Original article
https://doi.org/10.18019/1028-4427-2026-32-3-296-307

Femorotibial synostosis in the management of periprosthetic infection: analysis of the factors associated with adverse outcome

G.A. Bugaev[2]✉, A.E. Vinogradsky[1,2], D.Yu. Borzunov[1,2]

[1] Ural State Medical University, Ekaterinburg, Russian Federation
[2] Sverdlovsk Regional Clinical Psychoneurological Hospital for war veterans, Ekaterinburg, Russian Federation

Corresponding author: Gleb A. Bugaev, glebbugaev97@gmail.com

Abstract

Introduction Femorotibial synostosis (FTS) is a primary salvage surgical procedure for failed total knee arthroplasty complicated by periprosthetic joint infection (PJI). Despite its widespread use, clinical outcomes with FTS are highly variable, indicating the significant role of a combination of patient-related, infectious, and surgical factors in shaping treatment outcomes. Analysis of the factors that lead to failed synostosis outcomes is of practical interest for optimizing surgical treatment techniques and predicting outcomes.

The **purpose** of the study was to evaluate factors associated with an FTS adverse course and outcomes as an option for restoring limb weight-bearing ability in patients with PJI.

Materials and methods A retrospective study included 46 patients who underwent FTS for PJI. The influence of patient-related (gender, age, body mass index, comorbidities), infectious (PJI type according to D.T. Tsukayama, microbiological profile), and surgical factors (number of previous debridement surgeries, anatomical and functional features of bone defects according to AORI, fixation method) associated with poor outcomes was analyzed. Univariate binary logistic regression analysis was used with calculation of odds ratio (OR) and 95 % confidence interval (95 % CI). The prognostic significance of the model was assessed using discriminant analysis.

Results Adverse FTS outcomes were statistically significantly associated with rheumatoid arthritis (OR = 6.89; 95 % CI 3.78–12.35; $p = 0.002$), immunodeficiency states (OR = 2.7; 95 % CI 0.44–8.24; $p = 0.02$) and the predominance of gram-negative microflora (OR = 7.1; 95 % CI 1.23–35.77; $p = 0.028$). Large bone defects (AORI type III) and five or more debridement surgeries had a significant impact on functional results and residual limb shortening. The use of an intramedullary nail for fixation correlated with an increased risk of systemic complications (OR = 6.69; 95 % CI 1.33–9.9; $p = 0.035$) and severe functional limitations (OR = 10.67; 95 % CI 1.201–15.72; $p = 0.034$). A direct relationship was established between the number of risk factors and the probability of adverse outcome ($p < 0.001$). The constructed prognostic model had sensitivity (77.8 %) and specificity (85.7 %).

Discussion The findings obtained indicate the heterogeneous nature of adverse FTS outcomes. The cumulative effect of individual factors, rather than their isolated presence, is important. This nature of the relationships explains the high variability of clinical outcomes, creating the need for an integrated risk assessment and the development of a surgical treatment algorithm for patients.

Conclusion Adverse FTS outcomes in PJI results from the combined impact of patient-related, infectious, and surgical factors. The most significant factors are the patient's comorbidity, the microbiological profile of the infection, the complexity of the anatomical and functional changes in the limb due to bone defects, and the chosen fixation method. A comprehensive assessment of risk factors allows for more accurate prediction of treatment outcomes.

Keywords: femorotibial synostosis, knee arthrodesis, periprosthetic infection, risk factors, adverse outcome

For citation: Bugaev GA, Vinogradsky AE, Borzunov DYu. Femorotibial synostosis in the management of periprosthetic infection: analysis of the factors associated with adverse outcome. *Genij Ortopedii*. 2026;32(3):296-307. doi: 10.18019/1028-4427-2026-32-3-296-307.

