

RESULTS

Case 1

A 70-year-old patient reported pain in the mid- and hindfoot on the right side at rest, which intensified during walking and after physical activity. He had a history of an injury a year ago with his right foot being sprained. He did not seek medical assistance. Over time, he experienced severe pain with negative clinical dynamics. Physical examination showed moderate swelling of the soft tissues in the mid- and hindfoot on the right side. His medial longitudinal arch appeared to be flattened and calcaneus aligned in varus. Palpation revealed severe pain at the talonavicular joint of the right foot. He could not supinate or pronate with the right foot. Preoperative Vas scored 10 and AOFAS AH measured 22 points. Computed tomography demonstrated severe deformity and dislocation of the talonavicular articular surfaces, fragmentation of the scaphoid bone, linked wedging of the talar head and a scaphoid fragment (Fig. 1).

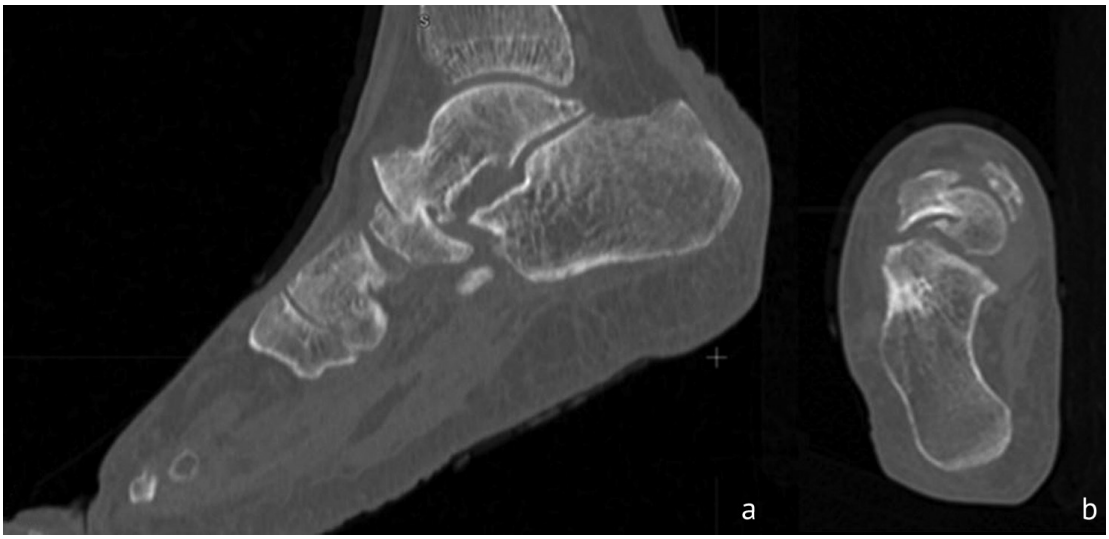

Fig. 1 Preoperative MSCT sections of the right foot (*a*) sagittal plane; (*b*) axial plane showing severe degenerative changes in the talonavicular joint with the talus and navicular bones impacted

The patient was diagnosed with stage 3 osteoarthritis of the talonavicular joint, osteonecrosis of the scaphoid and the talar head of the right foot, blockade of the talonavicular joint. Medical history and physical examination indicated a stress fracture of the scaphoid which caused destruction of the talar head, fragmentation of the scaphoid and development of Müller – Weiss syndrome. Surgical intervention included debridement, bone grafting of the scaphoid bone defect using the anterior articular process of the calcaneus, metal osteosynthesis (MOS) of the scaphoid bone with screws, hemiendoprosthetics of the talar head with a ceramic implant, lengthening resection arthrodesis of the calcaneocuboid joint with plastic surgery using a cancellous allograft and a staple, achilloplasty by Strayer. The patient could maintain full weight-bearing on the right lower limb and did not limp at 12 months. There was no swelling of the soft tissues at the hindfoot on the right side. Moderate flattening of the medial longitudinal arch of the right foot was observed with and the hindfoot alignment being satisfactory (Fig. 2). Postoperative scars heeled with no signs of inflammation. Palpation of the talonavicular joint was painless. The patient had full and painless range of motion in the right ankle. The range of painless supination-pronation of the right foot in the Chopart joint measured 10°–0°–10°. The AOFAS AH scored 72 and VAS was 2. Weight bearing radiographs of the right foot showed stable MOS of the scaphoid bone, calcaneocuboid ankylosis (Fig. 3), moderate flattening of the longitudinal arch with the foot function restored.

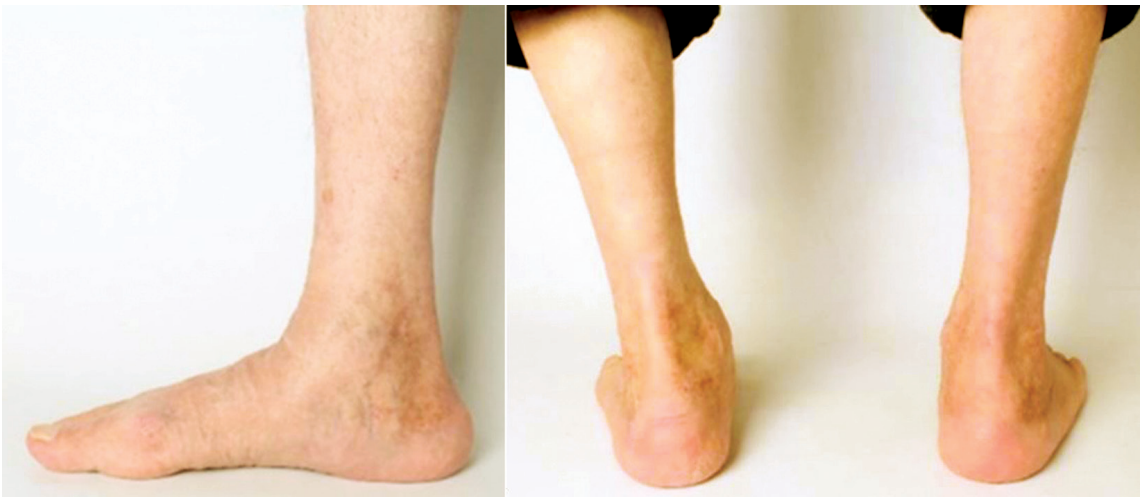

Fig. 2 Appearance of feet at 12 months showing moderate flattening of the medial longitudinal arch of the right foot, satisfactory alignment of the hindfoot

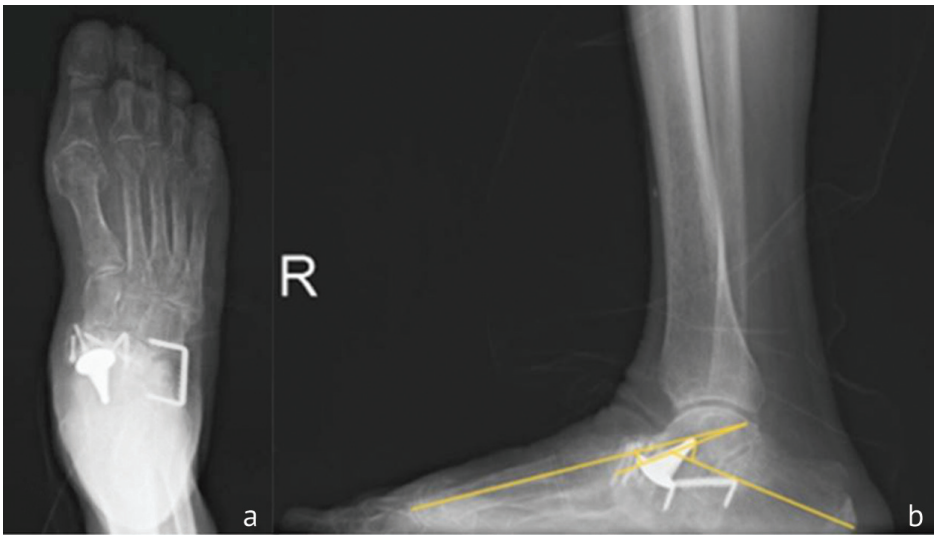

Fig. 3 Weight-bearing X-ray of the right foot at 12 months showing (*a*) AP view; (*b*) lateral view demonstrating Mary angle of 8° Kite and talocalcaneal angle of 45°

Case 2

A 43-year-old patient reported an acute pain in the mid- and hindfoot on the right side which developed for no apparent reason about one year ago. She underwent conservative treatment without positive dynamics. Clinical examination revealed pronounced swelling of the soft tissues of the mid- and hindfoot on the right side, flattening of the medial longitudinal arch and varus of the calcaneus of the right foot (Fig. 4).

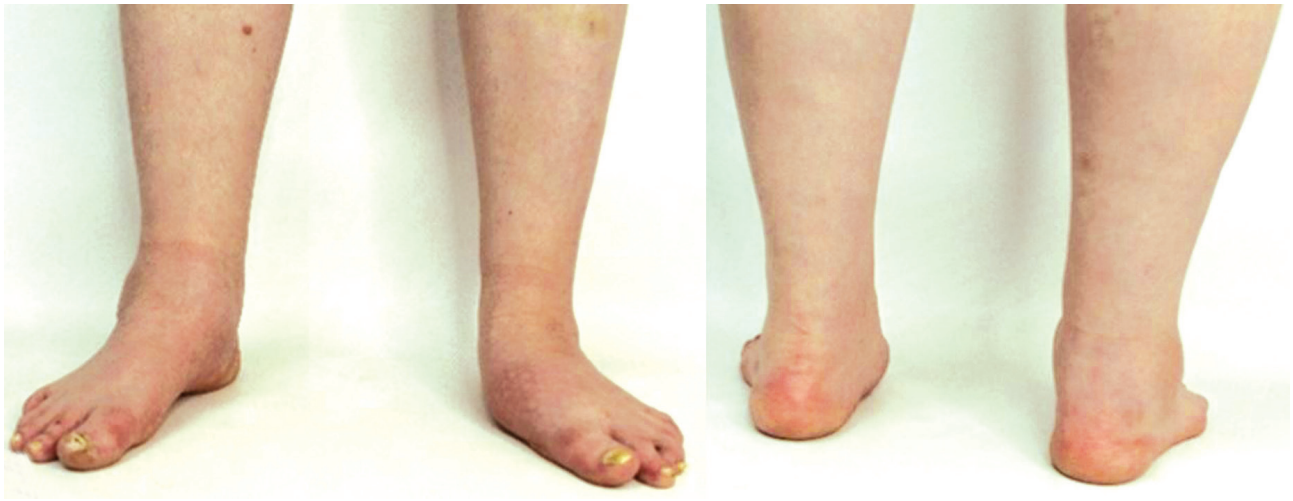

Fig. 4 Preoperative appearance of the feet showing varus of the hindfoot, pronounced flattening of the medial longitudinal arch of both feet, valgus of the hindfoot on the left side

The patient reported severe pain at the talonavicular joint on the right side on palpation. Supination and pronation of the right foot were not noted. No neurological deficit was identified. When testing the patient before surgery, Preoperative AOFAS AH scored 24 and the VAS scored 10. The left foot showed pronounced flattening of the medial longitudinal arch, valgus deformity of the hindfoot, and abduction of the forefoot. However, with the severe deformity, the foot was plantigrade and the patient reported no pain. Computed tomography of the right foot showed severe degenerative changes in the articular surfaces of the talonavicular joint, osteonecrosis, fragmentation of the scaphoid bone, and linked wedging between the talar head and a scaphoid fragment (Fig. 5).

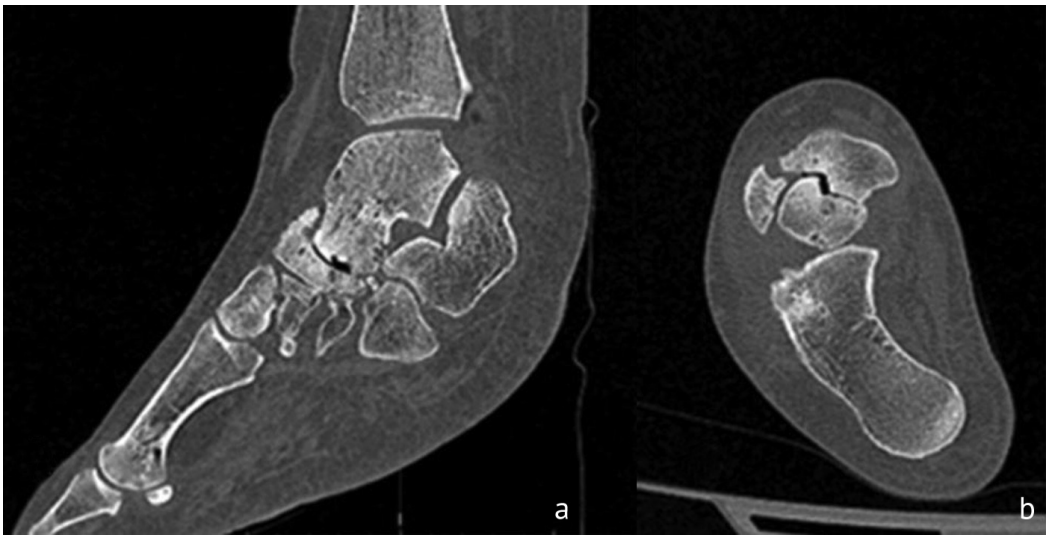

Fig. 5 Preoperative MSCT sections of the right foot in (*a*) sagittal plane; (*b*) axial plane showing severe osteoarthritis at the Chopart joint, fracture of the scaphoid, pathological angle of scaphoid inclination

The patient was diagnosed with Müller – Weiss syndrome, osteonecrosis of the navicular and the talar head of the right foot, blockade of the talonavicular joint. The first stage of surgical intervention included necrectomy of the scaphoid bone. MOS of the scaphoid bone was produced, pseudarthrosis of the scaphoid identified, and resected with an oscillatory saw down to the bleeding areas. The scaphoid bone fragments were reduced, fixed with a lag screw, and then with a mini-support plate with angular stability. The next stage included hemiendoprosthetics of the talar head with a ceramic implant, lengthening resection arthrodesis of the calcaneocuboid joint, plastic surgery with a bone cancellous allograft and fixation with a staple, and Vulpius achilloplasty. Physical examination showed slight swelling of the soft tissues of the hindfoot on the right side, the axis of the calcaneus aligned in a neutral position at 12 months (Fig. 6). Movements of the right foot in the Chopart joint, palpation of the talonavicular joint were painless, supination–pronation measured 10°–0°–5°. The AOFAS AH scored 95 and VAS scored 1. Weight-bearing radiographs of the right foot at 12 months showed a fracture of the staple, adequate osteosynthesis of the scaphoid and calcaneocuboid ankylosis identified (Fig. 7). The right foot was plantigrade and pain free.

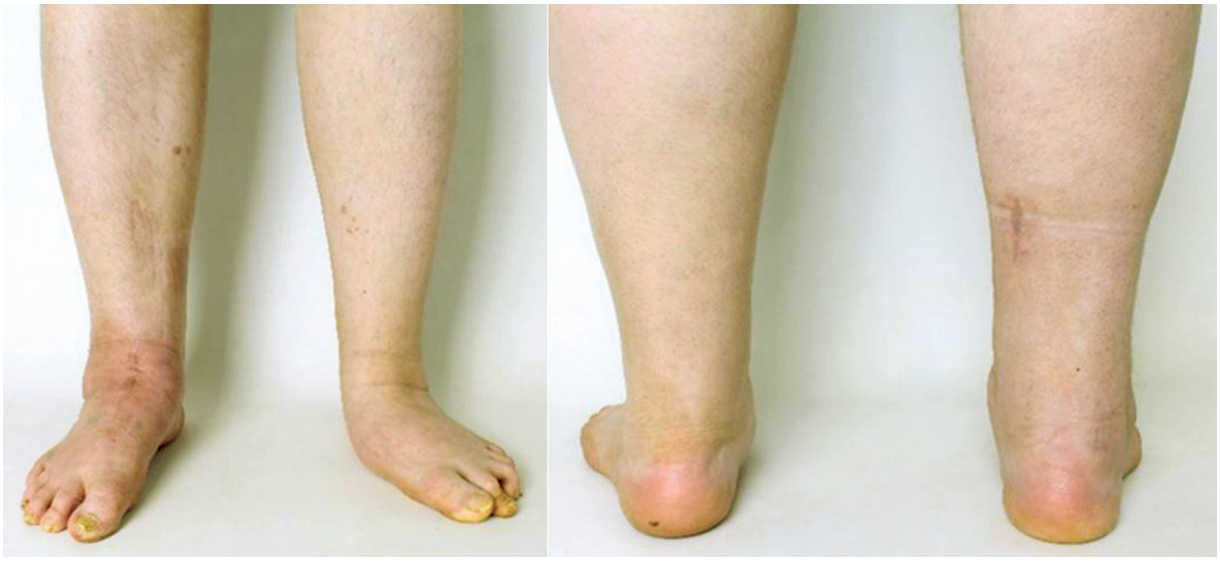

Fig. 6 Appearance of the feet at 12 months showing slight swelling at the level of the right ankle joint, neutral position of the heel bone on the right

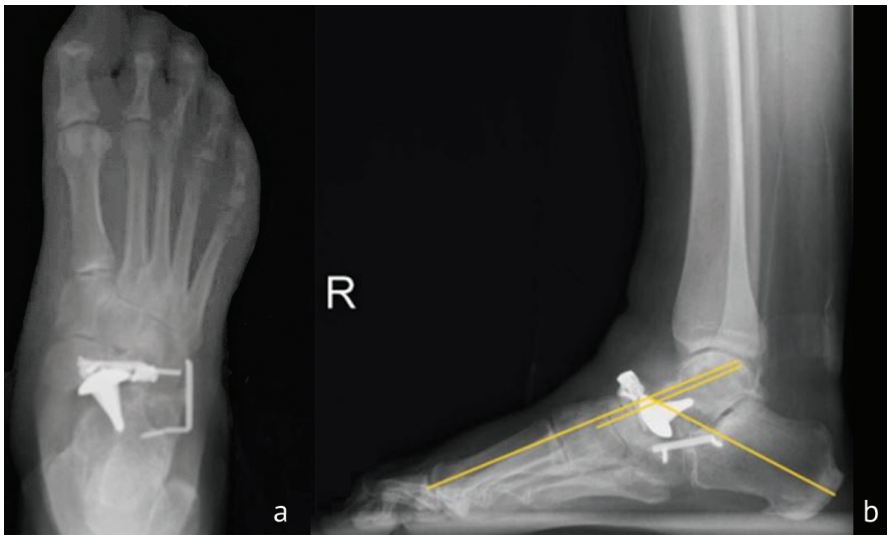

Fig. 7 Weight-bearing radiographs of the right foot at 12 months showing (*a*) AP view; (*b*) lateral view demonstrating Mary angle of 0°, Kite talocalcaneal angle of 50°. Scaphoid bone healed with MOS, satisfactory calcaneocuboid arthrodesis, broken connector bracket

Case 3

A 24-year-old female patient reported acute pain in the mid foot on her right side. She sustained an injury about 7 years ago, she sprained her right foot with no skeletal injury detected at the time. A physical examination revealed moderate swelling of the soft tissues in the mid- and hindfoot on the right side, flattening of the medial longitudinal arch of the right foot, and varus alignment of the calcaneus (Fig. 8).

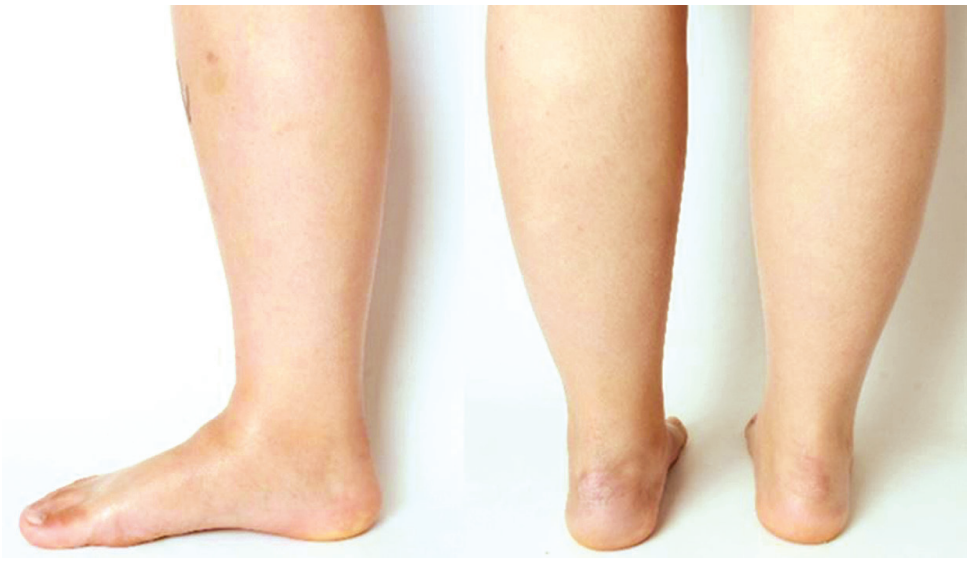

Fig. 8 Preoperative appearance of the feet showing moderate swelling of the right foot, flattening of the medial longitudinal arch, varus of the calcaneus on the right

Severe pain in the right foot was detected upon palpation at the talonavicular joint. The supination-pronation movements of the right foot are rocking and sharply painful. When testing the patient before surgery, the AOFAS AH score was 39 points, and the VAS score was 9 points. Severe pain in the right foot is detected upon palpation in the projection of the talonavicular joint. She had swinging, sharply painful supination-pronation movements of the right foot. Preoperative AOFAS AH scored 39 and VAS scored 9. Computed tomography showed severe deformity of the articular surfaces of the talonavicular joint, osteonecrosis and fragmentation of the scaphoid bone and local avascular necrosis of the talar head (Fig. 9).

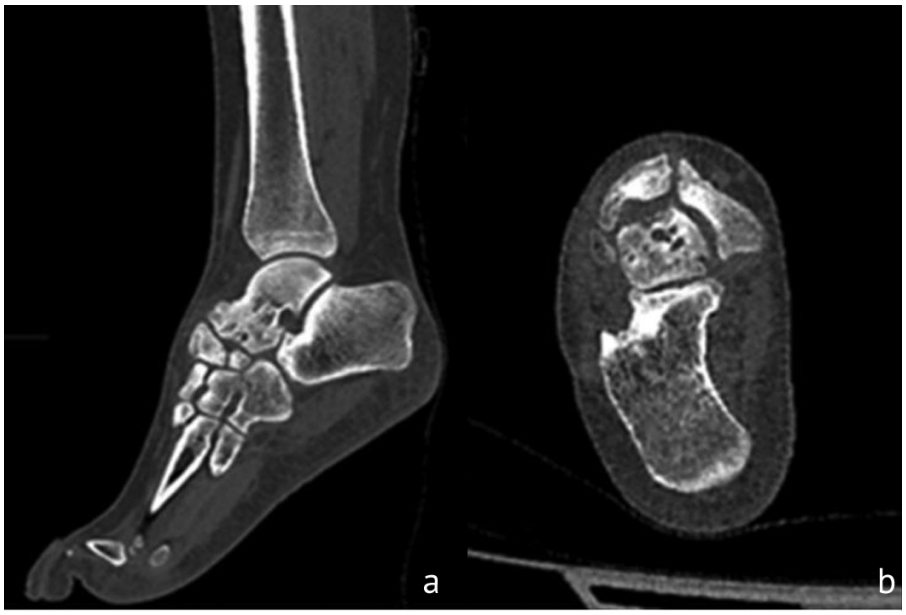

Fig. 9 Preoperative MSCT sections of the right foot in the sagittal plane (*a*) and axial plane (*b*) showing severe osteoarthritis of the talonavicular joint, cysts in the talar head, fragmentation of the scaphoid bone

The patient was diagnosed with Müller – Weiss syndrome, osteonecrosis of the scaphoid and the talar head of the right foot. Surgical intervention included necrectomy of the scaphoid bone, MOS with a mini-plate, hemiendoprosthetics of the talar head, Evans lengthening osteotomy of the calcaneus, plastic surgery with cancellous bone allograft and fixation with a connector staple. Physical examination at 12 months showed slight swelling of the soft tissues of the hindfoot on the right side and physiological position of the heel (Fig. 10). Painless supination and pronation of the right foot in the Chopart joint was 10°–0°–10° at 12 months. Palpation of the talonavicular joint was painless. AOFAS AH scored 87 and VAS scored 1. Weight-bearing radiographs of the right foot at 12 months demonstrated stable MOS of the scaphoid bone (Fig. 11). MSCT findings showed stable hemiendoprosthesis (Fig. 12).