INTRODUCTION

Femorotibial synostosis (FTS), better known in the literature and in everyday clinical practice as knee arthrodesis (KA), is currently the surgery of choice among salvage interventions performed in poor outcomes of total knee arthroplasty complicated by periprosthetic infection (PJI). Stable synostosis between the femur and tibia provides the integrity of the lower limb and an acceptable quality of life for a patient. However, the outcome of such interventions is far from always predictable [1]. A number of authors point out limited functional capabilities and persistent pain in 21–73 % of patients after achieving FTS [2, 3, 4]. Moreover, there is a risk (almost 20 %) of nonunion or delayed union in the FTS area [5]. Its alternative, limb amputation (LA), is associated with a 30 % mortality rate within two years after surgery [6], and more than half of patients after amputation are unable to move independently [7]. Addressing the problem of implant-associated knee joint infection, foreign colleagues cite data on 11.1–21.8 % of recurrence cases [8, 9]. In domestic publications, the probability of recurrence of the infectious process after KA varies between 14–27 % [10, 11].

Despite such information, most publications focus primarily on the comparison of fixation methods [12, 13]. It should be noted that studies devoted to the analysis of factors associated with adverse outcomes remain extremely few. Most of them are based on observations of small clinical series and the considered patient pools [14, 15, 16]. Moreover, there are no publications on this issue in the domestic literature, which creates a deficit of evidence necessary for planning surgical tactics and predicting the treatment outcomes of patients with PJI. The analysis of the international literature convincingly demonstrates that even with technically successful performance of salvage surgical interventions, treatment outcomes can vary significantly and largely depend on a number of factors (gender, age, somatic, clinical and microbiological).

Identifying predictors of an adverse FTS outcome is of great clinical importance, as it allows for an early assessment of the likelihood of complications, the optimal surgical strategy, and the adjustment of postoperative patient management. Furthermore, a systematic analysis of such factors would assist in the objective assessment of the severity of the patient's somatic and orthopedic status, which, in turn, ensures patient awareness of the potential risks of complications and expected treatment outcomes, and enhances compliance and the success of surgical rehabilitation.

The **purpose** of the study was to evaluate factors associated with an unfavorable course and outcomes of femorotibial synostosis as an option for restoring limb weight-bearing abilityin patients with PJI.

MATERIALS AND METHODS

A retrospective single-center study was conducted at the Traumatology and Orthopedics Department of the Regional Clinical Hospital for War Veterans. The treatment outcomes of 46 patients with PJI after failed primary knee arthroplasty (TKR) were analyzed using medical records and follow-up examination protocols. This study is based on a clinical sample of patients included in a previously published study by the authors, which compared the effectiveness of FTS methods [17]. The previous study described surgical technologies and postoperative management protocols for FTS, and provided a comparative analysis of the effectiveness of bone fusion using an intramedullary nail (IN) and the Ilizarov apparatus (IA). This study focuses on the analysis of unfavorable factors that affect treatment outcomes

Given the aim of the study, the analysis was performed within a single cohort of patients (n = 46) without prior division of the sample into groups. The proportion of males in the study sample was 32.6 % (n = 15), women were 67.4 % (n = 31). The mean age was 68.0 ± 11.6 years. The body mass index (BMI) was 28.7 ± 3.99 kg/m^2. The division into positive and adverse outcomes was used only

at the stage of descriptive statistics for the primary characterization of patients and the distribution of clinical manifestations.

The following independent variables (factors) were taken into account: gender, age, BMI, concomitant diseases, type of periprosthetic infection according to D.T. Tsukayama [18], nature of bone defects according to AORI [19], number of previous operations, fixation method (IN/IA) and microbial spectrum of infectious agents.

The dependent variables were indicators reflecting the treatment outcomes: duration of synostosis procedure (months), amount of residual limb shortening (cm), functional outcome (LEFS scale, %) [20], recurrence of infection and postoperative complications.

Descriptive data of independent (factors) and dependent variables are presented in the authors' previously published work [17], performed on the same clinical sample of patients, and are not repeated in this study.

In this study, adverse outcomes were defined as a combination of clinical events:

— lack of stable bone fusion or failure of synostosis (false joint, fracture in the consolidation zone);

— severe functional limitations (LEFS score less than 30);

— residual limb shortening of 6cm or more;

— infection recurrence;

— systemic complications and deaths in the early postoperative period.