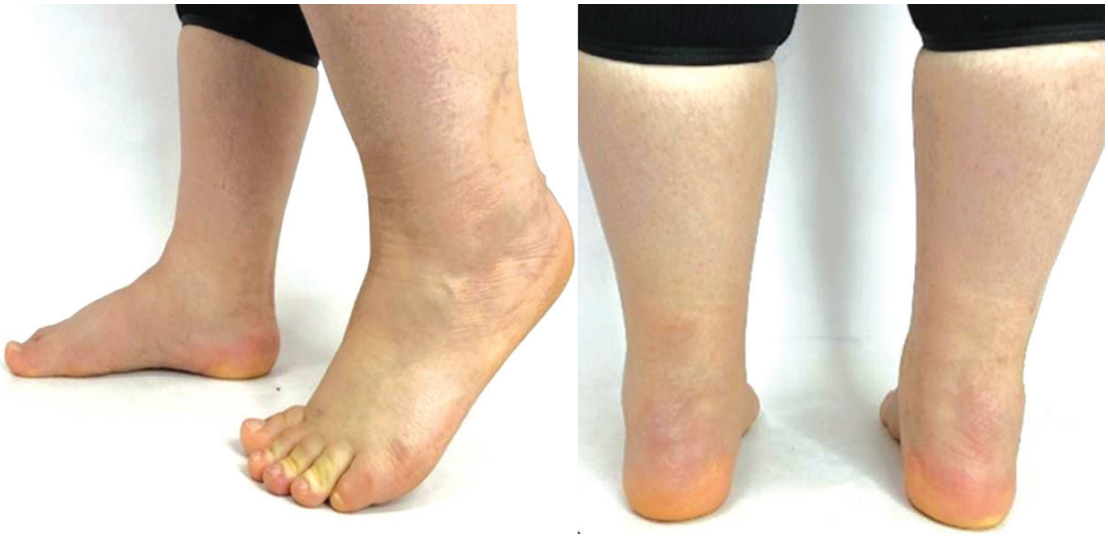

Fig. 10 Appearance of the feet at 12 months showing clean postoperative scar, no signs of inflammation with the physiological position of the heel provided

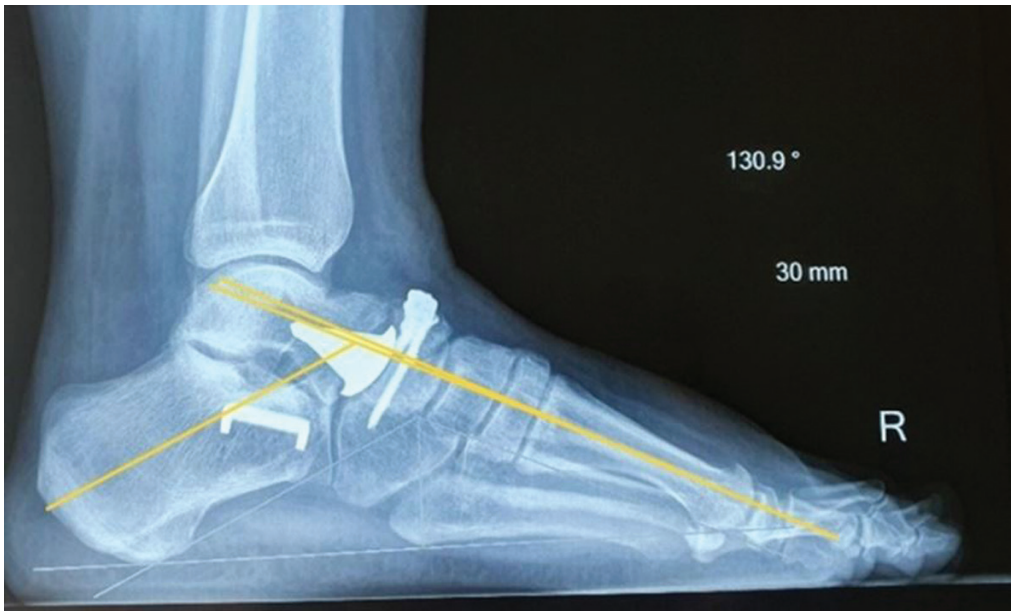

Fig. 11 Weight-bearing lateral radiograph of the right foot at 12 months showing no signs of migration with neutral physiological position of the foot; Mary angle of 2°, Kite talocalcaneal angle of 50°

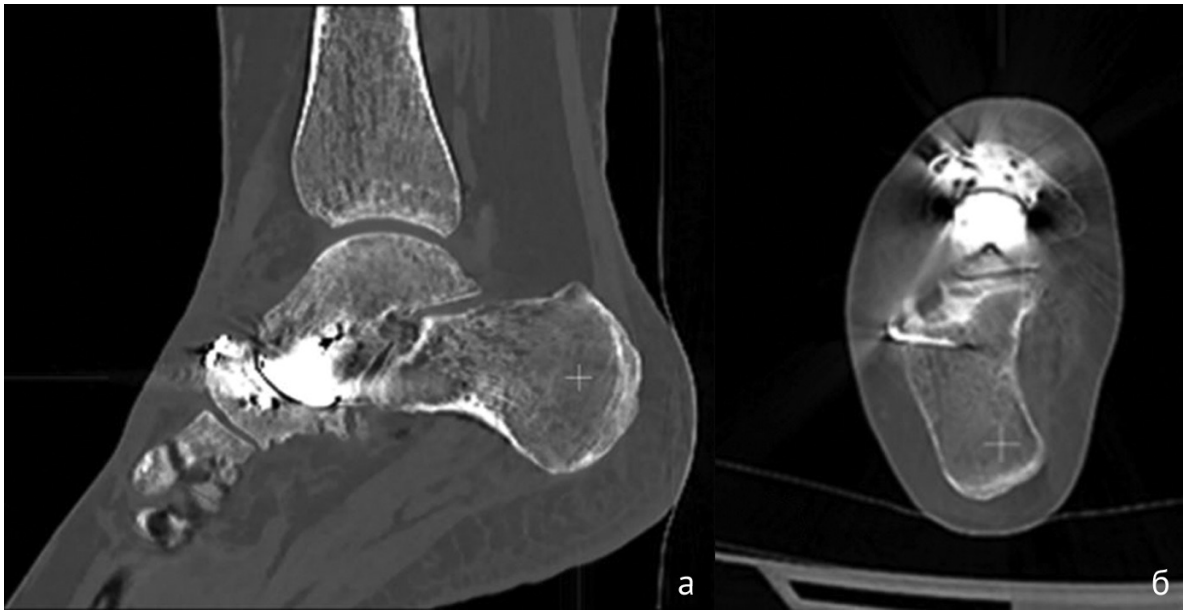

Fig. 12 MSCT sections of the right foot at 12 months in (a) sagittal plane and (b) axial plane showing consolidation of the scaphoid bone with MOS; adequate fixation of hemiprosthesis

DISCUSSION

Destruction of the articular surfaces of the talonavicular joint can be caused by primary osteonecrosis, previous trauma, osteochondritis, Keller disease, stress fracture of the scaphoid, rheumatoid arthritis or Müller – Weiss syndrome. Traumatic fractures of the scaphoid are a rare injury and diagnosis is difficult. About 30 % of all stress fractures of the foot involve injuries to the navicular bone [8]. The scaphoid is susceptible to osteonecrosis due to its complex anatomy and blood supply and an injury can lead to post-traumatic osteoarthritis of the surrounding joints. In childhood, avascular necrosis of the scaphoid is represented by Keller disease that normally develops at the age of 2–10 years [9]. In adults, the condition is termed Müller – Weiss syndrome and causes collapse and fragmentation of the scaphoid bone. Müller – Weiss syndrome was first described in 1927

by the German surgeon Walther Müller and the Austrian radiologist Konrad Weiss. However, some would suggest that this condition was first described by Schmidt in 1925 [10]. There is no generally accepted opinion about the cause of Müller – Weiss disease [11]. However, there are several theories to include osteonecrosis, osteochondritis, post-traumatic necrosis or a consequence of biomechanical disorders, osteoarthritis (OA) due to scaphoid dysplasia, congenital malformation, repeated stress fractures of the scaphoid and others. An etiopathogenetic theory has been recently accepted to involve dysplastic, mechanical, and socioeconomic environmental factors [12]. However, Doyle et al. did not find this relationship [13].

The blood supply to the navicular bone is provided by the medial plantar artery, the dorsalis pedis artery and the tarsal canal artery [14]. The central part of the scaphoid has a poorer blood supply, which also tends to decrease with age [15]. Tan et al. conducted the only pathological study to date and identified osteonecrosis in the material explored [16]. Other authors reported normal bone tissue [17].

In 2004, E. Maceira, R. Rochera reported dysplasia of the tarsal and scaphoid bones with delayed ossification and associated pathological load distribution [12]. The condition was associated with a significant increase in pressure on the lateral edge of the scaphoid. Varus deformity of the foot at th subtalar joint and a short first metatarsal bone could be predisposing factors. The prevalence of the disease in the population is unknown. The condition is asymptomatic and is often diagnosed with severe osteoarthritis of the talonavicular joint and an accurate diagnosis is difficult to make. This condition is most common in women aged 40–46 years, with an incidence rate of 6:1 or 2:1 compared to men. Bilateral involvement is observed in 50 % of cases [18]. Patients often experience pain along the dorsal-medial surface of the mid- or hindfoot, and there is a tendency for negative dynamics. The deformity is characterized by varus of the hindfoot, the so-called paradoxical flatfoot deformity (Pes planovarus, paradoxical flatfoot deformity) with flattening of the medial longitudinal arch and abductor deformity of the midfoot. In this case, manifestations of osteoarthritis are observed in the joints adjacent to the scaphoid bone. Progressive fragmentation of the scaphoid bone and collapse on the lateral surface, displacement of the talar head the lateral sphenoid bone are observed in the pathogenesis of the disease. Radiologic diagnostic criteria were offered by Maceira and Rochera in 2004 and summarized in Table 1 [12].

Table 1

Radiological classification of Müller – Weiss syndrome developed by Maceira and Rochera

Stage	Description
1	Standard radiographs, technetium scan, MSCT and MRI (intraosseous edema) Minor subtalar varus may be present
2	Lateral displacement of the talar head causes subtalar varus
3	Splitting or compression of the scaphoid bone leads to decreased height of the medial arch
4	Progressive compression of the navicular bone results in hindfoot equinus
5	Complete extrusion of the scaphoid and close contact of the talus and sphenoid

Radiological examination can show changes in the shape of the scaphoid bone: a concave shape (boat-shaped) is changed into a “comma” with decreased thickness along the lateral edge caused by progressive compression of the lateral aspect of the scaphoid bone. The cuboid bone can be displaced medially (cuboid sign). Radiographs show an open tarsal sinus, which is caused by varus alignment of the hindfoot. X-rays demonstrate a hypertrophied second metatarsal bone. The changes

are caused by the lateral shift and increased load on it. Increased plantar pressure in the midfoot and medial edge of the hindfoot can cause pathological changes in the foot [19]. MRI shows decreased signal intensity from the scaphoid on T1-weighted images (T1WI), hyperintense diffuse edema and hyperintense periarticular fluid on T2-weighted images (T2WI). Although conservative treatment can be applied for early stages of the disease (stages 1 and 2 as graded by Maceira and Rochera), and may fail to provide positive results, the treatment strategy is considered first-line therapy [3, 4].

Conservative treatment includes the use of orthopedic insoles, limited physical activity, immobilization, taking NSAIDs and analgesics and lasts at least 3 months. The use of orthopedic insoles with semi-rigid support of the medial longitudinal arch shows satisfactory results and the effectiveness of the treatment depends on the angle of inclination of the heel and abduction of the foot [20]. There is a variety of surgical treatments. Some authors recommend isolated arthrodeses of the talonavicular joint. The established methods of surgical treatment are various combinations of arthrodeses including double and triple arthrodeses [5, 6, 21]. Correction of rotational displacement of the talus followed by talonavicular or talonavicular-sphenoid arthrodesis can facilitate satisfactory treatment results [22]. Arthrodeses are used in combination with autologous bone grafting harvested from the iliac wing [23]. Scaphoid resection followed by medial column reconstruction using femoral head allograft for fusion using a plate is reported [16]. Blocking of the functionally significant joints leads to poor results, which become pronounced at a long term, therefore, arthrodesis of the talonavicular joint should be avoided [24, 25]. Joint-saving interventions in the treatment of Müller – Weiss disease include percutaneous decompression of the scaphoid in the early stages of the disease, debridement of the scaphoid and replacement with a bone cancellous graft using the ilium [26, 27], debridement of the scaphoid and bone grafting with a vascularized graft harvested from the medial femoral condyle [28]. It is difficult to draw conclusions about the effectiveness of the interventions due to the small number of observations. Realignment of the hindfoot is one of the important treatment goals that can be achieved with calcaneal osteotomy [20].

Lengthening osteotomy of the calcaneus unloads the lateral aspects of the navicular bone, corrects the deformity, relieves pain and improves foot function. Lengthening and stabilization of the lateral column can also occur due to lengthening calcaneocuboid arthrodesis with allograft reconstruction [29]. N. Wülker reports calcaneocuboid arthrodesis reducing the range of motion in the talonavicular joint by 19 % and after surgery measuring 32.95 ± 5.14° postoperatively [30]. In our opinion, this is not critical for the foot function of the and can stop progression of the deformity and reduce the load on the contact surfaces of the talonavicular joint. Maintaining the mobility of the talonavicular joint is important. The use of implants made by 3D printing can be promising in the treatment of osteonecrosis of the scaphoid and the talar head. The use of custom-made titanium scaphoid implants is reported in the literature. SB Adams and RM Danilkowicz reported a successful results for a patient with osteonecrosis of the scaphoid after implantation of a custom-made titanium scaphoid implant with a follow-up period of 4 years [24]. Zirconium ceramics cause less damage to the opposite cartilaginous surface than metal and is more preferable for hemiendoprosthetics [31. 32].

We have been using the technique of hemiprosthetics of the talar head since 2021; more than 20 surgical interventions aimed at replacing the articular surface of the talar head have been performed at the time of publication. We often used this surgical intervention for osteoarthritis of the talonavicular joint, accompanied by concomitant surgical techniques. These implants

are an original domestic development; patent No. 2788474 was received for the model of the endoprosthesis of the talar head and the method of its implantation [7]. The implant line is presented in 4 standard sizes, which allow you to select the necessary implant, regardless of the size of the patient's foot. We are conducting further work to evaluate the surgical technique in patients with lesions of the talonavicular joint of various origins.

CONCLUSION

The short-term findings showed that hemiarthroplasty was practical for restoration of the talonavicular mobility maintaining stable fixation of the talus.

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Information about the authors:

Vladimir V. Skrebtsov — Candidate of Medical Sciences, orthopaedic surgeon, Skrebtsov@mail.ru, https://orcid.org/0000-0003-0833-6628;

Victor G. Protsko — Doctor of Medical Sciences, Associate Professor of the Department, 89035586679@mail.ru, https://orcid.org/0000-0002-5077-2186;

Alexander V. Skrebtsov — orthopaedic surgeon, Skrebtsovalex@mail.ru, https://orcid.org/0000-0002-1418-3368;

Sargon K. Tamoev — Candidate of Medical Sciences, Head of the Department, orthopaedic surgeon, Sargonik@mail.ru, https://orcid.org/0000-0001-8748-0059.

Clinical case
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Treatment of patients with periprosthetic infection and management of Paprosky type 2C cavitary defects at the stage of articulating spacer installation

N.I. Rozhkov✉, A.M. Ermakov, A.S. Triapichnikov, N.V. Sazonova

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

Corresponding author: Nikita I. Rozhkov, digham@mail.ru

Abstract

Introduction Due to the constant increase in the number of primary and revision hip arthroplasties, the incidence of complications has been also increasing. Periprosthetic joint infection (PJI) is the most common and dangerous complication in joint arthroplasty, including PJI with cavitary defects of the acetabulum (Paprosky type 2C).

The **purpose** of the work was to demonstrate successful results of managing acetabular defects in patients with periprosthetic infection at the stage of installing an articulating spacer.

Materials and methods The patients underwent surgical management of cavitary defects of the acetabulum with allobone plastic material at the stage of installation of an articulating spacer impregnated with antibacterial drugs. A clinical and functional assessment of the effectiveness of treatment of patients with PJI of the hip joint, who underwent bone grafting of acetabular defects at the first stage of two-stage revision arthroplasty, was carried out. Remission of the infectious process was assessed according to the ICM 2013 (International Consensus Meeting), and the function of the affected limb was assessed according to the HHS (Harris Hip Score).

Results At a 6-month follow-up after implantation, there were no clinical and laboratory manifestations of PJI and radiological signs of instability of the implant components. Bone grafting was evaluated to be satisfactory; the function of the affected joint restored to 80–90 to HHS points. Remission of the infectious process according to ICM was achieved.

Discussion Clinical cases studied demonstrate a positive result of treatin PJI with plastic surgery of cavitary defects of the acetabular bottom at the stage of articulating spacer installation. Filling acetabular defects at the sanitizing stage (implantation of a spacer) subsequently provides improvement of primary fixation and osseointegration of the acetabular component when converting the spacer to a permanent implant. This is due to an increase in the contact area of the acetabular component with bone tissue (native bone and remodeled allobone material).

Conclusion The treatment of the first clinical case improved joint function from 24 to 85 HHS points, and in the second from 27 to 76 HHS points. The use of defect filling techniques enabled to stop the infection and improve functional results.

Keywords: clinical case, two-stage revision arthroplasty, hip joint, periprosthetic infection, osteomyelitis, acetabulum defects according to Paprosky

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INTRODUCTION

Along with the increasing number of scientific works on the topic of the study, the following factors indicate on the relevance of studying periprosthetic joint infection (PJI): an increase in life expectancy, an increase in the labor activity of the elderly population due to the available treatment conditions that improve the quality of life, the annual increase in the number of joint implants and, as a consequence, an increase in the number of infectious complications [1]. PJI is observed in 1–2 % of cases after primary arthroplasty and in 4 % of cases after revision interventions [2]. Two-stage revision arthroplasty remains the preferred treatment option for PJI [3]. However, the mortality rate in elderly patients after multiple surgeries remains high [4]. Moreover, relapses of infection are often observed in the presence of resistant strains of microorganisms, severe comorbidity in a patient and failures of revision interventions [5]. In chronic PJI, extensive defects of bone and soft tissues are formed after multiple sanitizing surgical interventions [6, 7]. Methods for filling bone defects depend on their size, the patient's bone density, the presence of cavitary defects of the acetabulum and the disrupted integrity of the pelvic ring, which determines the quality of fixation and the area of contact with the native bone [8].

Severe acetabular defects account for 1–5 % of the reasons for revisions of the acetabular component. The etiology of these defects is the result of osteolysis, mechanical loosening of the acetabular component, and infection [9]. Bori et al identified statistically the risk factors for the development of recurrent PJI in significant bone defects of the hip joint [10]. The complexity of filling acetabular defects during revision interventions on the hip joint is confirmed by the fact that there are many reconstruction options, none of which has a clear advantage over the others. During revision surgery, it is necessary to achieve reliable fixation of the endoprosthesis components and fill in the bone defect of the acetabular bottom [11].

Purpose: to demonstrate successful results of managing acetabular defects in patients with periprosthetic infection at the stage of installing an articulating spacer

MATERIALS AND METHODS

The series of clinical cases included patients who were treated in the clinic of bone and joint infection (purulent osteology) of the Ilizarov National Medical Research Center of Traumatology and Orthopaedics. The patients under study were diagnosed with chronic PJI according to Cheng Li [12] with Paprosky type 2C acetabular cavitary defects.

The bone tissue defect was preliminarily assessed using a series of X-ray images. X-ray signs of a defect in the medial wall and anterior column with a violation of the Kohler line and pronounced lysis shaped as a "teardrop" were noted. The patients underwent the first stage of surgical treatment with radical debridement of the infection site and filling cavitary defects with allobone material; an articulating spacer was installed for restoration of limb function.

The technique of bone defect filling was performed in the following sequence. The osteoplastic matrix in the form of blocks was soaked in a physiological solution and then crushed using surgical instruments. Antibacterial drugs (1 g of vancomycin and 1 g of ceftazidime) were added to the bone-plastic material; then dense impaction of the acetabulum defects was performed.

At the second stage of treatment, after the spacer was removed, the superficial layer of allograft bone was taken for bacteriological examination, which subsequently did not reveal any growth of pathogens. The plastic material turned to dense and intensely bleeding bone tissue of a pale yellow color, which was slightly inferior in density to the maternal bone. At the same time, no signs of necrosis, sequestration, or sclerosis were observed. The interval between operations of two-stage revision arthroplasty in the treatment of hip PJI was 5 months.

The patients were re-hospitalized and microbiological and cellular composition of the joint synovial fluid (the number of leukocytes and neutrophils), as well as an assessment of hematological inflammation markers (CRP, ESR and leukocytes) to control the suppression of the infectious process was performed. Based on the obtained laboratory data, a decision was made on the possibility of conducting the second stage of revision surgery with the installation of a permanent joint implant. Then, the dynamics of hematological, radiological, bacteriological examination indicators and the functional state of the involved limb were monitored.

Remission of the infection process was assessed according to ICM 2013 года (International Consensus Meeting) and Harris Hip Score (HHS) was used to assess limb function.

RESULTS

Case 1

Patient P., 49 years old, was admitted to the clinic of bone and joint infection (purulent osteology) with the diagnosis: chronic hematogenous PJI of the right hip joint (according to Cheng Li); chronic osteomyelitis of the right hip and pelvis, fistulous form; combined contracture of the right hip joint with shortening of the right lower limb by 2 cm; instability of the pelvic component of the endoprosthesis (Fig. 1). Concomitant disease: mild chronic iron deficiency anemia.

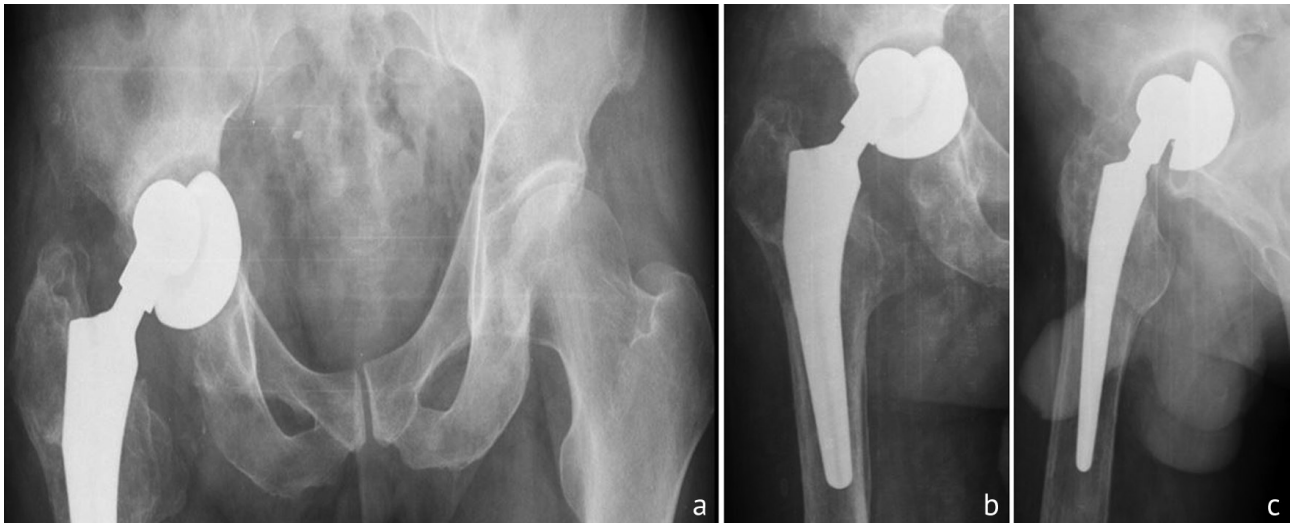

Fig. 1 AP view of the pelvis (*a*) and AP (*b*) and lateral (*c*) view of the right hip joint at 1-m focus before the intervention

Upon admission, the patient complained of a fistula in the upper third of the right thigh with purulent discharge, decreased weight-bearing capacity, shortening of the right lower limb and significant limitation of range of motion in the right hip joint due to pain.

From the medical history: total arthroplasty of the right hip joint in February 2021; swelling and severe pain in the right thigh developed after 3 months, a fistula with purulent discharge was functioning; conservative treatment was ineffective.

Local status: fistula in the area of the right hip communicating with the cavity of the hip joint (absolute sign of PJI according to ICM 2018); relative shortening of the right lower limb was 2 cm; the patient moved with crutches. At the time of admission, the functional state of the right hip joint was 24 HHS points.

Laboratory test results were mild anemia (Hb 91 g/l), increased ESR (97 mm/h) and CRP (30 mg/l); growth of *Staphylococcus aureus* was detected in the right hip joint puncture 104 CFU/ml.

The intervention was performed in 2023. The first stage of a two-stage revision total hip arthroplasty of the right joint: removal of the implant; debridement; installation of an articulating

spacer. A 50/32 cup was modeled from press molds using 1 packet of bone cement with antibiotics (1 g vancomycin and 1 g cefatoxime). The pelvic component of the 50 mm spacer was implanted using 1 packet of bone cement with antibiotics (2 g vancomycin and 1 g cefatoxime). A cemented stem was installed using 1 packet of bone cement with antibiotics (4 g vancomycin and 4 g cefatoxime). Intraoperatively, a Paprosky type 2C acetabular defect with total protrusion of the inner wall was detected which was filled with allobone chips. The operation was completed by installing drainage and layer-by-layer suturing of the wound. Radiographs of the pelvis and right hip joint in direct and lateral views with a focus of 1 m after the surgical intervention are shown in Fig. 2.

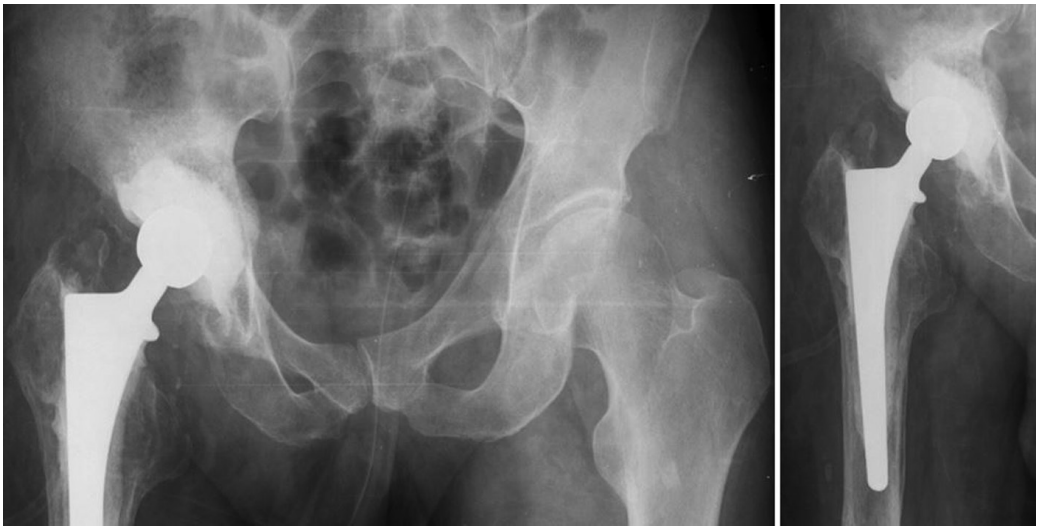

Fig. 2 Radiographs pelvis and of the right hip joint after surgical treatment with the defect filled with allograft bone and an installed articulating antibacterial spacer

Blood loss was 500 ml, intraoperative blood transfusion was 500 ml. Results of intraoperative microbiological testing: *Staphylococcus aureus* — 10^4 CFU/ml. *Psenudomoas aeruginosa* (S) — 10^4 CFU/ml was cultured from the implant. The wound healed by primary intention. The drainage was removed on the 6th day after the surgery.

After the first surgical stage, a course of etiotropic antibacterial therapy was administered for 6 weeks. In the hospital, the patient received amoxicillin + clavulanic acid 1.2 g three times a day intravenously and levofloxacin 100 ml twice a day for 2 weeks. In the outpatient stage of treatment, levofloxacin 500 mg twice a day and cefoperazone sulbactam 2.0 g twice a day were prescribed intramuscularly for 4 weeks.

The patient was recommended to use crutches for walking with limited load on the affected limb until the following stage of surgical treatment.

After one month, control studies of ESR and CRP and radiography of the pelvis and right hip joint were performed (Fig. 3). Results of laboratory tests: mild anemia (Hb 118 g/l), ESR 10 mm/h and CRP 2 mg/l. At the follow-up after one month, it was established that there were no clinical and laboratory signs of relapse of the disease (no wounds or fistulas); the spacer components were stable, the functional state of the right hip joint was 64 HHS points.

Five months later, the patient was admitted to the clinic again for further examination and the second stage of surgical treatment.

Local status: no fistulas, normotrophic scar in the right hip area. The patient moved with crutches. At the time of admission, the functional state of the right hip joint was 64 HHS points. Laboratory test results of complete blood count: Hb 130 g/l, ESR 20 mm/h and CRP 1.4 mg/l. No growth of the pathogen was detected in the puncture from the right hip joint.

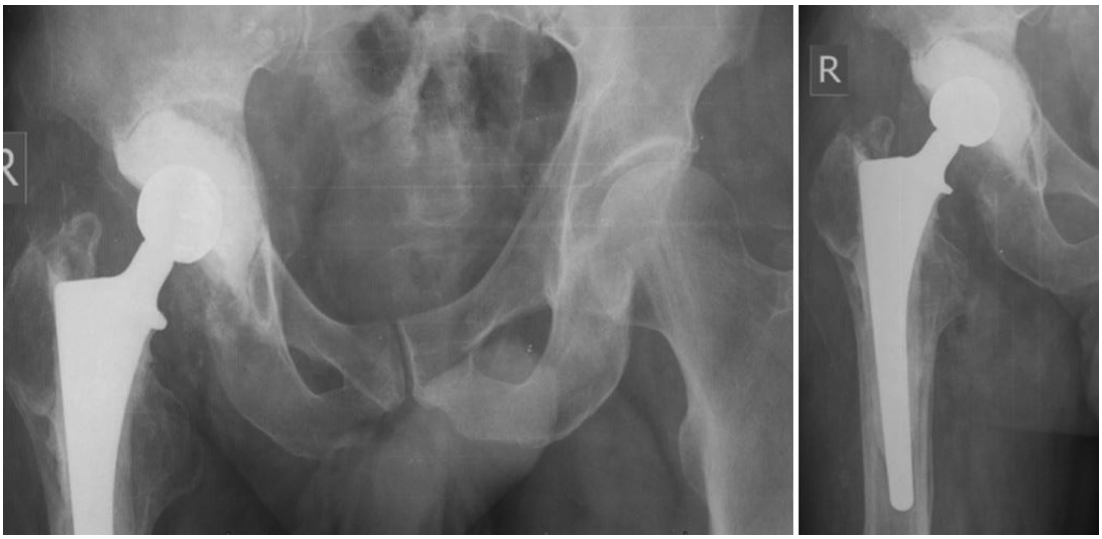

Fig. 3 Radiographs of the pelvis and right hip joint 1 month after the intervention

After the examination, the second stage of surgical treatment was performed: revision arthroplasty of the right hip joint; removal of the spacer; debridement; installation of a cementless hip joint implant. The intraoperatively repaired defect had dense bleeding bone tissue of a pale yellow color without signs of necrosis. The X-ray of the pelvis after surgery is shown in Figure 4. Blood loss was 250 ml; intraoperative blood transfusion was 250 ml. No growth of pathogens was detected on the removed spacer. The wound healed by primary intention. The drainage was removed on the sixth day after the surgery.

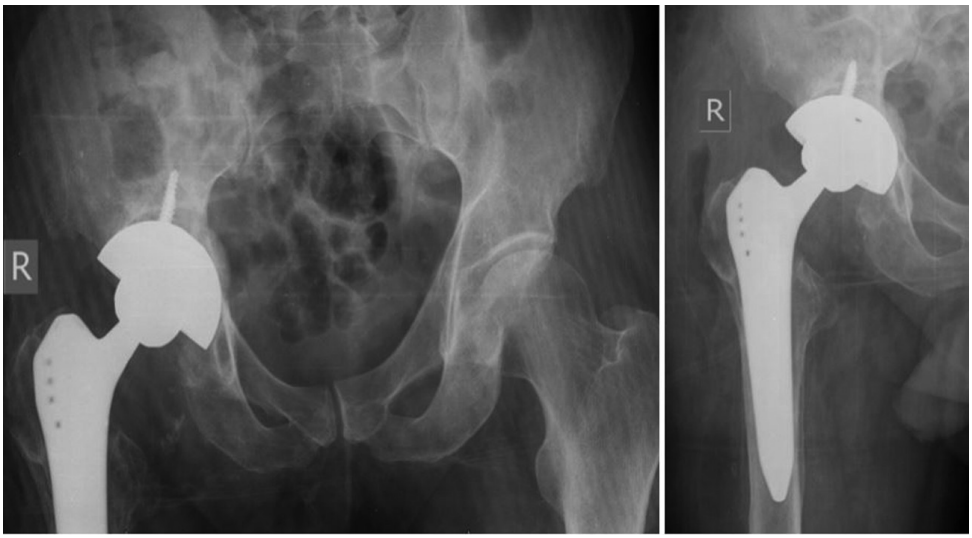

Fig. 4 AP radiographs of the pelvis and right hip joint with a focus of 1 m after the intervention

After the second stage of revision arthroplasty, a six-week course of antibacterial therapy was administered. In the hospital, the patient received vancomycin 1.0 g intravenously twice a day and meropenem 1.0 g three times a day for 2 weeks. At the outpatient stage of treatment, a course of oral antibiotics was prescribed for 4 weeks: levofloxacin 500 mg twice a day and doxycycline 100 mg twice a day. The patient was recommended to use crutches for walking with limited load on the affected limb for 3 months.

After 6 months, ESR and CRP levels were examined, and X-ray of the pelvis and right hip joint was performed (Fig. 5). Laboratory test results: mild anemia (Hb 120 g/l), ESR 15 mm/h, and CRP 3 mg/l. A follow-up examination revealed that there were no clinical and laboratory signs of disease recurrence (no fistulas, normotrophic scar), the implants components were stable, and the functional state of the right hip joint was 85 HHS points.

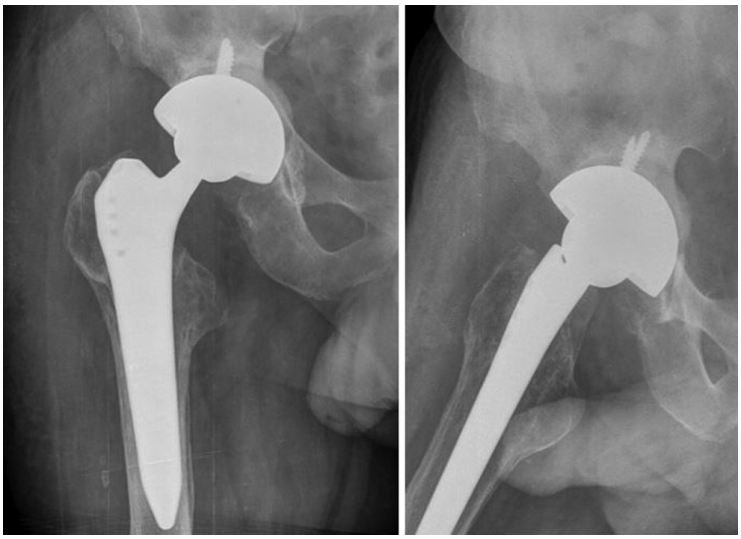

Fig. 5 Radiographs of the right hip joint 6 months after the revision intervention

Case 2

Patient Sh., 64 years old, was admitted to our clinic with the following diagnosis: chronic hematogenous PJI of the left hip joint (according to Cheng Li); chronic osteomyelitis of the left femur and pelvis, fistulous form; combined contracture of the left hip joint with shortening of the left lower limb by 2 cm (Fig. 6). Concomitant diseases: hypertension stage 2, risk 3, chronic heart insufficiency-0, FC-3; atherosclerosis of the arteries of the extremities.

At admission, the patient complained of a fistula in the left thigh with purulent discharge, decreased weight-bearing ability, shortening of the left lower limb and severe pain in the left hip joint.

According to the history of the disease, he was ill since 2020 as he sustained a fracture of the left femoral neck. Total arthroplasty of the left hip joint was performed at the place of his residence (Chita) on 27.02.2020 and at the end of 2020, a fistula appeared in the left hip joint.

Local status: fistula in the left femur communicating with the hip joint cavity (an absolute sign of PJI according to ICM 2018); relative shortening of the left lower limb by 2 cm; the patient moved with crutches. At the time of admission, the functional state of the left hip joint was 27 HHS points and VAS scale pain was 5 points.

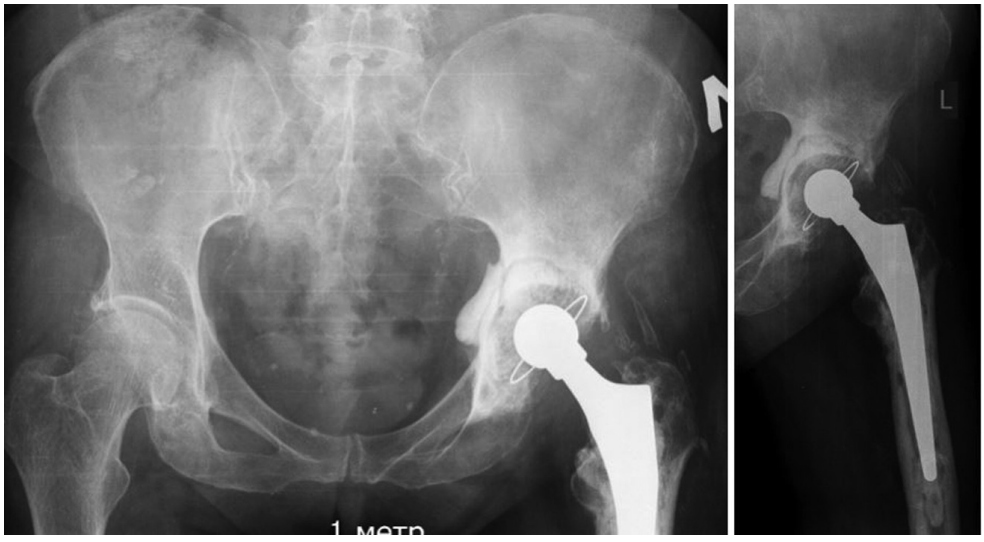

Fig. 6 Radiographs of the pelvis and left hip joint at 1-v focus before the operation

Laboratory test results: mild anemia (Hb 121 g/l), elevated ESR (93 mm/h) and CRP (30 mg/l). *Providence arustigianii* growth of 10^4 CFU/ml was detected in the left hip joint puncture material. The operation was performed in 2023. The first stage of a two-stage revision left hip arthroplasty: previous implant

removal; debridement; installation of an articulating spacer. A 50/32 cup was modeled from molds using 1 packet of bone cement with antibiotics (1 g vancomycin and 1 g cefotaxime). A 50 mm pelvic component of the spacer was implanted using 1 packet of bone cement with antibiotics (2 g vancomycin and 1 g cefotaxime). A cement stem was installed using 1 packet of bone cement with antibiotics (5 g vancomycin and 3 g cefotaxime). Intraoperatively, the acetabulum defect was assessed as Paprosky type 2C with a protrusion of the bottom, which was filled with allobone chips. The operation was completed by installing a drain and layer-by-layer suturing of the wound. Radiographs of the pelvis and left hip joint after surgery are shown in Figure 7. Blood loss was 250 ml, intraoperative blood transfusion was 250 ml. The results of intraoperative microbiological tests were *providence arustigianii* 10^6 CFU/ml, *finegoldiamagna* 10^3 CFU/ml. The wound healed by primary intention. The drain was removed on the 7th day after the operation.

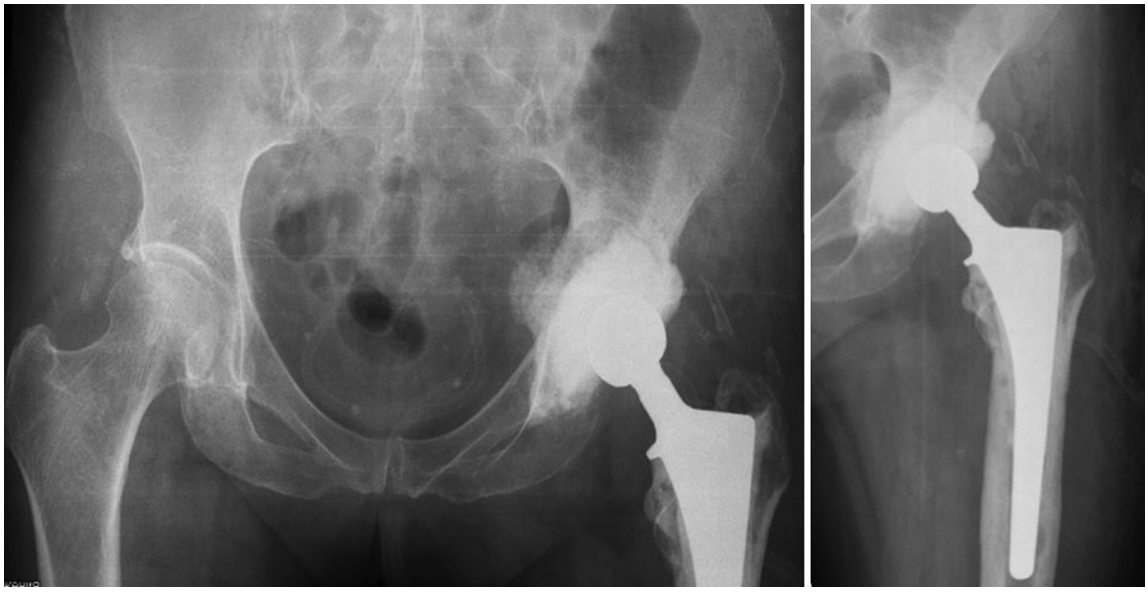

Fig. 7 Radiographs of the pelvis and left hip joint after surgical treatment that comprised defect filling with allobone and installation of an articulating antibacterial spacer

After the first stage of surgical intervention, a six-week course of etiotropic antibacterial therapy was administered: in the hospital for 2 weeks, intravenously vancomycin 1.0 g twice a day and cefoperazonsulbactam 2.0 g twice a day. In the outpatient stage of treatment, a course of oral and intramuscular antibiotics was prescribed for 4 weeks: amoxicillin + clavulanic acid 1000 mg twice a day in tablets and cefoperazonsulbactam 2.0 twice a day intramuscularly.

Further, it was recommended to use crutches for walking with limited load on the affected limb until the following stage of surgical treatment.

After one month, some tests (ESR and CRP) were checked and radiography of the pelvis and left hip joint was repeated (Fig. 8). Laboratory test results: mild anemia (Hb 118 g/l), ESR 20 mm/h and CRP 2 mg/l.

During the follow-up examination after one month, it was established that there were no clinical and laboratory signs of recurrence of the disease (no wounds or fistulas, normotrophic scar); the spacer components were stable; the functional state of the left hip joint was 57 HHS points.

After 4 months, the patient was admitted to the clinic again for additional examination and the second stage of surgical treatment. Local status: no fistulas; a normotrophic scar in the left hip area; the patient moved with crutches. At the time of admission, the functional state of the left hip joint was 57 HHS points. Laboratory test results: complete blood count (Hb 130 g/l), ESR 30 mm/h and CRP 5 mg/l. No growth of the pathogens was detected in the puncture material from the left hip joint.

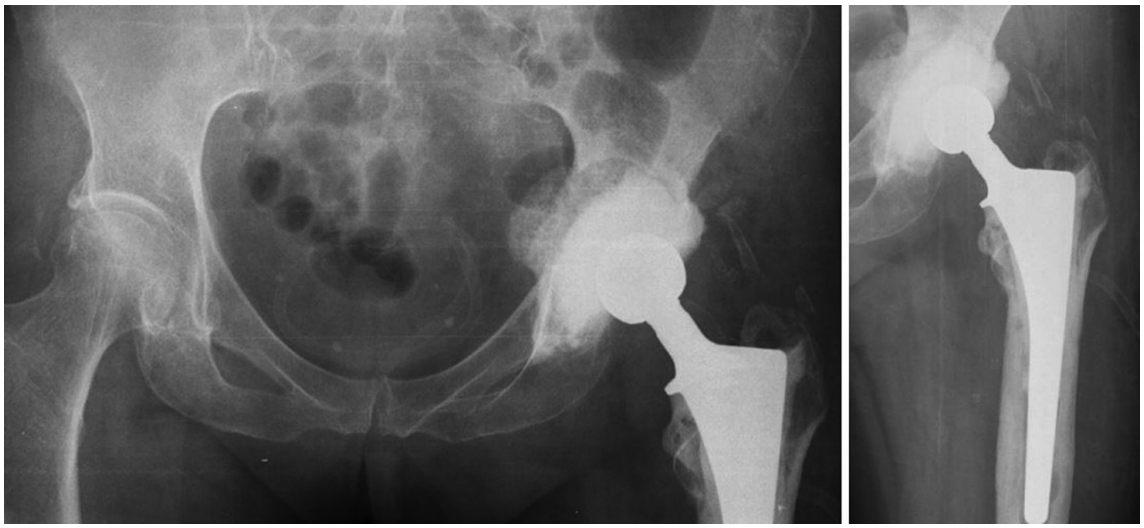

Fig. 8 Radiographs of the pelvis and left hip joint one month after the operation

In 2023, the second stage of a two-stage revision arthroplasty of the left hip joint was performed: removal of the spacer; debridement; installation of a cementless joint implant. The intraoperatively repaired defect was filled with dense bleeding bone tissue of a pale yellow color without signs of necrosis. Radiographs of the pelvis and left hip joint after surgery are shown in Figure 9. Blood loss was 300 ml, intraoperative blood transfusion was 250 ml. No growth of the pathogen from the implant was detected. The wound healed by primary intention. The drain was removed on the 5th day after the operation.

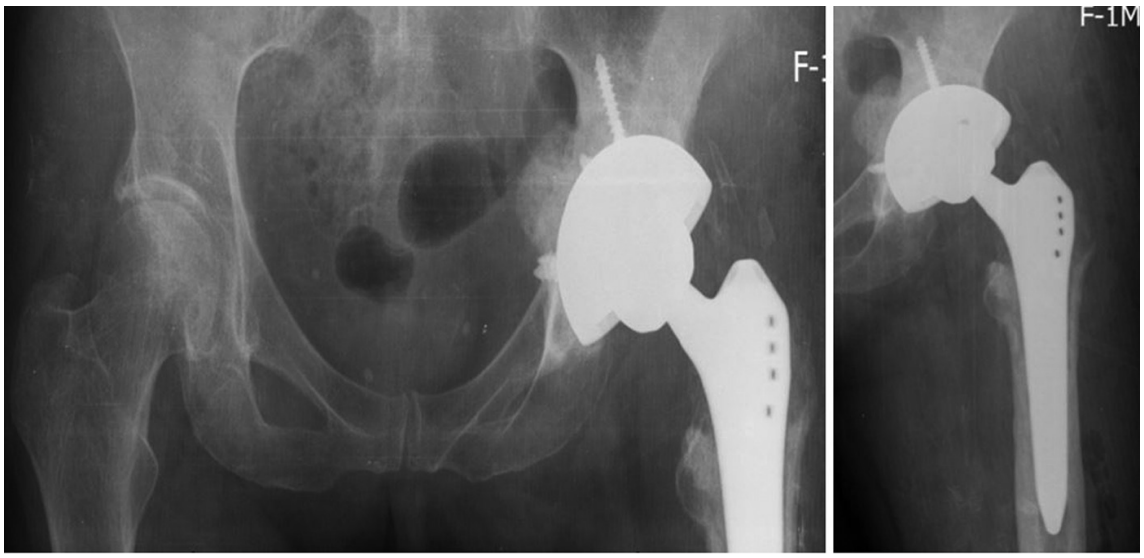

Fig. 9 Radiographs of the pelvis and left hip joint after surgical treatment

A 2-week course of antibacterial therapy was administered: intravenous linezolid 600 g twice a day and meropenem 1.0 g twice a day. At the outpatient stage of treatment, a 4-week course of oral antibiotics was prescribed: amoxicillin + clavulanic acid 1000 mg twice a day and levofloxacin 500 mg twice a day. The patient was recommended to use crutches for walking with limited load on the affected limb for 3 months. After 6 months, ESR and CRP studies and pelvic radiography were performed (Fig. 10). Laboratory test results: mild anemia (Hb 102 g/l), ESR 22 mm/h and CRP 6 mg/l.