Positive outcomes were recorded in 28 of 46 patients (60.9 %), while adverse outcomes were observed in 18 patients (39.1 %). Among patients with an adverse outcome, 12 patients (26.1 %) experienced one adverse event including two clinical cases (4.3 %) of death in the early postoperative period. A combination of two or more adverse outcomes was recorded in six patients (13 %).

Inclusion criteria:

— FTS performance if revision arthroplasty was impossible due to PJI;

— follow-up for at least two years after surgery to objectively assess clinical outcomes, recurrence of infection, and complications;

— documented cases of systemic complications and deaths in the early postoperative period;

— availability of complete medical documentation to assess independent variables (age, sex, somatic, clinical, and microbiological characteristics) and analyze treatment outcomes.

The non-inclusion criterion was incomplete medical documentation, making statistical processing and comparison of data impossible.

Exclusion criteria were patient's refusal to participate in the study or loss of contact during follow-up.

All patients provided written informed consent to participate in the study and to publish anonymous data. The study protocol was approved by the local ethics committee of the Regional Clinical Hospital for War Veterans, Yekaterinburg (protocol No. 2/2025, dated February 25, 2025).

The initial database was formed and descriptive and summary tables were compiled using Microsoft Excel (version 16.75.2, USA). Quantitative variables with normal distribution were described as the mean and standard deviation (M ± SD), while those with non-normal distribution were described as the median and interquartile range (Me [Q1; Q3]). The normality of data

distribution was tested using the Shapiro–Wilk test. Categorical variables were described as absolute values and percentages (n, %). The main analysis method for assessing the influence of independent variables (factors) on the likelihood of adverse outcomes was univariate binary logistic regression analysis. The results were presented as odds ratio (OR) with a confidence interval (CI) of 95 % and *p*-value. Statistical significance was set at $p < 0.05$. Discriminant analysis was used to evaluate the predictive accuracy (AUC), sensitivity (Se), and specificity (Sp) of the model. The Jamovi software package (version 2.6.17, Australia), supplemented with R modules (Rj Editor), was used for data processing and visualization of statistically significant predictors (forest plots).

RESULTS

Synostosis failure

The incidence of synostosis failure was recorded in four of 46 patients (8.7 %). According to univariate logistic analysis, the synostosis failure was significantly associated with older age, rheumatoid arthritis (RA), and extensive bone defects around the knee joint (Fig. 1). In patients aged 75 to 84 years, a trend towards an increased risk of synostosis failure was noted (OR = 7.71; 95 % CI 0.68–87.25; $p = 0.041$). The presence of RA was a significant risk factor: the likelihood of pseudoarthrosis development in such patients was almost seven times higher (OR = 6.89; 95 % CI 3.78–12.35; $p = 0.002$). AORI type III defects also demonstrated a statistically significant association with bone fusion failure (OR = 6.9; 95 % CI 2.54–10.4; $p = 0.0005$). The remaining factors included in the analysis did not have a significant impact on the development of this outcome ($p > 0.05$).

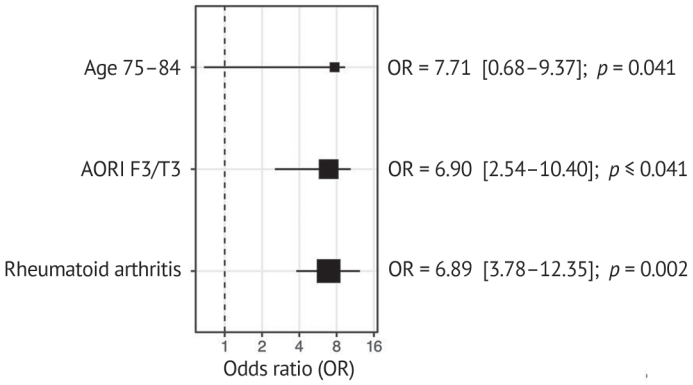

Fig. 1 Significant factors associated with the FTS failure

Functional limitations (LEFS ⩽ 30)

Severe functional limitations (LEFS ⩽ 30) were observed in nine of 46 patients (19.6 %). A significant decrease in functional indicators was associated with comorbidities, a large number of previous debridement surgeries, the method of fixation, and bone defects with their anatomical and functional impact on the patient's orthopedic status (Fig. 2).