At a follow-up examination after 6 months, it was established that there were no clinical and laboratory signs of recurrence of the disease (no wounds or fistulas, normotrophic scar), the components of the implant were stable, the functional state of the left hip joint was 76 HHS points.

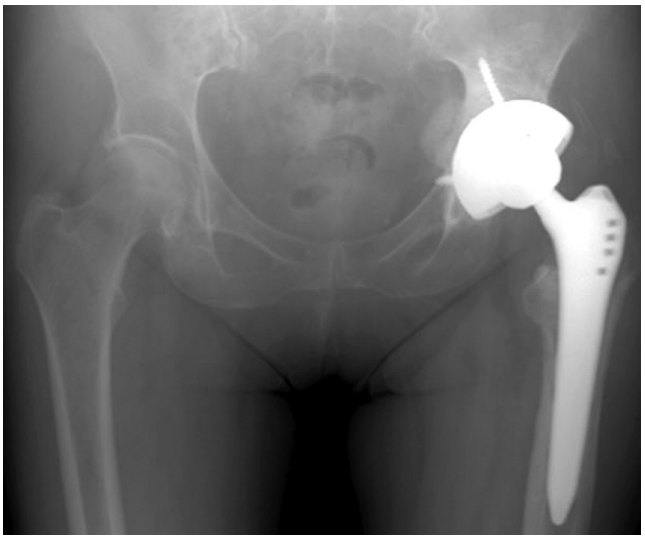

Fig. 10 Radiograph of the joint 6 months after the operation

DISCUSSION

Treatment of PJI usually requires several traumatic surgical interventions, long courses of etiotropic antibiotic therapy, which together affect the quality and duration of life of the patient [13, 14]. In the domestic literature, clinical examples of PJI treatment are not numerous [15]. In the case of recurrent PJI, persistent microflora and large bone defects, surgeons are often forced to use radical operations, such as resection arthroplasty and limb disarticulation [16]. In the clinical cases presented, we managed to avoid possible complications, including damage to the main vessels, which, according to literary data, occur in 0.25 % of cases [17].

There are many different types of spacers for the treatment of periprosthetic infection: block-shaped and articulating, preformed and custom-made, as well as those made in the operating room [18, 19]. Revision arthroplasty is often complicated by decreased tissue elasticity and the formation of dense scars. Large cavitary defects of the bottom and walls of the acetabulum due to a pronounced infectious process, as well as osteoporosis, affect the quality of osseointegration of the pelvic component when installing a permanent implant at the second stage of surgical revision. The main advantages of an articulating spacer after radical debridement are compensation for shortening and restoration of weight-bearing capacity, as well as filling the wound cavity and preventing tissue shrinkage.

In our clinical examples, cavitary defects were repaired and the function of the hip joint was restored at the sanitizing stage. Similar clinical data are not available in the literature. According to the literature, failures are often accompanied by aseptic loosening, recurrent infection, as well as dislocations and possible periprosthetic fractures [20, 21]. Reconstructive repair of large defects is a challenging task for surgeons. Multiple revision surgeries on the same joint impair the quantity and quality of bone tissue significantly. In large defects of the bottom, reconstructive implants are used, which increase the cost of patient treatment. The examples described above demonstrate the implementation of the second stage of revision intervention without the use of antiprotrusion rings, augments and columns with porous tantalum, which technologically simplifies the operation.

In general, the treatment of PJI is a complex clinical task, the solution of which requires comprehensive monitoring by various specialized specialists (orthopedist, pharmacologist, microbiologist, and others) and the development of personalized treatment and diagnostic measures with the optimal selection of etiotropic antibiotic therapy and technical means for implementing revision interventions (including implants) in each specific case [22]. All of the above factors have impact on the duration of inpatient treatment for patients with periprosthetic infection and the amount of financial costs [23, 24].

In the clinical examples presented above, the defects of the acetabulum were filled with bone-plastic material. As a result of treatment, in the first clinical case, it was possible to restore the joint function from 24 to 85 HHS points, in the second one from 27 to 76 points. These scores correspond to the literature data in the tactics of two-stage revision arthroplasty [25, 26].

The series of clinical cases was small. We believe that such methods of defect repair might gain popularity in patients with severe acetabular defects,.

CONCLUSION

The technique of defect compensation in the treatment of PJI shown in the presented above clinical cases is effective and cost-expedient. It enables to stop infection and improve functional results.

Conflict of interest *Not declared.*

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Information about the authors:

Nikita I. Rozhkov — post-graduate student, orthopaedic surgeon, digham@mail.ru, https://orcid.org/0000-0003-1848-9839;

Artem M. Ermakov — Doctor of Medical Sciences, Head of the Clinic, ema_cab@mail.ru, https://orcid.org/0000-0002-5420-4637;

Aleksandr S. Triapichnikov — Candidate of Medical Sciences, Researcher, Head of Department, pich86@bk.ru, https://orcid.org/0000-0001-7305-506X;

Natalia V. Sazonova — Doctor of Medical Sciences, Head of Department, nv.sazonova@yandex.ru.

Review article
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Temporary osteosynthesis of the tibial bones in repair of multiple and combined injuries

I.Yu. Khodjanov[1], L.A. Amonov[2]✉, F.M. Makhsudov[2]

1 Republican specialized scientific and practical medical center of traumatology and orthopedics, Tashkent, Uzbekistan

2 Navoi branch of republican research center of emergency medicine, Navoi, Uzbekistan

Corresponding author: Laziz Amonovich Amonov, lazizamonov0728@gmail.com

Abstract

Background The incidence of injury worldwide remains high, with a global estimate of 6763 cases per 00,000 population (95 % confidence interval 6412–7147). Trauma to the limbs is a common injury to an individual anatomical area during multiple or combined trauma that accounts for 40 % to 85.2 % of cases. Assessment of the effectiveness of different fixation options and development of treatment algorithms are essential for patients with tibial fractures and multiple (combined) injuries.

The **objective** was to determine how often temporary tibia fixation is applied for patients with multiple and combined injuries.

Material and methods The original literature search was conducted on key resources including Scientific Electronic Library (www.elibrary.ru), the National Library of Medicine (www.pubmed.org), CyberLeninka between 2008 and 2023 using search words and phrases: tibial injuries, osteosynthesis of lower limbs, multiple injuries, combined injuries, temporary osteosynthesis of the tibial bones.

Results and discussion A differentiated approach to the repair of bone fractures resulting from multiple and combined injuries is mostly common with the choice of fixation technique depending on the severity of injury and the severity of the patient's condition. The definitive internal bone fixation is normally used for stable patients, "damage control" strategy is secured for borderline and severe cases using primary temporary external fixation followed by staged surgical intervention. There is no generally accepted strategy for the use of early mobilization of long bone fractures as a component of anti-shock measures in a polytrauma patient.

Conclusion Certain issues remain unresolved, including the use of osteosynthesis for tibial fractures in some cohorts of patients, the optimal time of transition to definitive internal fixation, the possibility of using extrafocal osteosynthesis as a definitive treatment, the optimal configuration and assemblies to be employed. The lack of high-quality randomized controlled trials in this field is an important limitation.

Keywords: bone fixation, multiple injuries, combined injuries, tibia

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INTRODUCTION

The incidence of injury worldwide remains high, with a global estimate of 6,763 cases per 100,000 (95 % confidence interval 6412–7147). In European countries, it varies depending on the region ranging between 9,600–16,100 cases per 100,000, and in Central Asia it is about 10,300 cases per 100,000 [1]. Trauma is one of the main causes of disability in adolescents, young and middle-aged individuals (range, 10–49 years). According to the Global Burden of Disease (GBD) study, transport injuries are a major cause of global disability-adjusted life-years (DALYs) and mortality [2]. The frequency of injuries is higher in male patients [1].

Although there is a decrease in mortality caused by injuries observed in recent decades, the frequency of trauma remains high and is estimated at 738 cases per 100,000 in 2017 [1], while injuries can account for 9 % of the total mortality [3]. The problem of injuries is essential for modern medicine.

Injuries to the limbs are among the most common injuries to individual anatomical areas in the structure of multiple or combined trauma and are observed in 40–85.2 % of patients [4–6]. Moreover, a limb fracture can be a dominant injury in terms of severity in severe combined trauma and polytrauma cases [7]. Long bone fractures are most common among the limb injuries observed in patients with multiple and combined trauma [4, 5]. Tibial bone fractures are one of the most common injuries to the limbs in patients with severe multiple injuries with tibial fractures observed in 12.6 % of patients, and fibula in 5.7 % [6]. Open tibial fractures are registered in 59.5 % of patients with severe injuries and 40.5 % sustain closed fractures [8]. Tibial fractures are common in patients with road traffic injuries (43 % of all limb injuries) [5]. Assessment of the effectiveness of different fixation options and development of treatment algorithms are essential for patients with tibial fractures and multiple (combined) injuries.

The **objective** was to determine how often temporary tibia fixation is applied for patients with multiple and combined injuries.

MATERIAL AND METHODS

The original literature search was conducted on key resources including Scientific Electronic Library (www.elibrary.ru), the National Library of Medicine (www.pubmed.org), CyberLeninka between 2008 and 2023 using search words and phrases: tibial injuries, osteosynthesis of lower limbs, multiple injuries, combined injuries, temporary osteosynthesis of the tibial bones. Literature reviews, original articles, and clinical studies were considered. About 700 sources that included the keywords were found. 52 sources were selected for review. Selection criteria included compliance with the topic of the review, consideration of the most relevant approaches in the strategy and treatment of the pathology. The review mainly includes articles by European authors.

RESULTS

Temporary osteosynthesis and its use in modern traumatology

In modern traumatology, osteosynthesis is understood as surgical reduction and alignment of bone fragments until they are completely fused [9]. According to the method of bone fixation, the following variants of osteosynthesis are distinguished [9, 10]:

Internal osteosynthesis:

— extramedullary osteosynthesis using plates, cerclages (not common);

— intramedullary osteosynthesis using screws or nails:

- intramedullary osteosynthesis with reaming;
- intramedullary osteosynthesis with blocking;
- osteosynthesis using implants made of titanium nickelide with shape memory.

Extrafocal osteosynthesis:

— transosseous osteosynthesis using external fixation devices (EFD) (for example, Ilizarov apparatus):

— osteosynthesis with EFD using pins;

— osteosynthesis using wires and pins (hybrid) devices.

Hybrid osteosynthesis using implants and EFD

Nailing can be combined with open reduction of bone fragments or performed as part of a minimally invasive intervention with the reduction performed in a closed manner and the implant be placed through small holes [9]. Osteosynthesis is divided into early (in the first 48–72 hours of injury) and delayed fixation performed at 7–10 days [10], late delayed osteosynthesis (more than 3 weeks). In addition, osteosynthesis can be primary or consist of two stages (conversion osteosynthesis): primary temporary and final. Conversion osteosynthesis is often used for multiple or combined injuries [11, 12].

Extrafocal techniques are employed for temporary osteosynthesis during staged surgical repair of fractures using pins, wires or hybrid EFD. According to the functional principle, EFD are divided into compression, distraction, compression-distraction and hinge-distraction. The EFD designs developed, often bear the author's name [13]. The Ilizarov compression-distraction apparatus is one of the most famous and widely used frames to facilitate bone reduction and fixation, distraction and compression, which promotes regeneration at the site of the bone defect. In addition to the use of the frames for acute fractures as a method of osteosynthesis, compression-distraction devices are used in the treatment of malunited fractures and nonunions, for arthrodesis and distraction of malunited bones [9, 14]. In the literature the title of the Ilizarov method covers the original design of the device and modified versions, including the use of wires and pins and pins only with circular supports, since they are based on the principle developed by G.A. Ilizarov [15].

The advantage with EFD includes the ability to quickly fix bone fragments in fractures of almost any anatomical location, low trauma, low blood loss, which allows for temporary osteosynthesis to be combined with other surgical interventions, which is important for patients with concomitant trauma and polytrauma. Extrafocal osteosynthesis can be performed by several trauma teams in the presence of fractures of different anatomical locations [10, 16]. Although there is controversy in the incidence of infectious complications during the staged treatment of fractures compared with primary intramedullary nailing temporary extrafocal osteosynthesis can be practical for preventing deep infection in open fractures [17, 18]. The availability of equipment for extrafocal osteosynthesis in most trauma hospitals and departments is another advantage with the techniques.

The disadvantages of temporary extrafocal osteosynthesis include the difficulty of optimal reduction in closed fractures, instability and a higher incidence of malunion [19]. With the advantages of using half-pins with EFD for temporary bone fixation, the constructs fail to provide sufficient fixation for ambulation and rehabilitation and cannot be employed for a long term. Also important for when using AVF is Regular checkups of the attending orthopaedic and trauma surgeon is essential for successful fracture consolidation with EFD [16, 17, 20].

The use of conservative methods including plaster cast and skeletal traction, is limited for lower limb fractures due to long-term immobilization and a greater risk of associated complications for patients with severe multiple and combined injuries. Conservative methods may fail to provide good bone fixation and are associated with a higher risk of instability and malunion [21]. Conservative methods were recommended for severe cases with ISS greater than 40 and unstable hemodynamics, considering the condition as a relative contraindication to EFD [10]. However, in recent years, the results of studies have shown successful use of EFD in severely injured patients with ISS > 40 [22]. The use of EFD used to repair fractures in patients with severe trauma and unstable hemodynamics is included in the draft of the Russian clinical guidelines for the management of patients with combined trauma and polytrauma, while conservative treatment is secured for extremely unstable patients. The advantages of temporary osteosynthesis using EFD explain facilitate the method to be applied in patients with severe and extremely severe condition, concomitant trauma and polytrauma. Temporary osteosynthesis is well consistent with the principles of "damage control" strategy, discussed below, which are now generally accepted in the treatment of patients with multiple injuries or polytrauma [23, 24].

In recent years, new external fixation systems have been developed to provide more reliable fixation [25] and potentially reduce the incidence of malunion with temporary osteosynthesis. Tibial fractures are a common indication for various types of osteosynthesis. Depending on the location, tibial fractures are divided into fractures of the tibial shaft (isolated or in combination with broken fibular), fractures of the proximal epiphysis (tibial plateau, tibial condyles) and fractures of the distal epiphysis (including pylon fractures). In addition, patellar fractures are sometimes classified as tibia fractures [12]. The 2018 the Orthopedic Trauma Association (OTA) and the AO Foundation provided fracture classification scheme including tibia [12]:

1. Tibial fractures:

- *Proximal end segment (41)*:
  - 41A — extraarticular (A1 — avulsion, A2 — simple metaphyseal, A3 — metaphyseal wedge or multifragmentary);
  - 41B — partial articular (B1 — split, B2 — depression, B3 — split depression);
  - 41C — complete articular (C1 — simple articular, simple metaphyseal, C2 — simple articular, wedge or multifragmentary metaphyseal, C3 — fragmentary or multifragmentary metaphyseal);
- *Diaphyseal segment (42)*:
  - 42A — simple (A1 — spiral, A2 — oblique, A3 — transverse);
  - 42B — wedge (B2 — intact wedge, B3 — fragmentary wedge);
  - 42C — multifragmentry (C2 — intact segmental, C3 — fragmentary segmental);
- *Distal end segment (43)*: classification of subtypes A, B and C is similar to that for proximal end segment fractures.

2. Fibula (4F):

- *Proximal end segment (4F1)*:
  - 4F1A — simple;
  - 4F1B — multifragmentry;

- *Diaphyseal segment (4F2)*:
  - 4F2A — simple;
  - 4F2B — wedge or multifragmentary;
- *Distal end segment (4F3)*: subtypes A and B are similar to those for the diaphyseal segment.

3. Malleolar segment (44):

- *Infrasyndesmotic fibula injury (44A)*:
  - 44A1 — isolated fibula injury;
  - 44A2 — with medial malleolar fracture;
  - 44A3 — with posteromedial fracture;
- *Transsyndesmotic fibula fracture (44B)*:
  - 44B1 — simple fibula fracture;
  - 44B2 — with medial injury;
  - 44B3 — with medial injury and fracture of the posterolateral rim (Volkmann's fragment);
- *Suprasyndesmotic fibula fracture (44C)*:
  - 44C1 — simple diaphyseal fibula fracture;
  - 44C2 — wedge or multifragmentary diaphyseal fibula fracture;
  - 44C3 — proximal fibula injury.

According to modern concepts, fracture fixation should be provided for patients with multiple and combined injuries on the first day of injury. The strategy with primary internal fixation or staged interventions (temporary external osteosynthesis and subsequent delayed definitive procedure) must be chosen individually, and unreasonable refusal of early definitive osteosynthesis in stable patients and long-term surgical interventions in unstable and borderline patients should be avoided. Dynamic assessment of clinical and laboratory parameters is essential for the timing of surgical intervention [26, 27]. However, there is a lack of research regarding the effectiveness of the approaches in patients with certain fracture sites [28].

The use of temporary osteosynthesis for tibia fractures and multiple and combined injuries

Conservative methods of fracture fixation including plaster cast are a good method for low-energy closed fractures of the tibia [29], but are associated with a high risk of complications in patients with multiple and combined trauma including hypostatic pneumonia, thromboembolic complications and bedsores. Long-term use of conservative techniques can lead to a higher risk of muscle atrophy and joint contractures, and inadequate circulation can result in a greater risk of nonunion, which is generally higher in polytrauma patients [30]. The use of internal osteosynthesis in patients with multiple and combined injuries can be limited because of the severe condition and the risk of "secondary impact" during long-term surgical interventions. External osteosynthesis with EFD is an option for this cohort of patients [16, 31, 27].

EFD is commonly used for tibia fractures is due to the anatomy, superficial location and the absence of muscles on 1/3 of the surface of the tibia. Extrafocal osteosynthesis may have additional advantages compared to internal techniques taking into account the relatively poor development of soft tissues and the high risk of open fractures due to the anatomical localization of the tibial bones. Wires and half-pins can be practical for tibia placement due to muscles of small thickness [21].

There is a paucity of data to compare the effectiveness of EFD and internal hardware with regard to external fixation as the definitive treatment. The results of treatment are difficult to interpret because many studies report patients with no differentiation of multiple, associated injuries, isolated fractures. Evidence regarding functional benefits of EFD or internal osteosynthesis and risk of complications remains controversial. A retrospective descriptive study showed a lower overall complication rate with use of transosseous osteosynthesis in patients with tibial fractures, as compared with conservative treatment, extramedullary and intramedullary osteosynthesis [32]. Major complications with transosseous osteosynthesis included bone displacement and osteomyelitis. External fixation can be associated with deformity at the level of a consolidated fracture, displacement of bone fragments and contractures of the ankle joint. Nailing can result in bone displacement and weak consolidation. Bone displacement, deformity at the level of a consolidated fracture and knee contracture were common complications observed in patients who received conservative treatment [32]. Good outcomes were reported in patients with complex fractures of the tibia treated with extrafocal osteosynthesis who developed local infection and broken wires [33]. Similar results were reported with EFD and circular supports used to treat patients with open tibial fractures and severely compromised soft tissues (Gustilo grade III). Good functional outcomes were reported with the use of the Ilizarov apparatus in patients with fractures of the proximal tibia [34].

Artemyev et al. reported the use of wires and half-pins of EFD for patients with open fractures of the tibial diaphysis (Gustilo grades I–II) complicated with pin tract infection (42.1 %) and delayed healing (1.8 %). The study included patients with isolated (75.4 %) and multiple and combined fractures. The authors first applied a temporary assembly using half-pins added with wires and half-pins for definitive phase without preliminary dismantling of the half-pin frame to reduce the length of surgical interventions. The use of half-pin devices as temporary fixation for short periods of transportation can be redundant and temporary transport immobilization followed by primary Ilizarov fixation can be more practical [15].

A higher rate of complications was reported in an earlier study of Ilizarov fixation of closed diaphyseal fractures of the tibia: 59 % of patients reported difficulties using the frame, 6 % developed pin tract infection, and 5 % had malunion of the fracture. The authors reported a lower incidence of knee pain with Ilizarov fixation [34]. A number of studies and meta-analyses have shown a higher incidence of infectious complications with EFD compared to IM nailing in patients with isolated open fractures of the tibial shaft and in polytrauma [35, 36, 37]. A meta-analysis suggested a higher incidence of fracture healing failures with EFD as compared with intramedullary osteosynthesis [36].

Outcomes of patients with severe tibial shaft fractures treated with external ring fixation were compared with those treated with internal fixation in a recent randomized trial (n = 254). Patients in the external fixation group were significantly more likely to have complications such as bone malalignment or rejection of the construct, while the incidence of other complications (deep infections, likelihood of amputation, nonunion or malunion, soft tissue problems), and the healing time were comparable [38].

Liu et al. reported a statistically higher incidence of superficial infections and malunion with external fixation as compared to intramedullary osteosynthesis in patients with open fractures of the tibia. Rejection of the construct was significantly greater with IM nailing. No statistically significant differences were reported for deep infections, the timing of fusion and nonunion rate [39]. Similar results were presented in a meta-analysis comparing the outcomes of ORIF and external fixation

in patients with open pylon fractures: superficial infections, nonunion, osteoarthritis, and the need for bone grafting were statistically significantly more common in the external fixation group, and no differences were observed in the incidence of deep infectious complications and functional outcomes [40].

However, caution should be exercised in transferring the results of studies involving patients with isolated fractures to patients with multiple and associated injuries, since concomitant injuries have an impact on fracture healing [41]. In this regard, the outcomes of different fixation methods may differ in patients with isolated and multiple (combined) injuries. In a retrospective analysis Bondarenko et al. suggested that the lowest complication rate was observed in patients with tibial fractures treated with ORIF or IM nailing at the second stage of treatment, and EFD was useful for patients with severe open fractures [42]. Extrafocal osteosynthesis as temporary fixation could not be recommended for patients with less severe injuries in a stable condition [43].

Gasser et al. reported the results of a retrospective study of 210 patients with diaphyseal fractures of the tibia or femur (a total of 244 fractures) as part of multiple trauma (ISS 16 or more) or with severe soft tissue damage (open fractures grade II and higher according to the Gustilo classification). The authors compared outcomes using three fracture treatment strategies: ETC (primary intramedullary osteosynthesis), DCO (staged intervention including temporary external fixation followed by definitive osteosynthesis with an intramedullary screw) and external fixation as definitive osteosynthesis [43], and showed a statistically significantly higher complication rate in the definitive external fixation group (69 % of fractures) compared with DCO and ETC (23 % and 20 %, respectively). The differences persisted when adjusting for severity of condition at admission, which was higher in the definitive and DCO groups. Major complications included failure in consolidation or function of the fixation system, delayed fusion or nonunion, and infectious complications. Based on the results of the study, it was concluded that external fixation could be used as a temporary technique in patients with diaphyseal fractures of the long bones of the lower limbs to be followed by internal fixation after stabilizing the patient's condition [43].

There are limitations of the above studies including the retrospective nature and small sample sizes, as conducting randomized trials in these patient populations poses significant challenges [44, 45]. Special registers and analysis of the accumulated data can be practical to obtain more objective data. For example, results from the multicenter FROST registry (Fracture-Related Outcome Study for operatively treated Tibia shaft fractures) are currently awaited, which could potentially increase understanding of complication rates across modalities used to repair tibial fractures [46].

An optimal configuration and assembly of EFD for osteosynthesis of long bone fixation in patients with multiple and combined injuries or polytrauma are an open question. They must provide reliable bone fixation, and the ability to quickly apply the device is important for patients in serious condition. In the study by Alsmadi et al. it was noted that in patients with severe trauma (ISS more than 40), the use of single-plane half-pin EFD can be associated with a higher risk of complications (pin tract infection, migration of half-pins and formation of bedsores) as compared to two- and multi-plane devices, which may occur due to insufficient stabilization of the fracture. The differences were not found in patients with less severe injury (ISS less than 40) [22].

A decrease in the incidence of pin tract infection, formation of joint contractures was detected with use of the original design of a transosseous single-plane external fixation device [47]. Hybrid half-pin distraction-reduction constructs consisting of rings or half-rings connected by rods

can be used for temporary osteosynthesis; however, further research is needed to evaluate their advantages and disadvantages in clinical practice [48, 49, 50]. Good results have been shown using EFD with sectors, bars and half-pins to repair fractures of long bones of the lower limbs [50].

The optimal time for conversion to definitive internal fixation in patients with tibial fractures as part of multiple and combined injuries is debatable at the moment. Research results remain conflicting. A recent study showed no statistically significant differences in complications (superficial or deep infection and nonunion) in patients who underwent definitive osteosynthesis at 7 days, at 7–13 days, or at 14 or more days, although the latter group had a longer surgical intervention to convert to definitive fixation [51].

Another study showed a statistically higher occurrence of infectious complications in patients with open tibial fractures repaired with external fixation for ⩽ 14 days compared with external technique used for the first 14 days or 15–28 days of injury with a relatively small number of patients with severe soft tissue injuries (Gustilo type III) being a limitation of the study [20].

DISCUSSION

Literature review has shown that there is no generally accepted strategy among the professional community for early mobilization of long bone fractures used as an anti-shock measure in polytrauma patients. The statistical data on errors, complications and treatment outcomes vary significantly and sometimes contradict each other, which indicates the complexity and multifactorial nature of the process that can have a decisive influence on the final clinical and functional outcome.

Internal and external fixation techniques are commonly used for the condition. The internal surgical intervention is produced according to the “do it and forget it” principle. The procedure cannot be produced for polytrauma patients due to the lack of necessary equipment or conditions for its implementation, the presence of fractures complicated by compromized soft tissues, neurovascular structures, infection which are common for polytrauma. The factors significantly limit indications for the use of the techniques. Another limitation with the techniques is the impossibility of creating optimal conditions for reparative osteogenesis while the patient is in bed and the difficulty of manipulating bone fragments if needed.

The transosseous osteosynthesis method, which can be performed in any modifications, does not have these disadvantages; it can be easily supplemented in a minimally traumatic form at the initial stages to solve a specific clinical problem. The advantages include the ability to create optimal conditions for bone consolidation during early functional loading and the ability to reduce the bone, which can be performed at a suitable time. The Ilizarov apparatus can be applied for all cases where internal fixation fails.

Therefore, the cases that cannot be treated with internal techniques on the “set and forget” principle, the Ilizarov fixation can be used as a temporary modification and the most universal and adaptable method of transosseous osteosynthesis, that can be supplemented to expand its functionality.

CONCLUSION

With high prevalence of tibial fractures in patients with multiple and combined injuries, the choice of optimal treatment remains an important issue. Currently, the most common is a differentiated approach is employed for repair of fractures in this cohort of patients with the choice of osteosynthesis technique being based on severity of patient’s condition and severity of injury. Stable patients

benefit from early definitive internal fixation; borderline and severe cases are treated with "damage control" strategy where temporary external fixation is initially performed to be followed by a staged surgical procedure. However, certain issues regarding the use of extrafocal osteosynthesis for tibia fractures in patients with multiple and combined injuries, including the optimal timing for transition to definitive internal fixation, the possibility of using extrafocal osteosynthesis as a method of final fixation, optimal configuration and assembly remain open. The lack of data from high-quality randomized controlled trials in this area is an important limitation.

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Information about the authors:

Iskandar Yu. Khodzhanov — Doctor of Medical Sciences, Professor, Head of Department, prof.khodjanov@mail.ru, https://orcid.org/0000-0001-9420-3623;

Laziz A. Amonov — Resident doctor, lazizamonov0728@gmail.com, https://orcid.org/0009-0008-4553-8046;

Farrukh M. Makhsudov — Head of Department, maxsudov707F@gmail.com.

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Surgical correction of posttraumatic triphalangeal joint flexion contractures of the fingers (systematic literature review)

N.V. Abdiba✉, L.A. Rodomanova, A.O. Afanasyev, A.E. Chizhov, A.R. Mironov, D.V. Romanov, E.S. Tsybul

Vreden National Medical Research Center for Traumatology and Orthopedics,
St. Petersburg, Russian Federation

Corresponding author: Nino V Abdiba, ninoabdiba@gmail.com

Abstract

Introduction Triphalangeal joint flexion contracture of the fingers is a common and challeging posttraumatic hand condition. The goal of surgical treatment is to correct finger deformity and increase interphalangeal range of motion.

The **objective** was to systematize data on the causes of post-traumatic triphalangeal joint flexion contracture of the fingers and methods of surgical correction.

Material and methods The original literature search was conducted on key resources including Scientific Electronic Library (www.elibrary.ru), the National Library of Medicine (www.pubmed.org), ScienceDirect, Google Scholar, Ovid databases according to PRISMA recommendations. Literature searches included both Russian and English studies, with one or more cases of post-traumatic triphalangeal joint flexion contracture of the fingers with the deformity surgically corrected. Cases of non-traumatic flexion contractures were excluded. Etiological factors of flexion contractures, heterogeneity of definitions and methods for recording the range of motion in the joint, anatomical features, surgical correction of flexion contractures and postoperative complications were reviewed.

Results Common causes of flexion contractures included burns (32.3 %), dislocations and fracture-dislocations of the finger joints (23.5 %). The median postoperative follow-up period was 13.5 months after surgical treatment. Surgical correction was produced with external fixation device (EFD) in 40 % of cases, open procedures performed in 50 % and a combined technique employed in one case (10 %). Based on calculations of the odds ratios of postoperative complications, a weak positive linear relationship was revealed between EFD and pain syndrome, and a weak negative linear relationship was observed between the open procedure and pain.

Discussion There is heterogeneity of approaches regarding methods for correcting flexion contractures, surgical approaches, techniques for mobilizing joints and releasing the anatomical structures of the finger with open procedures, the distraction rate with EFD, methods for repair of soft tissue defects following the treatment of flexion contractures of interphalangeal joint of a finger.

Conclusion Open procedures are commonly used for precise elimination of all components of flexion contracture of the joint and repair of soft tissue defects of the finger. A weak positive linear relationship was revealed between EF and pain syndrome. There was no significant correlation between open techniques and complications. There were no correlations between the treatment method and the contracture type; there are no treatment regimens for patients with this pathology.

Keywords: interphalangeal joint, contracture, flexion contracture of the joints of the fingers, stiff finger, contracture of the fingers, posttraumatic contracture of the fingers

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INTRODUCTION

Improvements in surgical techniques, metal constructs and suture material have significantly improved repair of hand injuries, but the long-term consequences of these injuries remain pertinent in modern traumatology and orthopedics [1]. Stiff finger joints, flexion contractures of the interphalangeal joints are difficult to treat. Contractures of the interphalangeal joints develop in 20–38 % of cases after hand injuries of varying severity [2–4]. In 1956, Sterling Bunnell was the first to note that the fingers tend to become rigid and assume a physiologically disadvantageous position reducing the limb function [5, 6]. Flexion contracture has a pathophysiological origin and becomes the outcome of hand injury with inadequate treatment strategy and postoperative rehabilitation [5]. There are many classifications of contractures of the finger joints.

Yang et al. graded contractures depending on the involvement of certain anatomical structures including pathology of the skin and fascia; muscle and tendon damage; injury to the capsular-ligamentous apparatus; injury to the bone structures of the hand [7]. Considering the anatomical substrate and the deficiency of joint function, contractures are graded as dermatogenous with a deficient function of 30 % of the norm; dermatodesmogenic with a deficient function of 60 %; dermatodesmoarthrogenic with a functional deficit of more than 60 % [8]. Jupiter et al. identified 8 types of finger joint contractures depending on injury to the volar or dorsal aspects of the fingers and limited range of passive or active movements in the joint [9]. A similar ambiguous situation is typical for methods of surgical treatment of flexion contractures. Depending on the severity of the contracture and involved hand structures, tenolysis of the flexors, reconstructive operations on the flexor and extensor apparatus of the hand [10, 11]; reconstruction, mobilization of the volar plate and retinaculum of the volar plate [7]; release of collateral ligaments of joints; elimination of scar contractures of the skin, including non-free and free skin grafting [12–14]; corrective operations on the bones of the hand can be produced [15]. A variety of methods for surgical correction of contractures is not a predictor of successful treatment; therefore, there is no consensus or strict algorithm for the treatment of flexion contractures of the three-phalangeal fingers in the world literature.

The **objective** was to systematize data on the causes of post-traumatic triphalangeal joint flexion contracture of the fingers and methods of surgical correction.

MATERIALS AND METHODS

Search and selection of publications

The systematic review was performed in accordance with the international requirements of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). First, three authors (A.N.V., A.A.O., Ch.A.E.) selected publications independently using the keywords: interphalangeal joint, contracture, surgical treatment, flexion contractures, stiff finger, posttraumatic / post-traumatic, digital, finger joint, joint mobilization / arthrolysis in Russian and in English.

The original literature search was conducted on key resources including Scientific Electronic Library (www.elibrary.ru), the National Library of Medicine (www.pubmed.org), ScienceDirect, Google Scholar, Ovid databases according to PRISMA recommendations using combinations of operators OR, AND, NOT and the above keywords. The search in PubMed (MEDLINE) included the following combination of keywords: (posttraumatic OR post-traumatic) AND (flexion deformity finger) OR (stiff OR contracture) AND (finger OR proximal OR distal interphalangeal joint) AND (surgery OR surgical) NOT arthritis NOT Dupuytren NOT congenital NOT foot NOT elbow.

The retrospective search was unrestricted and the last search date was 01/10/2023. Literature search included the MeSH term (Flexion contracture of finger). Search queries in the databases were used in various combinations as a preliminary option. Inclusion and exclusion criteria of articles were determined at the first stage.

Inclusion criteria included:

— articles in Russian or English;

— patients aged greater than 9 years at the time of surgical treatment;

— use of surgical techniques aimed at correcting flexion deformity of the three-phalangeal fingers;

— etiologically post-traumatic nature of the flexion contracture of the three-phalangeal fingers;

— case reports analyzing treatment outcomes of one or more patients - the study included articles of level IV (case series) and higher in accordance with the hierarchy of evidence of the National Health and Medical Research Council (NHMRC);

— combination of post-traumatic deformity of the interphalangeal joint and metacarpophalangeal joint was acceptable, provided that the first was necessarily present.

Exclusion criteria:

— neurogenic contractures of the interphalangeal joints of the fingers, diseases and consequences of damage to the central nervous system;

— multiple malformations of the upper limbs;

— severe burns grades 3, 4, extensive burns covering the hand and fingers;

— orthopedic consequences of autoimmune diseases (systemic lupus erythematosus, scleroderma, rheumatoid arthritis, etc.);

— flexion contractures of the finger joints due to palmar fascial fibromatosis (Dupuytren's disease);

— exclusively minor research subjects (articles with groups of patients of heterogeneous age characteristics are included in the review).

The study included original articles with information about minor patients due to a paucity of publications matching the inclusion criteria. A manual search of references in identified articles was conducted to review additional studies that may be of interest. At the second stage, abstracts of publications were analyzed for compliance with inclusion and exclusion criteria, and duplicate works were searched for the purpose of the elimination. Full-text articles that met the criteria of the systematic review were examined at the third stage. The analysis of the literature in the libraries over the past 50 years revealed a paucity of contributions on the topic, a lack of uniformity in definitions, interpretation of goniometry parameters and calculation of the amplitude of movements in the interphalangeal joint of the hand, therefore, articles with incomplete data were included in the work. To avoid misunderstandings, we would discuss flexion contractures of the interphalangeal joints of the fingers, meaning the finger flexed in the interphalangeal joint with limited active and passive extension, preserved or deficient flexion in the joint [16]. The articles where the condition was interpreted in a different manner were excluded to maintain the homogeneity of the study.

Design of the study

An initial search in the databases identified 267 sources. Articles that were not relevant to the topic, book chapters, comments to articles, and articles in other languages (except for English and Russian) were excluded and 136 articles were selected for initial screening. With titles, abstracts, and full-text publications reviewed 10 articles (3.7 %) were identified that met the inclusion criteria and were relevant to the objective of the work, considering the exclusion criteria and heterogeneity in the interpretation of nosology definitions. The study selection process is presented in Figure 1.

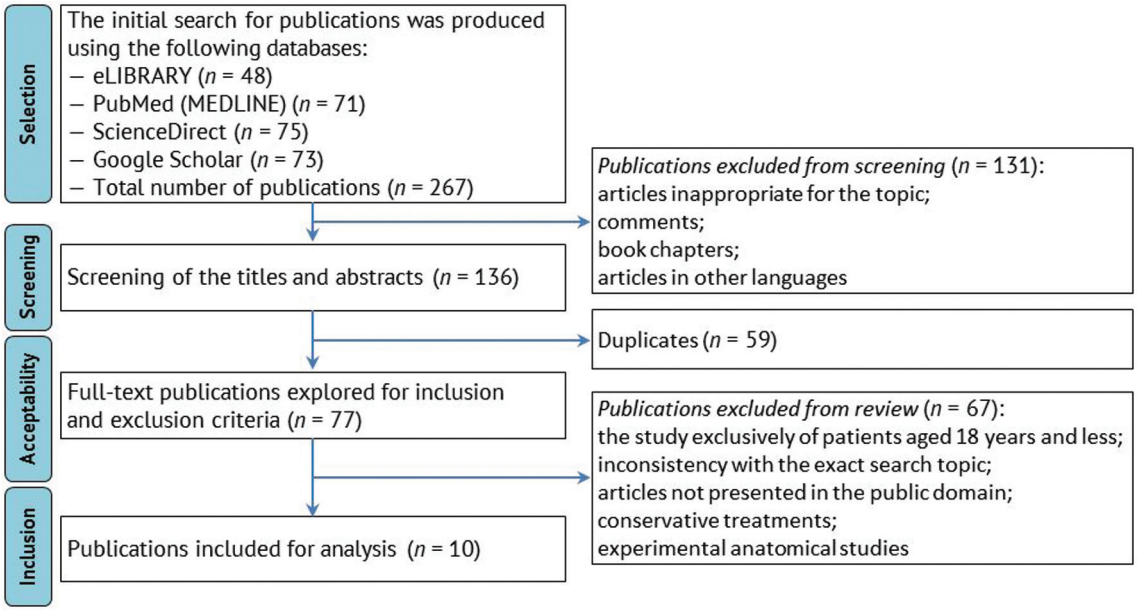

Fig. 1 Study inclusion flowchart using Preferred Reporting Items for Systematic Reviews and Meta-Analysis Guidelines [26]

Table 1

Summary table of articles included in the systematic literature review

Authors	Number of patients included in the study (*n*)	Patients who received treatments (*n*)	Type/mechanism of primary injury (*n*)	Average time from injury to surgery (months)	The joint of the triphalangeal finger involved in the deformity (*n*)
Ravishanker et al., 2003 [18]	17	21	burn (*n* = 15); posttraumatic (*n* = 2) (ns)	–	PIPJ DIPJ
da Silva et al., 2004 [17]	1	2 (II — 1; III — 1)	flexor tendon injury. 2,3 fingers	240	PIPJ DIPJ
Houshian et al., 2007 [24]	10	10 (II — 2; III — 1; IV — 2; V — 5)	dislocations, fracture-dislocations (ns)	15.5	PIPJ
Houshian et al., 2007 [19]	30	30 (II — 5; III — 2; IV — 7; V — 16)	dorsal fracture-dislocation (*n* = 19); volar fracture-dislocations of the middle phalanx (*n* = 7); dislocation of the middle phalanx (*n* = 4)	20	PIPJ
Hahn et al., 2010 [20]	9	9 (III — 1; IV — 5; V — 3)	burn (*n* = 4); use of split skin grafts to repair defects on the palmar surface of fingers (*n* = 3); tumor removal (*n* = 2)	249.6	PIPJ
Ahmad, 2014 [21]	56	–	burn (*n* = 31); posttraumatic (ns) (*n* = 21); post-infection (*n* = 4)	–	PIPJ
Antonova, Ivchenko, 2016 [14]	13	14 (II — 6; III — 5; I — 3)	burn (*n* = 5); electric trauma (*n* = 2); laceration (*n* = 3); incised wound (*n* = 2); mine-blast wound (*n* = 1)	5	PIPJ
Tsenget al., 2017 [22]	2	3 (III — 1; IV — 2)	surgery for stenosing ligamentitis (*n* = 1); industrial combined injury (ns) (*n* = 1)	–	PIPJ
Bogov et al., 2022 [25]	30	37	posttraumatic genesis (ns)	–	PIPJ
Su et al., 2023 [23]	2	2 (III — 1; IV — 1)	Impact with a ball (n = 1) (ns); incised wound and flexor tendon injury (*n* = 1)	1 patient (240) 2 patient (> 12)	PIPJ

Table 1 (continued)

Summary table of articles included in the systematic literature review

Authors	Surgical treatment used	Conservative treatment added	Mean follow-up period (mo)	Complications (*n*)
Ravishanker et al., 2003 [18]	EFD	hand rehabilitation; antimicrobial therapy	the longest follow-up period of 31 months	pin tract infection (*n* = 2); marginal necrosis (*n* = 2)
da Silva et al., 2004 [17]	EFD (patent) monolateral external fixator	hand rehabilitation	9	none
Houshian et al., 2007 [24]	EFD	hand rehabilitation	12	relieved pain syndrome (*n* = 3)
Houshian et al., 2007 [19]	EFD monolateral external fixator	hand rehabilitation; antimicrobial therapy; NSAID	34	pin tract infection (*n* = 5); relieved pain syndrome (*n* = 9); temporary flexion deformity of the DIPJ (*n* = 1)
Hahn et al., 2010 [20]	scar excision, arthrolysis, transarticular fixation of the PIP joint with a wire, defect repaired with a cross flap	hand rehabilitation	41.2	paresthesia of the fingers (*n* = 2); marginal necrosis (*n* = 1)
Ahmad, 2014 [21]	Z-plasty (*n* = 4); mobilization, skin graft (n = 38); mobilization, flap (*n* = 11)	hand rehabilitation	15	partial necrosis of the skin graft (*n* = 5); infection (*n* = 3);
Antonova, Ivchenko, 2016 [14]	island flap on the proper digital artery from the adjacent finger (*n* = 14), of which (*n* = 9) the proper digital nerve was included in the flap pedicle; PMJ capsulotomy of PIPJ (*n* = 4)	hand rehabilitation, NSAID, drugs that improve rheologic blood properties (ns)	12	relapse (*n* = 2)
Tsenget al., 2017 [22]	palmar neurovascular displacement flap (*n* = 3); tenolysis of the flexors (*n* = 2) and mobilization of the palmar plates, collateral ligaments (*n* = 3)	hand rehabilitation	–	hypaesthesia of the flap (*n* = 5); marginal necrosis (*n* = 1)
Bogov et al., 2022 [25]	arthrolysis, dynamic distraction device (modified)	hand rehabilitation, administration of hyaluronic acid and platelet-rich plasma	–	none
Su et al., 2023 [23]	arthrolysis, tenolysis, replacement of the defect with a displaced skin-fat flap	hand rehabilitation	3	–

Note. PIPJ — proximal interphalangeal joint; DIPJ — distal interphalangeal joint; NSAID — nonsteroid anti-inflammatory drugs; n — number of observations; IPJ — interphalangeal joint; EFD — external fixation device; «–» — no data presented in the article; ns — not specified.

Risk of systemic errors

A methodological quality assessment was produced for each series according to the Oxford Center for Evidence-Based Medicine (CEBM) criteria to determine the level of evidence. Case reports and case series were analyzed using the eight-item Joanna Briggs Institute Critical Appraisal Tool (JBI), and the same JBI Critical Appraisal Tool consisting of eleven questions was used for two cohort studies. The results of the study are presented in Figure 2.

Statistical analysis

Statistical analysis was performed for 10 articles corresponding to the objectives of the work; summing up the study objects, 170 patients were identified. Treatment effectiveness could not be evaluated due to the fact that 80 % of the studies [14, 17–23] were represented by case series and individual clinical observations. The available data allowed us to identify common surgical treatments, anatomical application of surgical correction, analysis of outcomes (primary evidence of effectiveness), and complications. Descriptive statistics methods were used: percentage of etiological causes of flexion contractures, median postoperative observation period, percentage distribution of surgical correction methods.

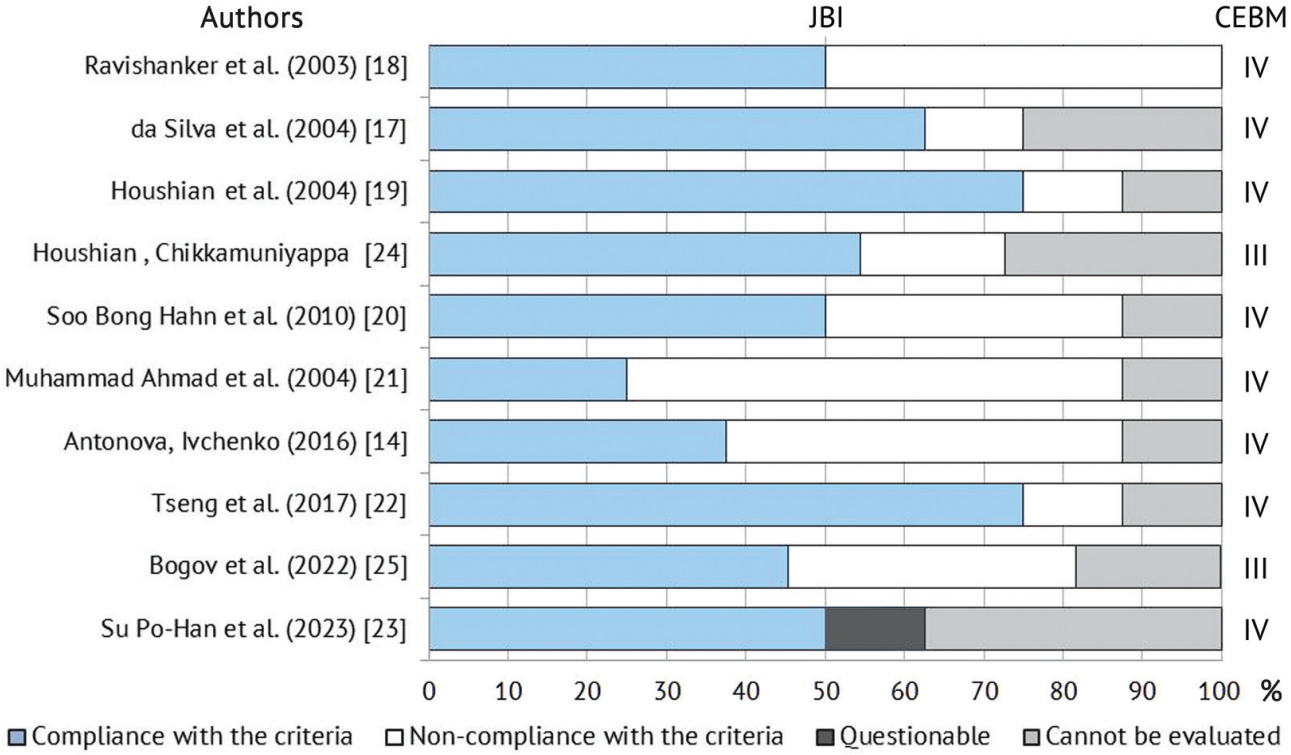

Fig. 2 Methodological assessment of the quality of articles included in a systematic literature review

Postoperative complications were analyzed using the odds ratio (OR) with the compilation of a multifield contingency table. None of the studies revealed correlations between the choice of treatment method and the type of contracture; none of the classifications mentioned were used. The linear relationship between two methods of surgical treatment (EFD, open method) and six types of complications (marginal necrosis, infection, recurrence of deformity, pain, other nonspecific complications, neurological disorders) was considered.