Diabetes mellitus increased the risk of functional limitations by 8.5 times (OR = 8.5; 95 % CI 1.455–50.05; $p = 0.018$), and cardiovascular diseases by 4.1 times (OR = 4.1; 95 % CI 2.24–64.28; $p = 0.004$).

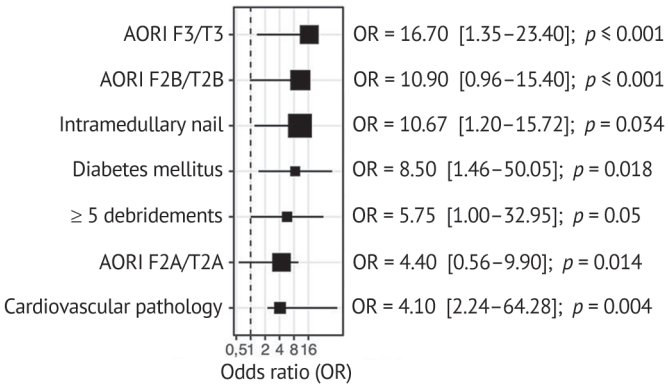

Fig. 2 Significant factors associated with severe functional limitations (LEFS ⩽ 30)

History of five or more debridement surgeries was also associated with an increased likelihood of poor functional outcomes (OR = 5.75; 95 % CI 1.003–32.95; $p = 0.05$).

The use of an intramedullary nail as a fixation method was a significant predictor of severe functional limitations (OR = 10.67; 95 % CI 1.201–15.72; $p = 0.034$) compared with limb fixation with the Ilizarov apparatus.

A clear relationship was found between bone defect size and worsened functional outcomes after FTS. Thus, for type II defects (F2A/T2A), the probability of an adverse outcome increased by 4.4 times (OR = 4.4; 95 % CI 0.564–9.9; $p = 0.0137$), for F2B/T2B — by 10.9 times (OR = 10.9; 95 % CI 0.963–15.4; $p = 0.0001$), and for type III (F3/T3) — by 16.7 times (OR = 16.7; 95 % CI 1.35–23.4; $p = 0.0001$) compared to type I defects (F1/T1).

Residual shortening (⩾ 6 см)

This outcome was observed in six of 46 patients (13.0 %). Clinically significant residual limb shortening was associated with the number of previous surgeries and the severity of bone defects around the knee joint (Fig. 3).

Having five or more sanitizing surgeries increased the risk of limb shortening by more than 6 cm almost fivefold (OR = 4.6; 95 % CI 0.904–8.325; $p = 0.003$).

Moreover, type III bone defects (F3/T3) significantly increased the likelihood of this adverse outcome by 3.65 times (OR = 3.65; 95 % CI 1.21–8.45; $p = 0.0001$).

Compared with type I (F1/T1), type II (IIA and IIB) and type III defects were associated with an increase in limb shortening by 0.81 cm ($p = 0.095$), 1.48 cm ($p = 0.063$) and 3.65 cm ($p = 0.0001$), respectively (Fig. 4).Compared with type I (F1/T1), type II (IIA and IIB) and type III defects were associated with an increase in limb shortening by 0.81 cm ($p = 0.095$), 1.48 cm ($p = 0.063$) and 3.65 cm ($p = 0.0001$), respectively (Fig. 4).

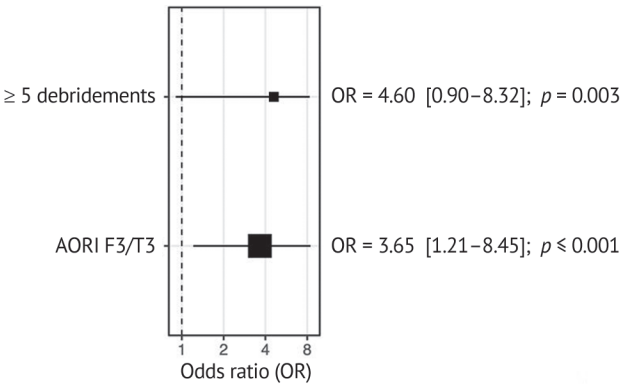

Fig. 3 Significant factors associated with limb shortening of more than 6 cm

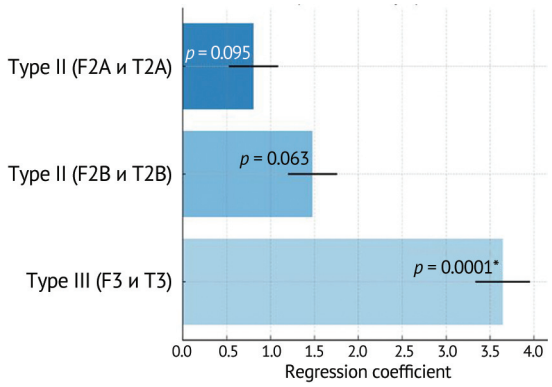

Fig. 4 Impact of AORI defect type on limb shortening

Infection recurrence

Recurrence of periprosthetic joint infection after FTS was recorded in four of 46 patients (8.7 %). According to univariate logistic analysis, infection recurrence was significantly associated with the presence of RA, immunodeficiency states, and the predominance of gram-negative microflora (Fig. 5).

In RA patients, the risk of recurrent infection was increased more than threefold (OR = 3.4; 95 % CI 1.82–23.55; $p = 0.012$).

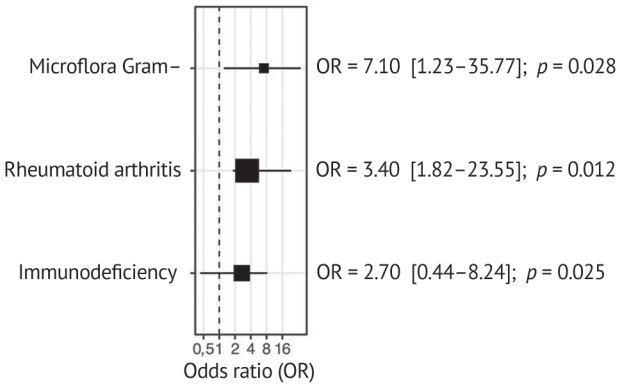

Fig. 5 Significant factors associated with recurrence of infection

Immunodeficiency conditions also demonstrated a statistically significant impact on the risk of infection recurrence (OR = 2.7; 95 % CI 0.44–8.24; $p = 0.025$). It should be noted that this subgroup was represented predominantly by patients with HIV infection ($n = 8$; 17.4 %), five of whom (10.9 %) had stage 4A and three (6.5 %) had stage 4B.

A significant impact of gram-negative microflora on the risk of PJI recurrence by 7.1 times (OR = 7.1; 95 % CI 1.23–35.77; $p = 0.028$) was found. Gram-negative pathogens were identified in a total of 37.0 % ($n = 17$) of patients as a monoculture and in 8.7 % ($n = 4$) as part of microbial associations.

Systemic complications and deaths

Systemic complications were reported in three of 46 patients (6.5 %). The development of systemic complications was statistically significantly associated with the presence of cardiovascular pathology and the use of an intramedullary nail as a fixation method (Fig. 6).