The data are presented on a dichotomous scale (Table 2), where:

(1) presence of a complication or use of an appropriate treatment method;

(0) no complication or use of another treatment method.

The calculation was produced using a contingency table, which reflects the number of joint occurrences of pairs of values of two variables (method, complication):

To determine the linear relationship, we used the correlation coefficient for dichotomous variables — coefficient φ:

Table 2

Scheme for constructing a contingency table

		Method	
		0	1
Complication	0	*A*	*B*
	1	*C*	*D*

Note: *A* is the number of cases when variables were equal to 0 at the same time; *B* is the number of cases when the "Method" variable was equal to 1, the "Complication" variable was equal to 0; *C* was the number of cases when the "Method" variable was equal to 0, the "Complication" variable was equal to 1; *D* was the number of cases when the variables were equal to 1 at the same time

$$\varphi = \frac{(AD - BC)}{\sqrt{(A + C)(B + D)(A + B)(C + D)}}.$$

Table 3 presents the correlation between surgical treatment methods and types of complications. The resulting correlation coefficient allowed us to assess the strength of the relationship between two variables (Table 4).

Table 3

Correlation coefficient of two methods in relation to various types of complications

Complication	EFD	Open method
Marginal necrosis	–0.06452903769908233	0.06452903769908233
Infection	0.17059725865786293	–0.17059725865786293
Recurrent deformity	–0.07839895392736086	0.07839895392736086
Pain	0.35317945776459336	–0.35317945776459336
Other nonspecific complications	0.09884244757168141	–0.09884244757168141
Neurological disorders	–0.1487282099557987	0.1487282099557987

Table 4

Correlation of the resulting coefficient with the strength of the relationship between two variables

Value (modulo)	Correlation
up to 0.2	very weak
up to 0.5	weak
up to 0.7	medium
up to 0.9	high
over 0.9	very high

RESULTS

Based on this number of patients, the percentage of etiological causes of flexion contractures of the finger joints was calculated, which are presented in Table 5. Common causes of flexion contractures included burns (32.3 %) [14, 18, 20, 21], dislocations and fractures. dislocations of the joints of the fingers (23.5 %) [19, 24]; post-traumatic genesis of the pathology without an accurate description of the mechanism of injury and damaged structures (32.3 %) was reported [18, 21, 23, 25].

Table 5

Etiology of flexion contractures of the finger joints

Etiology	Number of patients	
	abs.	%
Posttraumatic genesis (not specified)	55	32.3
Burn	55	32.3
Dislocation, fracture-dislocation	40	23.5
Complication after surgery for stenosing ligamentitis	1	0.6
Electric trauma	2	1.2
Laceration	6	3.5
Incised wound	4	2.4
Mine-blast trauma	1	0.6
Removal of tumour	2	1.2
Post-infection genesis	4	2.4

The causes of flexion contractures can be predictable with explainable etiological factors to include electrical injuries, mine blast wounds and infections. Incised and lacerated wounds with the directions of skin injury being spontaneous and not corresponding to the surgical lines of the incisions can be associated with pathological scars and limited mobility in the joint [27, 28].

In our series, the procedure caused flexion contracture in one patient [22], and complications were reported in some articles that were not included in the systematic review [29, 30]

The frequency of complications after open ligamentotomy ranges from 1 to 43 %. Surgical outcomes of 795 fingers were associated with complications (pain, swelling, stiffness, recurrence, superficial infection, deep infection, neuropraxia, bowstring deformity) recorded in 12 % *(n* = 95) of cases and flexion contracture of the finger joints was observed in 2.5 % (*n* = 20) [29, 30]. The median postoperative follow-up period was 13.5 months, with the longest follow-up period of 41.2 months reported by Hahn et al. [20], the shortest follow-up period of 3 months [23]. Follow-up period was not reported in several studies [22, 25]. Surgical correction was produced with EFD in 40 % (*n* = 4), open procedures in 50 % of cases (*n* = 5) and a combined technique was used in one case (10 %) with sequential mobilization of the joints of the involved finger and fixation with a dynamic distraction device.

Postoperative complications were analyzed using the odds ratio (OR) with the compilation of a multifield contingency table. The calculations showed a weak positive linear relationship between the EFD and pain. This meant that the use of the EFD method might cause pain to a minor extent. A weak negative linear relationship was discovered between the open procedure and pain. A very weak linear correlation was detected in other cases (marginal necrosis, infection, recurrence of deformity, other nonspecific complications, neurological disorders). However, the possibility of a non-linear relationship should be taken into account, which requires a more complex study using more data.

DISCUSSION

The problem of definitions and standardization of measuring the range of motion in the finger joints

In the Russian literature, the term “flexion contracture of a joint” refers to the stable position in which the joint is located, but there is also an interpretation that implies a deficient joint function, that is, flexion with a fixed extension in the joint [31–33].

Probably, an erroneous judgment regarding the definition of flexion contractures is based on one of the fundamental works written by Marx in 1978, where the following definition is given: “The position of contracture is understood as the forced position that the joint takes due to the restriction of movements in it.” This phrase, which can be interpreted as the contracture caused by one or another type of impaired movement in the joint, is taken out of the context, and the author clarifies: “Flexion contracture means a limited extension in the joint; extension contracture, on the contrary, means a limitation of extension movements in the joint — limitation of flexion" [34].

An inaccurate definition can be found in the neurorehabilitation manual, which provides the following: “In accordance with the position in which the limb is located as a result of a limited movement, contractures can be graded as flexion (limited flexion), extension (limited extension), adductor or abductor (limited adduction or abduction), rotational (limited rotation) contractures” [35]. Flexion contractures are defined in a similar way in the Great Medical Encyclopedia (https://бмэ.орг/index.php/КОНТРАКТУРА). For instance, flexion contracture is described as a defective position of flexion in the joint in the textbook edited by Volkov and Ter-Egiazarov [33]. In modern books on traumatology and orthopedics, Joint contractures are classified by malpositioned limb segment in flexion, extension, rotation and multicomponent” [31, 32].

In foreign literature, the Human Phenotype Ontology (HPO) was launched in 2008 with the support of the Monarch initiative (a large scale bioinformatics web resource) to provide a standardized

vocabulary of phenotypic abnormalities and clinical features found in human disease [36]. In this library, flexion contracture of a finger joint is interpreted as a bent joint of a finger or toe that cannot be straightened actively or passively [16].

In addition to different definitions of flexion contracture, there is a variety of terms for the pathology including stiff finger, hook finger, fixed flexion deformity, flexion deformity of the finger [11, 37, 38].

The range of motion in the joint measured perioperatively and at a long-term period is the most reliable indicator of the outcomes in traumatology and orthopedics, and in the surgery of flexion contractures of the finger joints, in particular. The terms "amplitude of movements" and "range of movements" are used in the Russian literature and the standardized term ROM can be found in foreign literature [39, 40]. Total active motion (TAM) is an important indicator in the surgery of flexion contractures described by the American Society for Surgery of the Hand (ASSH) as the sum of active MCP, PIP and DIP minus any extension deficits in the joint [41]. A goniometer is used to measure the range of motion, the angle of deformity, and it is important to accurately determine the preoperative position in the joint (reference point) or "zero degrees". Witthaut et al. designated the neutral position of the goniometer as zero degrees [42], while Lee reported full extension as 180° [43]. Full extension in a joint is often defined as 0°, and if both options are acceptable in clinical practice, numerical discrepancies in the preoperative measurements may cause incorrect interpretation of goniometric data in the literature or the impossibility of comparing two or more studies.

None of the studies presented in the systematic review reported calculated TAM, and preoperative and postoperative ROM measurements reported in some studies. The starting point with ROM was reported in the publications reviewed. Since goniometry has been recognized as the most common outcome measurement method [37, 44], therefore, it can be argued that the ROM and TAM protocol should be presented as a standard in publications to improve research transparency.

Surgical anatomy

The theoretical and practical complexity of flexion contractures of the interphalangeal joints of the fingers is associated with an obviously small area of surgical maneuvering and in the combination of a large number of anatomical structures. The interphalangeal joints are simple hinge-type joints that are surrounded by external stabilizers with a flexion/extension of approximately 90° to 100° at the PIP and 80° to 100° at the DIP [45].

The integrity of the joint is maintained by the balance of soft tissues at motion, primarily the volar plate, the own and accessory collateral ligaments [7, 45]. The flexor and extensor tendons provide secondary contributions to maintaining joint stability. The palmar plate is the main passive limiter of hyperextension of the IPJ; it is pleated in flexion and stretched in extension (Fig. 3). The palmar plate is stretched between adjacent phalanges, and there are the ulnar and radial retaining ligaments of the palmar plate (checkrein ligaments) at the site of the PIPJ [7, 15]. Stability in the frontal plane of the joint is provided by its own and additional collateral ligaments [45]. These structures have a biomechanical role in the formation of flexion contracture of the IPJ. Thus, the collateral ligament is attached proximally and distally to the bones and in a tension at each movement; additionally, the collateral ligament is attached distally to the palmar plate and tense in extension in the IPJ is, and in flexion in the MFS it is corrugated in flexion (Fig. 3), with a greater risk of fibrosis when immobilized in flexion, and often additional collateral ligaments become the point of application with elimination of flexion contracture of the fingers [11]. The dorsal structures of the MFS are more vulnerable to injury: the joint capsule is thin, the central fascicle and the terminal part of the extensor apparatus are susceptible to rupture during translation in the joint [45, 46].

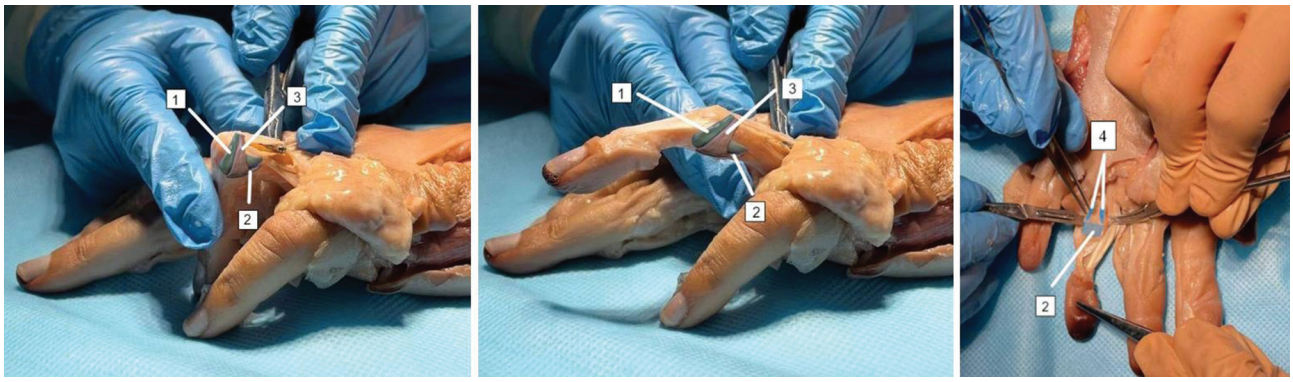

Fig. 3 Anatomy of the PIPJ: (1) the collateral ligament; (2) palmar plate; (3) accessory collateral ligament; (4) retaining ligaments of the palmar plate (checkrein ligaments)

The etiology of flexion contracture can be associated with the interphalangeal joint, the palmar plate, the ligaments that hold the palmar plate (checkrein ligaments), the flexor tendons of the finger, the osteofibrous canal of the flexor tendons, the extensor apparatus, a pathological scar of the skin finger [47, 48].

Surgical options

The surgical treatments of patients with flexion contractures of the interphalangeal joints of the fingers can be divided into two different groups: closed techniques (EFD of various modifications), open techniques (arthrolysis, release of the involved anatomical structures, mobilization/tomy of the palmar plate, etc.).

Open surgical correction of all components of the deformity is the standard method for eliminating post-traumatic flexion contracture of the finger joints, resistant to conservative treatment. Curtis [49] was the first who described the sequential release of the joint capsule and reported a slight increase in the amplitude of movement in the joint (by 13°) with involution of movements to values less than in the preoperative period, and then a series of studies appeared [50] with questionable results of open methods, and then a series of studies [50] reported questionable results of open methods, which caused the popularization of closed hardware methods for eliminating flexion contractures of the finger joints at the end of the 20th century and in the first decade of the 21st century.

Hardware techniques are justified by distraction histogenesis — the first general biological principle described by G.A. Ilizarov, based on the fundamental discovery of the general biological capability of tissues to respond to dosed stretching with regeneration and growth [51]. In our series, 50 % of the studies reported EFD as the method of choice with 30 % using 1.0 to 1.2 mm wires and the use of 2.0 mm half-pins were mentioned in two studies (20 %). Monoplanar devices were common, with the exception of R. Ravishanker, who used a two-plane wire device in a series of adult patients [18].

Various rates and frequencies of distraction ranging from 0.25 to 1 mm/day were reported [18] lasting from one to four weeks [17, 18, 24, 52].

A detailed prospective study on a small group of patients was conducted by Houshian et al. [24] to identify optimal distraction parameters. A comparison of two groups of patients with a distraction rate of 0.5 mm per day for 14 days and 1 mm per day for 7 days did not reveal statistically significant differences, so the authors gave their preference to the second distraction mode, and also emphasized the importance of further studies on a larger scale [24]. The studies report the use of the apparatus consisting of two wires or half-pins (the distal one is passed through the base of the middle phalanx, the proximal one through the border between the middle and distal third of the main phalanx), two fixing blocks and a threaded rod for a measured step [17–19].

Bogov et al. reported the use of a modified dynamic distraction device in a cohort study similar to the Suzuki clamp, which is described in the literature primarily for extrafocal osteosynthesis for fractures of the phalanges of the fingers [25, 53]. The method of distraction histogenesis is not always applicable and effective in treatment of flexion contractures of the fingers, taking into account the inconvenience and sometimes impossibility of early rehabilitation and the lack of differentiated effects on all components of flexion contracture [24].

A number of studies report contraindications to the use of EFD for flexion contractures: post-burn deformities, congenital deformities, Dupuytren's contracture, chronic regional pain, tendon injuries, crush injuries, history of replantation of segments [24].

Open operations are aimed at removal of scars or intersecting pathologically altered structures with the mobilization being not effective. Both palmar and dorsal anatomical formations are important. Surgeries on soft tissues are not effective for pathological changes in the metaepiphyseal surfaces articulating the joint and assessment of the condition and congruence of the joint is essential. Fusion of the phalanges of the fingers with rotational or angular deformity, the presence of exostoses in the joint area can cause the formation of contractures [11]. Surgical treatment in such cases is aimed at eliminating the deformity and resection of exostosis. In some series, patients with more than 30 % damage to the articular surface involved in finger flexion contracture were excluded from the studies [24]. The patients with the post-traumatic defect initially might have other goals and expectations from treatment, such as pain relief, stabilizing the finger to improve the hand functionality. These goals can be achieved either by arthrodesis in a functionally advantageous position, or by joint replacement, however, it is obvious that in the first case the range of motion in the joint (ROM) will not increase; with replacement, pain relief can be be achieved with a certain amount of active and passive movements, but numerous reviews have not demonstrated a significant improvement in range of motion compared to baseline [54, 55].

With regard to the volar structures of the proximal interphalangeal joint, some authors report mobilization of the volar plate, others describe its intersection without subsequent restoration or intersection of the ligaments holding the volar plate (checkrein ligaments) [11, 56]. Joint mobilization suggests cutting the accessory collateral ligaments and mobilizing the native collateral ligaments, if needed.

Surgical access to eliminate flexion contractures of the finger joints is also debatable. In a series of studies, preference is given to an incision made along the neutral line/midlateral of the joint, so that the neurovascular bundle is volar to the incision. The approach suggests the following sequence of actions: skin dissection, subcutaneous fat tissue, visualization of the osteofibrous canal of the flexors, dissection of the A3 ligament. The flexors and soft tissues of the volar surface are retracted with a hook, then the palmar plate is dissected, the ligaments holding the palmar plate are crossed, avoiding damage to the transverse digital artery, the joint is examined for the need of dissection/mobilization of the remaining anatomical structures (accessory and proper collateral ligaments) [4, 47].

Bruser et al. reported a greater increase in the range of motion in the joint at a long term with an incision made along neutral lines in their cohort study in comparison with the classic zigzag Bruner incision due to less trauma and the possibility of dynamic splinting early post surgery [57].

However, an adhesive process can be observed along the osteofibrous canal even in the absence of a history of flexor injury; this process is most pronounced in the second zone, at the site of the physiological intersection of the superficial and deep flexor tendons (R Camper). In this case, the incision along the neutral line of the finger can be ineffective with the zigzag Bruner incision and its modifications being most practical [28]. Saun et al. reported the volar oblique incision as a satisfactory alternative to the classic Bruner incision based on scar assessment using the Patient

and Observer Scar Assessment Scale (POSAS). Future studies are needed to assess the optimal approach for arthrolysis and tenolysis of the digital flexors [58].

The problems that can be associated with the dorsal structures of the finger include adhesions of the extensor apparatus, requiring tenolysis; dysfunction of the extensor apparatus of the finger, requiring its reconstruction [59].

Tenolysis of the extensor apparatus of the fingers, detachment of the tendon from the bone and medialization of the lateral bundles that the latter can be performed either openly under visualization or transcutaneously are reported [10, 58, 60].

A soft tissue defect can develop in case of a severe long-term contracture or pathological volar scars after eliminating the flexion contracture of the finger in the extension position [12, 22, 61, 62].

In our series, open methods for correcting flexion contractures were reported in 50 % of the studies reviewed and plastic replacement of the resulting tissue deficit of the volar surface was required after elimination of the flexion contracture in all cases. The authors use the following methods: cross skin grafting [20], displaced skin-fat flap, modifications of V-Y flaps [23], homodigital flaps with antegrade and reverse blood flow [14] were employed for the repair. Table 6 presents major surgical techniques used to repair flexion contracture by different authors.

Table 6

Articles reporting methods for open elimination of flexion contractures of the finger joints

Authors	Number of patients (*n*)	Type/mechanism of primary injury (*n*)	The joint involved in the deformity	Surgical technique	Anatomical structures "subjected" to arthrolysis/ tenolysis
Hahn et al. [20]	9	burn (*n* = 4); use of split skin grafts for repair of palmar defects (*n* = 3); tumor removal (*n* = 2)	PIPJ	scar excision, arthrolysis, transarticular fixation of the PIP joint with a wire, repair of the defect with a cross flap	release of the palmar plate, retinaculum of the palmar plate, collateral ligaments; partial release of accessory collateral ligaments
Ahmad [21]	56	burn (*n* = 31); posttraumatic (*n* = 21); postinfection (*n* = 4)	PIPJ	plastic repair of soft tissue defect after elimination of contracture	non specified
Antonova, Ivchenko [14]	13	burn (*n* = 5); electric trauma (*n* = 2); laceration (*n* = 3); incised wound (*n* = 2); mining injury (*n* = 1)	PIPJ	island flap on the proper digital artery from the adjacent finger	capsulotomy of PIPJ (*n* = 4) (non specified)
Tseng et al. [22]	2	surgery for stenosing ligamentitis (*n* = 1); occupational associated injury (*n* = 2)	PIPJ	tenolysis, arthrolysis, palmar neurovascular displaced flap	tomy of the palmar plate at the site of attachment on the base of the phalanx, tomy of the accessory collateral ligaments
Su et al. [23]	2	bump with a ball (*n* = 1) (not specified); incised wound with damage to the flexor tendons and surgical repair (*n* = 1)	PIPJ	arthrolysis, tenolysis, replacement of the defect with a displaced skin-fat flap	non specified

CONCLUSION

Review of the articles included in the statistical section showed that flexion contractures were caused by burns (32.3 %), dislocations and fracture-dislocations of the finger joints (23.5 %) and a routine surgery for stenosing ligamentitis (0.6 %).

Analysis of the literature revealed discrepancies in definitions and abundant terminology describing the same phenomena. Uniform terminology, initial angles for measuring the range of motion in joints,

a unified methodology for calculating TAM and ROM would be practical to ensure comparability of results in future studies. Accurate description of the calculation method used by the authors in the study is essential for correct interpretation of the data. The Human Phenotype Ontology (HPO, https://hpo.jax.org) dictionary can be useful for unification of scientific information from foreign and Russian literature.

Surgical methods offered for treatment of patients with flexion contractures of the interphalangeal joints were divided into two groups: closed techniques of external fixation devices of various modifications (50 %) and open procedures (40 %). A combined treatment technique with sequential mobilization of the joints of the involved finger and placement of a dynamic distraction device (10 %) was reported in one of the articles. A weak positive linear relationship was revealed between the EFD and pain based on calculations of the odds ratio (OR) of postoperative complications. However, no significant correlation was found between open techniques and complications (marginal necrosis, infection, recurrent deformity, other nonspecific complications, neurological disorders). Soft-tissue deficiency and the need for plastic repair of the volar tissues of the finger after eliminating the flexion contracture is one of the problems in the treatment of flexion contractures. Cross-cut skin grafting, displaced skin-fat flap, modifications of V-Y flaps, homodigital flaps with antegrade and reverse blood flow were methods used for the repair and reported in 50 % of contributions. Open techniques are commonly used for accurate correction of all components of the flexion contracture of the joint and repair of soft-tissue deficiency. No correlations between the treatment modality and the type of contracture were identified with the variety of treatment methods and classifications of the condition, and no treatment regimens were determined for patients with the pathology. The development of a universal decision-making algorithm is essential for the treatment of contractures of the interphalangeal joints of the fingers depending on the type of nosology and further research on larger cohorts groups of patients is required.

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Information about the authors:

Nino V. Abdiba — orthopaedic surgeon, research assistant, ninoabdiba@gmail.com, https://orcid.org/0000-0001-9152-5299;

Lyubov A. Rodomanova — Doctor of Medical Sciences, Professor, orthopaedic surgeon, Head of Department, rodomanovaliubov@yandex.ru, https://orcid.org/0000-0003-2402-7307;

Artem O. Afanasyev — orthopaedic surgeon, afar_kav@mail.ru, https://orcid.org/0009-0003-6407-5888;

Alexander E. Chizhov — resident doctor, Santillabox@mail.ru, https://orcid.org/0009-0002-2019-6242;

Artem R. Mironov — orthopaedic surgeon, laboratory assistant-researcher, ortopedix@yandex.ru, https://orcid.org/0009-0001-9273-8680;

Dmitry V. Romanov — orthopaedic surgeon, Head of Department, dr.romanov79@gmail.com, https://orcid.org/0000-0001-9847-7867;

Evgeny S. Tsybul — Candidate of Medical Sciences, orthopaedic surgeon, researcher, na4med@inbox.ru, https://orcid.org/0009-0001-8105-3635.

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Arthroplasty of the proximal interphalangeal joint of the hand: the current state of the problem

P.V. Fedotov✉, **D.V. Kovalev, A.S. Mikhailov**

Federal Center for Traumatology, Orthopedics and Arthroplasty, Cheboksary, Russian Federation

Corresponding author: Pavel V. Fedotov, mr_vulfgar@mail.ru

Abstract

Introduction The proximal interphalangeal joint (PIP joint) plays an important role in ensuring optimal finger dexterity, grip strength and overall hand functionality. Arthroplasty is a promising direction in the surgical treatment of arthritis of the PIP joint of the hand, however, the inconsistency of the results encourages the world scientific community to be restrained and further investigate the problems associated with PIP joint arthroplasty.

The **purpose** of the work was to identify the main problems of PIP joint arthroplasty based on the analysis of foreign and domestic medical literature.

Materials and methods In this literature review, an analysis of foreign and domestic scientific publications devoted to the treatment of diseases and injuries of PIP joint was carried out. The purpose of the study was to provide a brief historical background and identify the main problems of PIP joint arthroplasty based on the analysis of foreign and domestic medical literature.