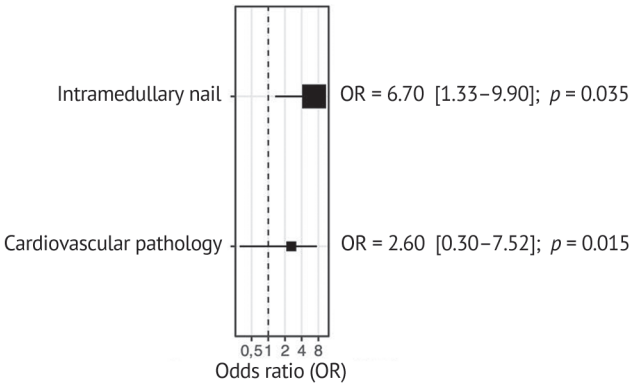

Fig. 6 Significant factors associated with the development of systemic complications

The presence of cardiovascular diseases increased the risk of developing systemic complications by 2.6 times (OR = 2.6; 95 % CI 0.305–7.52; $p = 0.015$). This category of diseases was recorded in 13 patients (28.3 %) with chronic heart failure in the sub- and decompensated stages. The structure of complications included two cases of massive pulmonary embolism with a fatal outcome and one case of acute cerebrovascular accident. In all cases of critical events, the patients were in a state of subcompensation on the eve of surgery and were monitored by a cardiologist/arrhythmologist, while all had a permanent form of atrial fibrillation recorded in their medical history.

The use of an intramedullary nail for fixation was associated with a 6.7-fold increased risk of systemic complications compared with the Ilizarov apparatus (OR = 6.69; 95 % CI 1.33–9.9; $p = 0.035$). All cases of systemic complications and fatal outcomes were recorded only in patients using an intramedullary nail. No such complications were observed among patients with the Ilizarov apparatus use.

Assessing the cumulative impact of risk factors

The distribution of FTS outcomes based on the total number of factors reliably demonstrates the likelihood of adverse outcomes as the number of predictors increases (Table 1). In patients with no more than one risk factor, an adverse outcome was observed in only one case out of 10 (10 %). In the presence of two or three risk factors, the incidence of adverse events almost doubled (22.2 %, $n = 4/18$). The highest incidence of adverse treatment outcomes was observed in patients with four or more predictors (72.2 %, $n = 13/18$). The obtained results indicate a significant impact of the total aggravating background on the treatment prognosis and confirm the role of a comprehensive risk factor assessment in FTS planning.

Table 1

Distribution of patients by the number of risk factors and FTS outcome

Number of risk factors	Number of patients			
	Positive outcome ($n = 28$)		Adverse outcome ($n = 18$)	
	n	%	n	%
0–1	9	90	1	10
2–3	14	77.8	4	22.2
4 and more	5	27.8	13	72.2

Discriminant analysis revealed a statistically significant direct relationship between the number of identified risk factors and the likelihood of an adverse outcome of BBS ($p < 0.001$). The resulting model demonstrated high predictive accuracy (AUC = 0.919): sensitivity was 77.8 %, specificity was 85.7 %.

DISCUSSION

FTS for periprosthetic joint infection (PJI) is a salvage procedure aimed at stopping the infection and restoring limb weight-bearing at the expense of knee joint function. Despite the formal uniformity of the ultimate goal of surgical intervention, the clinical outcomes of this procedure are characterized by significant variability, reflecting the complex interaction of anatomical, somatic, infectious, and surgical factors. In this context, FTS for PJI should not be considered an isolated surgical intervention, but rather a multifactorial clinical and surgical process, the outcome of which is shaped at various stages of treatment. The results obtained in this study confirm that an adverse outcome is not determined solely by the index surgery but is due to the combined impact of independent variables at all stages of the clinical and surgical process.

For a more holistic interpretation of the data obtained, we believe it is appropriate to consider predictors within the following clinically significant groups: patient-related, infectious, and surgical. This approach will allow us to move away from a formal analysis of individual variables, as isolated parameters are not completely independent but rather interact with one another. Thus, the number of previous debridement procedures determines bone defect extension and, consequently, the severity of the resulting orthopedic pathology in the patient, which in turn influences the choice of surgical and rehabilitation technology.