Results and discussion The choice of the implant and the surgical aproach used are the two most frequently discussed issues in PIP joint arthroplasty; dorsal, palmar and lateral surgical approaches are described, each with its own advantages and disadvantages. Dorsal approaches are used most often because they are easier to perform; however, the fragile extensor apparatus is damaged with the subsequent development of extensor lag. A number of authors concluded that stiffness and extensor lag were the most common postoperative complications. Several combinations of materials are available: from classic chrome-cobalt/polyethylene to ceramic/ceramic and pyrocarbon/pyrocarbon. Most of them have not stood the test of time yet, and for most implants there is still a lack of real long-term monitoring series for survival of the design.

Conclusion The morphology of joints, small bone sizes, complex biomechanics and the load on the hand are a special problem in PIP joint arthroplasty. It is still not possible to restore the full range of motion in this joint, despite the success of colleagues in arthroplasty of large joints.

Keywords: proximal interphalangeal joint; arthroplasty, hand joints; arthroplasty of the proximal interphalangeal joint, biomechanics of the fingers of the hand

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INTRODUCTION

The problem of treating osteoarthritis of the proximal interphalangeal joint (PIPJ) is caused by the low incidence of the disease along with its high medical and social important (significant limitation of motor functions of the fingers, leading to a decrease in the quality of life); insufficient coverage of the problem due to insufficient clinical experience and a shortage of highly qualified specialists in this field; continuous change of PIPJ implant lines on the medical market. All this limits the possibilities for comparing the clinical effectiveness of PIPJ arthroplasty, conducting multicenter studies of its results, including long-term follow-ups.

The proximal interphalangeal joint (PIPJ) plays an important role in maintaining optimal finger dexterity, grip strength, and overall hand function [1]. PIPJ osteoarthritis is relatively common, with a radiographic prevalence of 18 % [2], and affects primarily women aged 60 to 79 years, although both men and women are affected equally between the ages of 80 and 89 years. Based on radiographs (R) and photographs (P), the prevalence of osteoarthritis in the PIP joint of the hand (R, 18 %; P, 6 %) is lower than that in the distal interphalangeal (DIP) joint (R, 35 %; P, 24 %) or the carpometacarpal (CMC) joint (R, 21 %; P, 8 %) [2, 3]. Foreign colleagues report that the interphalangeal joints of the dominant hand demonstrate a higher prevalence of osteoarthritis than in the non-dominant hand [4]. Degenerative changes in this joint are most often a consequence of idiopathic osteoarthritis (up to 60 %), post-traumatic arthritis (consequences of intra-articular fractures, ligament damage) (up to 25 %), systemic inflammatory diseases (most often rheumatoid arthritis — up to 15 %), and are also observed in tumor lesions (enchondroma, chondrosarcoma) [5]. Osteoarthritis of the proximal interphalangeal joint of the finger (both primary and secondary) causes pain with concomitant limitation of range of motion, which often leads to global deterioration of hand function [6]. The PIPJ accounts for approximately 85 % of the movements required for a functional grip [7].

It is still not possible to restore the full range of motion in this joint, in contrast to the success of colleagues in large joint arthroplasty. Conservative treatment of osteoarthritis of the PIPJ may reduce symptoms such as pain, swelling, stiffness, and decreased grip strength in the early stages. However, if the symptoms of the disease progress, surgical intervention is indicated [8].

Secondary osteoarthritis is most often caused by post-traumatic changes, followed by chronic unstable inflammatory diseases. Being a hinge joint, it is extremely stable in the sagittal plane, but has limited tolerance to angular, axial and rotational loads. Thus, the PIPJ is one of the most injury-prone joints. The vulnerability of the PIPJ is due to its unprotected position in the finger and long moment arm. Among potential hand injuries, PIP joint injuries are quite common in the general population and are especially pronounced in athletes [9, 10].

According to the scientific literature, the main surgical methods for treating patients with stage III osteoarthritis of the PIP joint are arthrodesis and total joint replacement. The ideal treatment goal for end-stage PIP joint osteoarthritis is painless restoration of adequate mobility and stability. The index and middle fingers are the pinch partners of the thumb, while the fourth finger and little finger require mobility to grasp larger objects. The severity of instability and deformity must be considered for choosing the correct treatment method for PIP joint problems [11, 12]. The goal of all these treatments is to reduce pain, which leads to improved overall hand function. Arthrodesis remains the main salvage method for end-stage PIP joint arthritis and is especially useful in cases of instability, deformity, or bone insufficiency of the joints that are not typically amenable to arthroplasty. Although arthrodesis sacrifices joint mobility for stability, it is often a necessary compromise to optimize hand function [1].

The **purpose** of the work was to identify the main problems of PIP joint arthroplasty based on the analysis of foreign and domestic medical literature.

MATERIAL AND METHODS

This literature review analyzes foreign and domestic scientific publications devoted to the treatment of diseases and injuries of the PIP joint. The search was conducted in the electronic databases Google Scholar, PubMed, e-LIBRARY in Russian and English using the search phrases: arthroplasty of the proximal interphalangeal joint, arthrodesis of the proximal interphalangeal joint, osteoarthritis of the proximal interphalangeal joint. The depth of the study was 37 years.

The review is based on scientific publications on arthroplasty, functional anatomy and biomechanics of the proximal interphalangeal joint from 1988 to 2024 inclusive. Conference abstracts and case reports were excluded.

RESULTS AND DISCUSSION

The conducted analysis of medical literature on PIPJ arthroplasty as one of the surgical methods of treating patients with terminal stages of deforming arthrosis showed that from the moment of its introduction to the present day, many options and methods of its implementation have been proposed.

Many criteria play a role in determining surgical tactics: compliance, type of activity and functional needs of the patient, anatomical features of the structure of the PIP joint and the unique function of each finger of the hand. Thus, painless stability for effective opposition to the thumb is more important for the 2nd and 3rd fingers, while the maximum possible range of flexion is more important for the 4th and 5th fingers, since they are responsible for the grip strength of the hand. It follows that arthrodesis operations are preferable for the 2nd and 3rd fingers, and arthroplasty for the 4th and 5th fingers. However, there is currently insufficient reliable and complete research data to confirm or reject this thesis. Compared to arthroplasty, the undeniable advantages of arthrodesis are a significant reduction in pain, up to its complete absence, as well as the ability to achieve a satisfactory cylindrical grip of the hand with adequate fixation of the PIP joint in physiological positions (20–30° flexion for the 2nd and 3rd and 40–50° for the 4th and 5th fingers). However, this will significantly affect precision grip types, precise movements and fine motor skills, which may be important for some professions [13, 14].

Understanding the anatomical and physiological features of the PIP joint is of particular importance for restoring its function. The different morphology of the PIP joints of the 2nd to 5th fingers, small bone sizes, complex biomechanics and high load on the hand create a number of problems in their arthroplasty.

Features of anatomy and biomechanics of the proximal interphalangeal joint of the hand

The PIP joint is formed by the head of the proximal phalanx and the base of the middle phalanx of the finger. The head of the proximal phalanx has the shape of a trapezoidal ridge with condyles of radial and ulnar asymmetrical shapes and an intercondylar flat groove. The condyles differ from the 2nd to the 5th finger. In the frontal plane, the ulnar condyle of the index and middle fingers is more pronounced, and on the ring and little fingers, the radial condyle (Fig. 1).

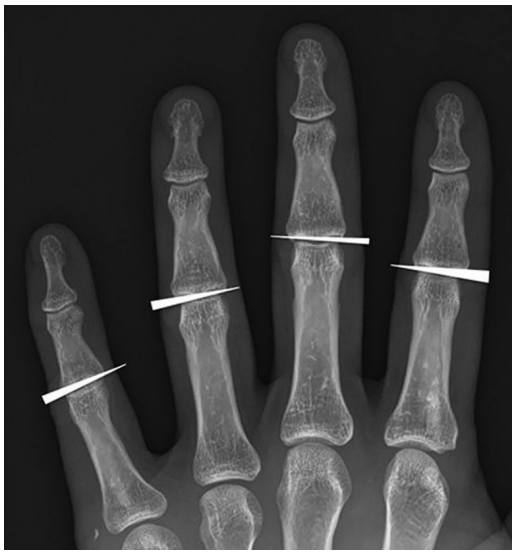

Fig. 1 Dorsal-palmar radiograph of four fingers of the left hand in the direct view. On the index and middle fingers, the ulnar condyle of the head of the proximal phalanx is more pronounced, on the ring and little fingers, the radial condyle of the head of the proximal phalanx is more pronounced (white wedges illustrate the angle of inclination) [18]

The corresponding articular socket of the base of the middle phalanx has two flat concave protrusions, between which a saddle-shaped ridge passes in the dorsal-palmar direction. The base of the middle phalanx is somewhat wider than the head of the basal phalanx in both the frontal and sagittal planes [15].

The range of motion in the PIP joint is 0–0–100° according to the neutral-zero method. This joint provides 85 % of the flexion arc of the fingers; the remaining 15 % is taken by the distal interphalangeal joint [16]. For a long time, the PIP joint was considered a "simple" block-shaped joint with only one center of rotation in the head of the base link. However, more precise anatomical studies showed that the joint partners, the head of the basal phalanx and the base of the middle phalanx, are not absolutely congruent [16, 17]. In the frontal plane, the condyles of the head of the proximal phalanx articulate with the corresponding concave protrusions of the joint cavity of the base of the middle phalanx through relatively small contact surfaces located not on the tops of the condyles, but closer to the center [18].

The radius of the arc of the articular surface of the base of the middle phalanx is approximately 30 % greater than the radius of the arc of the condyle of the head of the proximal phalanx. The difference in size and the discrepancy in the shape of the partner joints provide the possibility of rolling-gliding movements during flexion and extension, as well as lateral flexion and slight rotational movements. When clenching a fist, the shape of the finger joints leads to complex movements of separate phalanges: the middle and distal phalanges of the index and middle fingers, as well as the middle phalanx of the little finger are supinated, the middle and distal phalanges of the ring finger and the distal phalanx of the little finger are pronated [19, 20]. The choice of implant and the surgical approach used are the two most frequently discussed issues in arthroplasty of the PIP joint.

Surgical approaches for performing arthroplasty of the proximal interphalangeal joint depend on the clinical situation, or the choice is guided by the personal experience of the surgeon.

Surgical approaches to the proximal interphalangeal joint

Dorsal, palmar, and lateral approaches were described for PIP joint arthroplasty. Each has its own advantages and disadvantages. Dorsal approaches are the most commonly used because they are easier to perform, but they also involve damage to the fragile extensor apparatus, that further results in extensor lag [19].

The most common reason for reoperations in PIP joint arthroplasty is dysfunction of the extensor apparatus [21]. This has prompted surgeons to explore alternative palmar and lateral approaches to this finger joint. The palmar and lateral approaches offer several theoretical advantages over the dorsal approach. Both approaches allow surgeons to avoid incisions on the extensor apparatus and, therefore, do not require prolonged postoperative immobilization, which eliminates the possibility of postoperative adhesions and allows for immediate rehabilitation [22].

Dorsal surgical approach is the most widely used and technically the least demanding compared to the palmar and lateral approaches. It is also good when it is necessary to simultaneously correct certain soft tissue conditions, such as mild "swan neck" or "boutonniere" deformities. A straight or slightly curved longitudinal incision is made. Several methods of access to the joint were described. Swanson et al. advocated a midline split of the central glide of the extensor tendon [23]. An alternative is the approach described by Chamay, which uses a V-shaped extensor flap, which provides a good view of the joint and allows for the creation of a long, stable suture for tendon closure [24].

In their study, Bodmer et al. concluded that the tendon splitting approach generally yields better results and is associated with fewer complications compared to the approach described by A. Chamay [24, 25].

Bone canals are created and filed according to the requirements of the selected implant. For silicone implants, the resection line is planned according to the size of the implant, with care to preserve as much of the collateral ligament as possible. Tension should be chosen so that full flexion and extension are possible. If there is a delay in extension, either a smaller implant or a larger bone resection is necessary. In case of significant joint deformity or collateral ligament insufficiency, a reinforcing suture of the ligaments and/or a stepwise release on the contracted side is necessary. The joint should be well balanced and at the same time allow a full passive range of motion. It is almost impossible to correct the deformity that was not corrected on the operating table, even with a proper rehabilitation program.

The dorsal approach compromises the extensor mechanism, requiring immobilization. This exposes the patient to a high risk of loss of extension due to tendon elongation if mobilization is too early or joint stiffness if mobilization is prolonged [26, 27].

The *palmar surgical approach* has, at least theoretically, several advantages over other approaches. If this method is used, the tendons are not damaged directly and, in particular, the delicate extensor mechanism remains intact. However, the palmar approach is technically more challenging and offers limited space for implantation of the artificial joint. Moreover, a pre-existing tendon imbalance is more difficult to correct. The technique described by Herren et al. provides good access to the joint [28]. A skin flap is created on a radial basis, the flexor tendon is exposed and opened transversely; then the incision is continued on the ulnar and radial sides with release of additional collateral ligaments. Approach to the joint is achieved by hyperextension. Some relaxation of the ulnar collateral ligament may be necessary if the joint is not elastic enough for good exposure. Osteophytes are carefully removed, as this may be a potential site for entrapment of the bending implant. The head of the proximal phalanx is then resected, taking care to identify the neurovascular bundle and protect it with retractors. Bone preparation and implantation are performed in the same way as with the dorsal approach. In cases with pre-existing deviation of the flexor tendon due to lateral deformity, the tendon can be re-centered. It is important to re-check the passive range of motion before final closure. At the end of the procedure, the lateral edge of the palmar plate is sutured to the accessory ligament. The rehabilitation program follows the principles outlined for the dorsal approach, but does not require any special protection of the extensor tendons and even allows passive motion [29, 30].

It is difficult to conclude how good the palmar approach is. However, the dorsal approach requires immobilization to allow the tendon to heal. The palmar plate and flexor tendon sheath are compromised by the palmar or anterior approach. The palmar approach is less commonly used because it is more difficult to perform. Its advantage is maintaining the continuity of the extensor and flexor mechanisms and symmetrical stretching of the collateral ligaments [30–33].

The *lateral surgical approach* is the least common approach used for PIP joint arthroplasty. The incision is made in the midline on the ulnar side of the finger and curves dorsally over the middle phalanx. After releasing the oblique and transverse fibers of the reticular ligaments, the extensor apparatus is elevated and can be mobilized laterally while leaving the insertion of the central pad intact. The ulnar neurovascular bundle remains on the volar side of the joint. In the classic lateral approach, the ulnar collateral ligament must be completely separated so that the joint can be exposed on the radial side. This is best accomplished with a triangular flap that can be reflected proximally. The implant can be placed as described previously. For closure, the ulnar collateral ligament must be reattached so that active rehabilitation is possible. The ulnar side should be protected with a splint for up to six weeks. Bain et al. described a modified lateral approach in which the collateral ligament is split to accommodate the implant and reconstructed from side to side [34]. At least theoretically, the risk of instability is decreased and early, unrestricted active mobilization is possible.

The lateral approach is used rarely, since it provides limited impact on the joints. Its main disadvantage is the transection of the transverse reticular ligament and one of the collateral ligaments with the risk of lateral instability. Some authors have performed ligament reconstruction using transosseous sutures or anchors to solve this problem [35–36].

It should be noted that the advantage of the dorsal approach to the PIP joint is improved visualization of the articular surface, while the disadvantage can be considered a violation of the central sliding and extensor mechanism, which requires mandatory restoration of the extensor apparatus with a subsequent delay in the range of motor exercises. The palmar approach to the PIP joint can preserve the integrity of the extensor tendon, which allows for an early range of motion in the postoperative period.

There is no consensus on which approach provides better treatment results. Tranchida et al. in a study on 66 adult patients (88 fingers) who underwent PIP joint replacement compared the mean change in the range of motion, postoperative range of motion, and postoperative complication rates, and also examined the relationship between the duration of immobilization and time to rehabilitation with postoperative range of motion. This study found no statistical differences in mean postoperative range of motion, complication rates, or revision surgeries between the palmar and dorsal approaches in PIP joint replacement [37].

Moreover, it should not be forgotten that the palmar approach is more traumatic and difficult to use and requires more knowledge and time from the surgeon to perform.

Therefore, the dorsal approach is optimal, since it is the easiest to perform, but requires adequate restoration of the finger extensor apparatus, strong fixation and early rehabilitation. This is why this approach is more frequently used.

Choice of an implant

Due to the anatomical features of the PIP joint and the difficulties in choosing a surgical approach caused by them, an important problem remains the choice of an implant, which should have an identical morphology of the articular surfaces to a healthy joint, maximum mobility, identical stability and resistance, along with a little loss of bone mass during implantation. Moreover, stable and reliable fixation and a sliding pair without abrasion are properties that an ideal artificial joint should also have. The ways to implement all these requirements to the implant have not yet been fully found, and not only for the finger joint. With regard to the anatomy described above, the following observations can be made regarding the currently available implants for finger joints. None of the currently existing implant modifications corresponds to the morphology of the anatomical finger joint. However, by analyzing the literature, a certain tendency towards modular components and less connected structures can be traced. Despite the further development of materials and design, the silicone prosthesis developed by Swanson in the early 1960s remains the most frequently implanted artificial joint in the PIP joint of the fingers [23]. It is not a true prosthesis but rather a flexible filler that is encapsulated by connective tissue and slides back and forth along the medullary canal. Swanson (1994) was of the opinion that free sliding of the silicone filler is necessary for good joint mobility and has a positive effect on its durability. The ability to slide helps to reduce the forces acting on the bone. The author described this sliding: when the finger is flexed, the silicone filler in the medullary canal slides distally and when extended, proximally, as a “piston effect” [23, 38]. Lateral stability remains a problem, especially for the index and middle fingers, where stability is important for pinch [39, 40, 41]. Therefore, some authors still recommend arthrodesis of the index finger [42]. Compared with metal, ceramic or pyrocarbon prostheses, silicone filler implants are significantly less expensive. Despite good long-term results, their disadvantages include lack of stability, implant fractures and silicone fragmentation, which are repeatedly observed over time. According to current literature, silicone implants are not inferior to newer

implants, and complications are well known. Therefore, to improve the results, the emphasis should be shifted to the surgical approach [31, 43]. The newest generation of PIP joint implants is based on the principles of surface replacement using a two-component concept [44–49].

The proximal component replaces the bicondylar head of the proximal phalanx, and the distal component has a kind of cup that articulates with the head. Most of these implants do not represent a true resurfacing concept, as a significant amount of bone must be resected, and long stems are needed for both components to ensure adequate fixation. Several material combinations are available, from the classic chrome-cobalt-polyethylene to ceramic-ceramic and pyrocarbon-pyrocarbon.

Pyrolytic carbon implants have been used as an alternative to silicone arthroplasty with minimal limitations. Tuttle et al. reported a total of 15 postoperative complications, the most common of which was noticeable joint creaking [50]. Incomplete pain relief was observed in 50 % of patients in that series. Only two joints showed radiographic signs of loosening. Nunley et al. showed insufficient pain relief and no improvement in the range of motion in patients after placement of pyrolytic carbon implants for posttraumatic arthritis of the PIP joint [51]. Although pyrolytic carbon has excellent biocompatibility and ideal sliding characteristics, problems with osseointegration difficulties and joint creaking have been reported. The survival rate of pyrolytic carbon implants was 85 % (83 of 97) at five years of follow-up, with high patient satisfaction. Patients should be informed that the procedure provides good pain relief but does not increase range of motion [52].

Notermans et al. concluded in their study that stiffness and extensor lag were the most common postoperative complications [53]. Also, many authors call stiffness the most common complication [52, 54, 55]. In a review of 76 revision arthroplasties of the PIP joint, Pritsch et al. found that extensor dysfunction was the most common (67 %) indication for reoperation [56].

Overall, the new generation of PIP joint implants based on the resurfacing concept seemed to be a logical progression of PIP joint arthroplasty, but most of them have not yet stood the test of time, and most implants lack real long-term survival series [11].

The tremendous success of ceramic-ceramic friction pairs in large joint surgery has encouraged clinicians to more widely use this friction pair in small joint surgery [3, 57–59]. The use of ceramics in hip arthroplasty was highly appreciated by researchers good competitive qualities of this material: wear resistance, bioinertness, and biocompatibility. Hydroxyapatite-coated ceramic implants have shown an encouraging combination of an optimal tribological pair and osseointegration at the same time, which significantly stimulates interest in studying this material [60].

Certain advances in PIP joint arthroplasty were presented in the independent study of Muradova et al. and Fedotova et al. using the analysis of arthroplasty results. The authors note a stable increase in the range of motion and a high rate of patient satisfaction (82 %) [3, 61].

Although the results regarding implant loosening and pain have improved in recent years, some problems remain unresolved. The morphology of the joints, small bone sizes, complex biomechanics and load on the hand are a special problem in the PIP joint arthroplasty. It has not yet been possible to restore the full range of motion in this joint, despite the successes of colleagues in large joint arthroplasty.

CONCLUSION

This literature review shows that the choice of implant and surgical tactics are the most common problems in PIP joint arthroplasty, requiring solution and further study. A proper understanding of the various surgical approaches, their indications, techniques and shortcomings will help to optimize treatment results. The convenience of each approach helps the surgeon to minimize complications, improve function and individualize the treatment of primary or secondary arthritis of the PIP joint.

The use of different implants for PIP joint arthroplasty, which are available in various designs, enables to reliably eliminate pain while maintaining a definite mobility. However, the patient should be informed about the limited mechanical strength and service life of the implants. It is necessary to establish a feedback with the patient, since it is impossible to achieve a good result, without patient's adequate compliance and work despite excellent surgical techniques and the choice of the optimal implant.

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Information about the authors:

Pavel V. Fedotov — orthopaedic surgeon, mr_vulfgar@mail.ru, https://orcid.org/0000-0003-2833-235X;

Dmitry V. Kovalev — Head of the Department, orthopaedic surgeon, kovalev@orthoscheb.ru, https://orcid.org/0000-0002-4011-6409;

Anatoly S. Mikhailov — orthopaedic surgeon, polik_travm@orthoscheb.ru, https://orcid.org/0000-0003-0533-0570.

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Optimizing revision arthroplasty: the role of customized articulating spacers

B.Sh. Minasov, R.R. Yakupov, V.N. Akbashev✉, A.R. Bilyalov, T.B. Minasov, M.M. Valeev, T.R. Mavlyutov, K.K. Karimov, A.R. Berdin

Bashkir State Medical University, Ufa, Russian Federation

Corresponding author: Vladislav N. Akbashev, Vlad-akb@mail.ru

Abstract

Introduction The advancement of surgery is set against a backdrop of continuous development and surgical innovations have transformed the way clinical care is delivered. Revision surgery might be required to address complications of primary arthroplasty. The first stage of revision arthroplasty would involve removal of an implant and placement of an antibiotic-impregnated cement spacer to maintain the joint space and stability, prevent soft tissue retraction, provide local antibiotic release and preserve bone tissue for revision implantation at the final stage of revision. Custom-made articulating spacers are a promising tool for optimizing the first stage of revision arthroplasty.

The **objective** was to summarize the current data and present comprehensive information about spacers used in two-stage revision arthroplasty including manufacturing techniques, physical and chemical properties, clinical applications, the possibility of customization within the first stage of revision arthroplasty, current and promising directions for research.

Material and methods The original literature search was conducted on key resources including Scientific Electronic Library (www.elibrary.ru), the National Library of Medicine (www.pubmed.org), the Cochraine Library (www.cochranelibrary.com) between 2018 and 2023 using search words and phrases: total arthroplasty, complications, revision arthroplasty, articulating spacer, periprosthetic joint infection, additive manufacturing, 3D printing.

Results A comparative analysis of factory supplied, home-made, dynamic and static spacer models showed that the choice of articulating spacers for revision arthroplasty of major joints is of great relevance. Advantages of factory-made spacers include standardized range of sizes, the reliability and availability for medical institutions. They are characterized by limited use in repair of severe bone defects.

Discussion Custom-made articulating spacers enable specific tailoring to accommodate individual defects. Despite high expectations from custom-made spacers, development of optimal technologies for rapid prototyping is essential. Investments in research and development in this area have the potential to create innovative solutions that can significantly improve the results of revision arthroplasty.

Conclusion The paper explores the importance of systemization of knowledge about spacers and the role of new research in improving the design and functionality. Progress in the field of materials science, additive technologies and a personalized approach to spacer manufacturing can expand possibilities of revision arthroplasty and the effectiveness. Personalized approaches and improved methods of local drug delivery that provide controlled release of antibiotics can improve the results of treatment of periprosthetic joint infections.

Keywords: revision arthroplasty, articulating spacer, periprosthetic joint infection

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INTRODUCTION

Total joint arthroplasty is one of the most successful surgical treatments of degenerative diseases of major joints including osteoarthritis (OA) for restoration of the function and biomechanics of the joint [1]. However, patients who underwent primary arthroplasty (PA) require repeated surgical intervention of revision arthroplasty (RA) [2, 3].

New surgical techniques and technologies are developed to improve treatment results. Revision arthroplasty is a key direction in the field of orthopedic surgery and is becoming more important in the context of the increasing number of complications after primary arthroplasty. Periprosthetic joint infection (PJI) is a devastating complication after PA, accounting for 1 to 15.3 % of cases, giving way to aseptic loosening and dislocation of the implant [4]. Two-stage revision arthroplasty is considered to be the gold standard for the treatment of PJI and reported by Insall et al. in 1983 [5, 6]. The first stage consists of removing the previous implant and placement of a temporary implant made of bone cement with the addition of an antibiotic spacer. At the second stage, the spacer is removed and a revision endoprosthesis is placed. In addition to local antibiotic delivery, the spacer is aimed at maintaining mechanical stability of the joint ensuring optimal muscle tension and soft tissue tension, which would play an important role in the final functional outcome and treatment of PJI [7]. In recent decades, articulating individual spacers have been used to optimize the first stage of revision arthroplasty. Spacers can improve the surgical process and the efficiency compared to a one-stage procedure. A personalized approach to the manufacturing of articulating spacers based on individual biomechanical and rehabilitation characteristics of the patient can facilitate a higher degree of adaptation of the treatment process. The practice can improve surgical outcomes and accelerate restoration of joint functionality, which is critical for optimizing overall clinical results.

The **objective** was to summarize current data and provide information about spacers used in two-stage revision arthroplasty, manufacturing techniques, physicochemical properties and clinical use in the first stage of revision arthroplasty.

MATERIAL AND METHODS

The original literature search was conducted on key resources including Scientific Electronic Library (www.elibrary.ru), the National Library of Medicine (www.pubmed.org), the Cochraine Library (www.cochranelibrary.com) using search words and phrases: total arthroplasty, complications, revision arthroplasty, articulating spacer, periprosthetic joint infection, additive manufacturing, 3D printing. Articles that were most suitable to the topic of the study, containing relevant, significant ideas were selected from the resulting sample. Preference was given to publications brought out between 2017 and 2023 inclusive. We analyzed publications regardless of the language, without restrictions on study design.

RESULTS AND DISCUSSION

Epidemiology

The most common reasons for RA after primary knee arthroplasty are periprosthetic infection (PPI) (25.2–50.0 %) and instability of endoprosthetic components (16.1–36.5 %) [8]. The most common causes of RA reported in the United States between October 1, 2005, and December 31, 2006 included implant infections in 25.2 % and mechanical loosening in 16.1 %, with infection being the most common indication for arthrotomy and removal of the implant (79.1 %) [9]. In Russia, according to a study of 63,750 patients who underwent total knee arthroplasty (TKA), 2,573 patients (4 %)

required revision arthroplasty including 1,747 cases of PJI. The authors reported the inconsistency of accurate data on the number of infected patients due to problems with monitoring of patients who suffered PJI [2]. Epidemiology of PJI after TKA are presented in Table 1. By 2030, revision THA (rTHA) incidence is projected to increase by between 43 % and 70 %, whereas revision TKA (rTKA) incidence is projected to increase by between 78 % and 182 % [10].

A correlation can be seen in epidemiology of PJI in hip and the knee arthroplasties. In the German registry, PJI as the cause RA between 2004 and 2021 were aseptic loosening (49.2 %), infection (21.5 %), dislocation (13.4 %) and periprosthetic fracture (9.2 %) [11–13]. In Russia, the number of rTKA and rTHA caused by PJI was 2.91 % in 2019 [2]. Therefore, PJI is one of the major reasons for revision arthroplasty.

Table 1

Epidemiology of PJI in rTKA reported by different authors

Source of the publication	Period of study, years	Number of patients (*n*)		
		TKA cases	RTKA cases	PJI cases
The Swedish Arthroplasty Register [12]	2009–2018	127 060	4 669	1447
Levašič et al. [14]	2002–2018	10 698	870	109
Nham et al. [15]	2006 – third quarter 2015	5 901 057	465 968	114 721
Sereda et al. [2]	January 2019 – December 2019	63 750	2 573	1 747
Tarazi et al. [9]	01.10.2005 – 31.12.2006	–	60 436	15 233
Ivanov et al. [16]	2012–2016	483	–	39
Kornilov et al. [17]	2001–2016	373	28	4

Among the many treatment options for PJI, revision surgery (revision arthroplasty) is considered to be the best and can be divided into one or two stages [18]. One-stage operation suggests removal of the infected implant to be followed by debridement of soft and bone tissues and reimplantation of a new revision modality [19]. A two-stage RA can be used alternatively. The first stage of surgical treatment consists of removal of the infected implant and placement of a temporary implant made of bone cement and an antibiotic spacer. The main function of the spacer is to arrest the infection and fill in the "idle space" that appears after removal of the endoprosthesis and bone debridement. The second stage includes removal of the spacer and placement of a revision endoprosthesis. The treatment suggests an "intermediate stage" between removal and reimplantation with etiotropic antibiotic therapy administered based on intraoperatively cultured pathogen and its sensitivity to antibiotics. This stage allows for a proper assessment of the effectiveness of antibacterial treatment improving prognosis of treatment outcome through conservative therapy [15, 16]. Despite the recognition of two-stage RA as the "gold standard" for the treatment of PJI, the management is associated with high costs, greater risk of complications, mortality and longer hospitalization [20]. Modern studies indicate a comparable incidence of recurrent infection in one-stage and two-stage rTHA and rTKA, which emphasizes the need for an individual approach to the choice of a particular treatment method [19–22].

Knee and hip joint spacers can be presented in various types and shapes, depending on the manufacturing method and level of articulation [16–18]. Depending on the degree of mobility, spacers are classified into articulating (dynamic) and static (immobile) [23–25]. There is no consensus on which spacers are best to use. Foreign authors report no significant difference in the development of recurrent infection, however, the use of dynamic spacers allows for better functional results

after the second stage of the operation due to a range of motion in the joint. They are more practical for reimplantation, early rehabilitation and reduced length of surgery, and there is a lower risk of postoperative chronic infection and pain observed with static spacers [24–31].

As for a manufacturing method, spacers can be preformed and factory-made. Factory-made spacers are produced by medical companies for temporary use at the affected site [32]. This type of spacer has a specific shape and size that meets standard requirements [33]. Despite their versatility and availability, spacers have advantages and disadvantages. Advantages include standardization and immediate intraoperative use. Disadvantages include limited adaptation to the unique characteristics of each individual case, which may require additional adjustments during surgery (Table 2).

Table 2

Advantages and disadvantages of factory-made spacers [32–34]

Advantages	Disadvantages
— Wide selection of manufacturers — Extensive experience in clinical use — Does not require additional manufacturing steps for intraoperative use — The known mechanical properties and tribological characteristics	— Limited range of sizes — High cost — Short duration of antibiotic release — Cannot be used for various bone tissue defects or severely impaired joint anatomy — High risk of protrusion of the acetabulum — High risk of dislocations — Unstable fixation

Some patients can benefit from customized spacers that match the disturbed anatomy and characteristics of the patient [35–37]. This type of spacer can reduce the risk of secondary deformity, has a high postoperative WOMAC score, but is characterized by a higher cost [35–38].

In some cases, spacers can be made manually by the surgeon during surgery [39]. David et al. report a significantly higher rate of fracture of surgeon-fabricated spacers compared with preformed spacers. The author notes that spacers made by surgeons tend to degrade more aggressively than factory-made ones. This may be due to the method of mixing and delivery of cement during spacer preparation and placement, and disturbed congruence between articular surfaces. The combination of high-dose antibiotic mixing leads to a decrease in the mechanical strength of the spacer. A higher incidence of fractures can be ascribed to the lack of reinforcement with various metal structures [40].

A unique method of manufacturing and designing a spacer can be developed to combine standard techniques and customized components made from metal alloys, silicone, polyethylene and other materials (custom molds). The use of the combined technology provides the spacer with the necessary shape and enhances its mechanical properties, improves fixation, ensuring a reliable connection with bone structures. This increases the functionality of the spacer and reduces the risk of intra- and postoperative complications [35, 39].

Recent scientific advances in the field of medicine have led to the development of 3D printing technology and steady increase in its use in orthopedics [41]. These technologies allow the creation of customized spacers using precise models of the patient's anatomy [42–44]. Additive technologies are used to manufacture articulating spacers for the knee or hip joint; they represent an innovative direction in the field of medical implantation [41, 44]. Each method has advantages and disadvantages (Table 3), and their choice should be based on clinical and individual factors [41–44].

Table 3

Advantages and disadvantages of additive technologies in spacer manufacturing [41–44]

Advantages	Disadvantages
— Manufacturing a spacer of any shape, size and structure — Possibility of topological optimization — Manufacturing with regard to distured anatomy of bone structures and joint congruence, which is not available for factory-made spacers — Rapid prototyping — More stable fixation due to anatomical manufacturing, reinforcement and smaller cement mantle	— Prolonged manufacturing process — The need for specialized equipment and materials for the manufacture of customized spacers — Limited selection of materials

The choice of method for manufacturing knee and hip spacers depends on the specific situation, patient requirements, available resources and surgeon preference to ensure stability and functionality of the joint. Reinforcement suggests introduction of reinforcing constructs inside the spacer to improve the mechanical strength and increase stability increasing the resistance to wear and deformation and contributing to a longer service life. The spacer must survive to stage II RA [13, 45]. Reinforcement is developed for spacers with more complex shapes and constructs that would match the patient's anatomy. Reinforcement can be associated with disadvantages including higher costs of additional materials and an increase in the time and stages of manufacturing. Inadequate reinforcement or incorrect choice of materials can lead to complications, such as injury to the spacer or a fracture due to improper distribution of the load on the bone [46]. So, additional technology or methodology are needed for reinforcing constructs to be properly positioned relative to the spacer. Some types of hip and knee spacers, types and rates of mechanical complications are presented in Table 4.

Table 4

Types of spacer manufacturing and associated complications

Type of reinforcement	Manufacturing	Structural features	Number of spacers	Result	Source
Steinmann rod	Standard mold	The spacer is a femoral component of the implant, which is manufactured using a metal mold with additional reinforcement using a Steinmann rod	26	1 patient (3.8 %) had a spacer dislocation and 2 (7.7 %) had a spacer fracture	[47]
The authors do not report the type of reinforcement	Standard mold	The mold is made of polyoxymethylene	88	Spacer dislocation: *n* = 5 (17 %), spacer fracture: *n* = 9 (10.2 %), femoral fracture: *n* = 12 (13.6 %)	[48]
Steinmann rod	Standard mold	The spacer is a monopolar femoral component manufactured from a coated metal mold	138	Spacer fracture: *n* = 12 (8.7 %), spacer dislocation: *n* = 12 (8.7 %), periprosthetic femoral fracture: *n* = 1 (0.7 %), acetabular floor protrusion: *n* = 1 (0 .7 %)	[49]
Kirschner wire	Custom mold	The spacer is manufactured using a custom mold, which was obtained using additive technologies and computer modeling	1	The authors report a breakage of the spacer, which was associated with trauma (fall)	[38]
Kirschner wire	Mold	A Kirschner wire with a diameter of 5 mm was bent at an angle of 130° and filled with cement using a silicone mold	41	Spacer fracture: *n* = 2 (4.8 %), spacer dislocation: *n* = 3 (7.3 %), periprosthetic fracture: *n* = 1 (2.4 %)	[50]

Table 4 (continued)

Types of spacer manufacturing and associated complications

Type of reinforcement	Manufacturing	Structural features	Number of spacers	Result	Source
–	Factory-made	Factory-made sterilized components of implants used	21	Spacer fracture: *n* = 0, spacer dislocation: *n* = 1 (4.7 %), periprosthetic fracture: *n* = 1 (4.7 %)	[50]
Steinmann rod	Mold	Cement articulating spacers with vancomycin and two Steinmann rods were made using a homemade mold	266	Spacer fracture: *n* = 28 (10.5 %), spacer dislocation: *n* = 10 (3.8 %)	[51]
Implant components	Hand-made	Application of cement with the addition of 4.8 g of tobramycin and/or 4.0 g of vancomycin on the inner surface of the polyethylene liner of the acetabular or tibial component of the implant	54	The authors report no complications	[52]
–	Mold	The articulating spacer of the knee joint is made of femoral and tibial components manufactured using a mold	32	Periprosthetic tibial plateau fracture: *n* = 1 (3.125 %), patellar dislocation: *n* = 1 (3.125 %)	[53]
–	Mold	The spacer consists of femoral and tibial components made using a CR-type paraffin mold	66	Spacer instability: *n* = 3 (4.5 %), spacer fracture: *n* = 2 (3 %), periprosthetic fracture: *n* = 1 (1.5 %), dislocations: *n* = 20 (30 %)	[54]
–	Mold	The spacer consists of femoral and tibial components made using a PS-type paraffin mold	75	Spacer instability: *n* = 1 (1.3 %), spacer fracture: *n* = 2, periprosthetic fracture: *n* = 1 (1.3 %), dislocations: *n* = 1 (1.3 %)	[54]
Metal rod	Factory-made spacer	The spacer is made of acrylic cement impregnated with gentamicin and is a femoral component reinforced with a metal rod	23	Spacer dislocation: *n* = 2 (8.3 %)	[55]
K-wire	Mold	The spacer was a monopolar femoral component manufactured using a silicone mold and reinforced with a 5 mm diameter K-wire angled at 130°	13	Spacer fracture : *n* = 5 (38.46 %), spacer dislocation: *n* = 3 (23.08 %), periprosthetic fractures: *n* = 1 (7.69 %), partial or complete protrusion of the acetabulum: *n* = 3 (23.08 %)	[56]
Femoral component of the implant	Mold	The spacer was made using a silicone mold, but a fully functional femoral component without a head was used as reinforcement	10	Spacer dislocation: *n* = 3 (30 %), partial or complete protrusion of the acetabulum floor: *n* = 3 (30 %)	
Femoral component of the implant and polyethylene acetabular component	Hand-made	Antibiotic cement was applied to the femoral and acetabular components	13	Spacer dislocation: *n* = 1 (7.69 %), periprosthetic fractures: *n* = 1 (7.69 %)	

Reinforcement of spacers is aimed at improvement of mechanical properties, in segments with high axial loads, in particular. However, inadequate positioning, centration, type and shape of the reinforcement construct can lead to increased stress on the spacer or the bone with greater risk of complications including dislocations with the incidence of 4.86–16.4 % for the hip joint [57–59], periprosthetic fractures (1–3 % for the hip spacer), breakage of the spacer (3.0–5.9 %) [60, 61]. The incidence of medial-lateral dislocations and periprosthetic fractures varies between 9.1 % and 12.0 % for knee spacers [62, 63]. The frequency of complications may depend on the type of reinforcing construct, manufacturing technology and type of spacer, whether factory-made or home-made. Sambri et al. reported complications with use of different types of spacers in a systematic review. A total of 1659 spacers were analyzed including 798 factory-made, 301 preformed (made using molds) and 560 hand-made. A higher rate of mechanical complications was observed with preformed spacers 37.2 ± 21.6 %, handmade spacers showed complication rate of 19.2 ± 24.7 %, and factory-made spacers demonstrated 13.8 ± 5.2 % complications. However, no significant difference was found in the incidence of mechanical complications between spacers with and without different types of metal reinforcement: 18.2 ± 18.6 % and 23.2 ± 17.6 %, respectively [64].

Femoral offset adjustment

Adjustment of the femoral offset is an important aspect of revision hip arthroplasty [65]. Each patient has unique anatomy and functional needs, and proper adjustment and determination of optimal offset can improve surgical outcomes [66, 67]. Preoperative examination can help to adjust the femoral offset and plan the procedure. With modern technologies and methods including computer modeling, additive manufacturing and 3D planning, the stages can be faster and more predictable [68]. This can help to minimize errors and improve the results of the operation and restore biomechanics of the hip joint [69–71]. Inadequate adjustment of the femoral offset can result in limb length discrepancy, muscle tension imbalance, impaired load distribution, premature spacer wear and dissatisfaction with functional results [70]. Adequate customization will help the problems with optimal alignment and stability of the joint improving surgical results [71]. The femoral offset can be adjusted during the first stage of revision arthroplasty using a homemade articulating spacer with the femoral component and the head used for reinforcement. As for factory-made hip spacers with adjustable offset, there is no data on the availability of such medical devices.

Release of antibiotics

Prolonged release of antibiotics is an important aspect in the use of spacers in the treatment of PJI [72]. This approach allows for local, sustained release of antibiotics into the joint cavity to provide effective control of infection [73]. Various methods and technologies are used for prolonged release of antibiotics from the joint spacer. Antibiotics can be incorporated into the spacer during manufacturing, whereby the antibiotics are incorporated into the spacer and can be released gradually over time [74]. Antibiotics can be microencapsulated in spacer with microspheres or microbeads containing antibiotics being embedded in the spacer matrix, providing controlled release of antibiotics over time [75]. Reservoirs can be created inside the spacer in which antibiotics are placed, for example, before introducing the spacer into a joint. Coating the spacer with a thin layer of material containing antibacterial drugs is another way to introduce an antibiotic with the possibility of controlling the release of antibiotics over a long period of time [76]. Numerous studies have examined the suitability of different antibiotics for certain types of cement mixtures (Table 5).

Table 5

Concentration of antibiotic release with different types of cement combined

Cement	Antibiotic	Antibiotic concentration (g / per 40 g cement)	Antibiotic release time (μg/ml)					Source
			1 h	1 day	2 days	7 days	Total number of days	
Palacos	Vancomycin	2	–	72	–	6.6	up to 7	[82]
Palacos	Gentamicin	0.5	–	39	–	1.9	up to 7	[83]
Palacos	Gentamicin	1	30.61	–	53.9	–	up to 2	[84]
Simplex	Azertonam	4		1003	–	313.6	up to 7	[85]
Palacos	Voriconazole	8	–	–	–	–	up to 14	[85]
Cemex	Vancomycin	0.15–0.17	–	13.8–40	–	–	up to 1	[63]
ПММА	Moxifloxacin	4	–	–	29.8	27	up to 14	[83]
ПММА	Rifampin	4	–	–	21.7	23.2	up to 21	
ПММА	Meropenem	4	–	–	18	14	up to 14	
ПММА	Cefotaxime	4	–	–	15	11.6	up to 14	

The amount of antibiotic to be impregnated into the cement is one of the most important factors, since excessive amounts can alter the mechanical strength of the cement [72, 77]. The antibiotics are recommended to use in a volume of 10–15 % of the mixture. With greater amount, the mechanical properties of cement can deteriorate significantly. Manufacturers recommend to use 5 % of the mixture weight and the dose would depend on whether the antibiotic is being used to prevent or treat an active infection. A lower dose is used to prevent adverse mechanical effects on the implant and higher doses are required to ensure local prolonged release of the antibiotic during the treatment. For example, a prophylactic low dose is 0.5–1 g of antibiotic per 40 g of cement powder, a therapeutic dose is 1–2 g per 40 g of powder, and a high dose is about 4.6 g per 40 g of powder [77]. Manual addition of vancomycin to a spacer containing gentamicin indicated significantly increased rate of release of both antibiotics with a decrease in the compressive strength of bone cement. Antibiotics combined with polymethyl methacrylate cement is reported as the best strategy to broaden the antimicrobial spectrum. For example, gentamicin, vancomycin and tobramycin are mainly included in cement mixtures due to their ability to act on various gram-positive organisms such as *Staphylococcus aureus*, streptococci and gram-negative bacteria (*Pseudumonas aeruginosa*). Glycopeptides such as vancomycin are commonly used as a prophylactic agent or to treat severe infections caused by Gram-positive cocci. The medicine can effectively inhibit synthesis of the cell wall of gram-positive microorganisms having a bactericidal effect [77].

In recent years, interest has focused on the selection of different antibiotics combined with more than one drug and biomaterials with a particular emphasis on delivery systems such as implant coatings with hydrogels, ceramics, microcarriers, microspheres or nanoparticles [50, 78–80]. Rough surfaces commonly found on metal implants (cobalt-chromium or titanium alloys) have been shown to enhance bacterial colonization if the surface roughness approaches the size of an individual bacterium (1 μm) and inhibit colonization if surface pores are close to osteoblasts in size. Foreign authors reported the factors such as high surface hydrophobicity and low surface free energy, characteristic of cobalt-chromium surfaces being able to prevent the spread of bacteria on the surface [62]. Calcium sulfate is the most common bone graft substitute and can be formed intraoperatively into radiopaque capsules that dissolve at 30 to 60 days.

In vitro studies of antibiotic-loaded calcium sulfate showed superior performance compared to polymethimethacrylate (PMMA) [81]. Cyclodextrin is also used in clinical practice, which is a cyclic oligosaccharide consisting of 6–8 glucose monomers with a hydrophobic inner and relatively hydrophilic outer surface. Cyclodextrin bound to an insoluble polymer containing drugs forms a complex of cyclodextrin inclusions, which contributes to the controlled and prolonged release of the drug [62]. A comparative analysis of factory-made, home-made, dynamic and static spacer models shows a growing need for articulating spacers for revision arthroplasty of major joints in the Russian Federation and worldwide. This can be explained by the annual increase in the number of revision arthroplasties, taking into account the forecasts. Factory-made spacers have advantages, including a standardized range of sizes, reliability and ease of use in medical institutions where there is no technical ability to manufacture spacers. However, they have limitations in patients with severe bone tissue defects. In this context, customized spacers represents a promising direction, since they can be tailored to the unique characteristics of each specific case. Despite high expectations from individual spacers, development of optimal technologies for rapid prototyping remains challenging. Investments in research and development in this area open up the prospect of creating innovative solutions that can improve the results of revision arthroplasty.

CONCLUSION

A personalized approach to manufacturing the articulating spacers is promising and allows for consideration individual characteristics of the patient and selection of the optimal method for prolonged local release of the antibiotic and reinforcement. This goal can be achieved by improving scanning and rapid prototyping technologies to accurately recreate the anatomy of the joint.

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Information about the authors:

Bulat Sh. Minasov — Doctor of Medical Sciences, Professor, Head of Department, B.minasov@ya.ru, https://orcid.org/0000-0002-1733-9823;

Rasul R. Yakupov — Doctor of Medical Sciences, Professor, Professor of the Department, rasulr@mail.ru, https://orcid.org/0000-0001-7650-1926;

Vladislav N. Akbashev — Assistant of the Department, Vlad-akb@mail.ru. https://orcid.org/0009-0000-7070-217X;

Azat R. Bilyalov — Candidate of Medical Sciences, Associate Professor, Associate Professor of the Department, azat.bilyalov@gmail.com, https://orcid.org/0000-0002-1273-9430;

Timur B. Minasov — Doctor of Medical Sciences, Professor, Professor of the Department, m004@yandex.ru, https://orcid.org/0000-0003-1916-3830;

Marat M. Valeev — Doctor of Medical Sciences, Associate Professor, Professor of the Department, valeevmm@rambler.ru;

Tagir R. Mavlyutov — Doctor of Medical Sciences, Associate Professor, Professor of the Department, mavlutovtagir@mail.ru, https://orcid.org/0000-0002-5398-9356;

Kiemiddin K. Karimov — Candidate of Medical Sciences, Associate Professor, Karimov-doktor@mail.ru;

Azamat R. Berdin — 3rd year student, Limoroshow@gmail.com, https://orcid.org/0000-0002-7624-5528.

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