In the present study, the patient-associated group of factors included gender, age, BMI, and comorbidities reflecting the general somatic and immune status of the patient. Most publications consider male gender, smoking, and morbid obesity (BMI > 40 kg/m^2) as socio-demographic factors of adverse outcomes, while age does not have a significant effect on them [21, 22, 23]. In our study, a tendency was found in the older age category of patients (from 75 to 84 years) to synostosis failure (OR = 7.71; 95 % CI 0.68–87.25; $p = 0.041$), which is explained by a decrease in the biological potential of bone tissue reparation. We attribute the lack of influence of BMI on outcomes to the fact that BMI values in the study cohort were in the borderline index value (28.7 ± 3.99) kg/m^2. Examining the impact of underlying medical conditions on functional outcomes, we found that diabetes mellitus and cardiovascular disease significantly reduced these indicators (according to LEFS, %), and were reflected in the rehabilitation period and quality of life of patients.

Cardiovascular diseases significantly influenced the development of systemic complications and fatal outcomes (OR = 2.6; 95 % CI 0.305–7.52; $p = 0.015$). With a multidisciplinary approach, the presence of even subcompensated types of chronic heart failure initially determines the functional limitations of patients due to reduced functional reserves before surgery and limits the possibilities of early activation and postoperative adaptation. The presented data are consistent with the results of Podmore et al., who showed a negative impact of diabetes mellitus (OR 1.14; 95 % CI 0.96–1.35) and cardiovascular diseases (OR 1.24; 95 % CI 1.01–1.52) on functional outcomes after arthroplasty. The authors also point to a threefold increase in the risk of early mortality in patients with cardiovascular diseases (OR 2.96; 95 % CI 1.95–4.48) [24].

The immunological status of the patient largely determines control of the infectious process. Thus, the systematic review by Dimitriou et al. found an association of HIV infection with a more than two--fold risk of developing PJI (OR 2.28; 95 % CI 2.14–2.43) [25]. Ferraro et al. noted a three-fold increase in the risk of revision surgery within 2–10 years (OR 2.74; 95 % CI 1.51–4.99; $p < 0.001$) [26]. According to our data, the probability of PJI recurrence in HIV-infected patients was 2.7 times higher (OR = 2.7; 95 % CI 0.44–8.24; $p = 0.025$). The CD4 cell level reflects

the severity of immunodeficiency and plays a key role in the addition of a secondary infection or reinfection [27]. The optimal level of maintaining immunological compensation in such patients is considered to be 500–1500 cells/mm^3 [28].

There are no direct data on the impact of RA on the FTS outcomes in the literature we reviewed. In our study, the presence of RA was associated with a significant increase in the risk of synostosis failure (OR = 6.89; 95 % CI 3.78–12.35; p = 0.002) and recurrent infection (OR = 3.4; 95 % CI 1.82–23.55; p = 0.012). According to Lenguerrand et al., RA increases the risk of developing PJI, which is the reason for revision, by 2.5 times (OR 2.52; 95 % CI 1.51–3.93) [29]. Systematic reviews of prognostic factors in osteoarticular infection also indicate the key role of comorbid conditions in the development of recurrent infection and treatment failure [30].

In recent years, there has been an increasing interest among researchers in the integrated assessment of a patient's somatic status using comorbidity scales, indices, and calculators that consider the cumulative effect of comorbidities on the risk of adverse outcomes. Universal scales exist, such as the well-known Charlson 10-Year Survival Index [31], as well as more specialized tools, such as the reinfection risk calculator proposed by Klemt et al. [32]. The development and implementation of an integrated risk index for adverse outcomes for FTS appears to be a promising application for developing a treatment algorithm. A comprehensive analysis of the factors that have impact on the outcome creates the preconditions for the development of such a tool.

We included the type of periprosthetic joint infection (according to D.T. Tsukayama) and the microbiological profile of the pathogen in the infectious group of factors. Traditionally, the analysis of periprosthetic joint infection pays considerable attention to the clinical classification of the process according to Tsukayama, which mainly reflects the temporal and pathogenetic features of the infection onset. In clinical practice, it is assumed that chronic late and acute hematogenous forms are associated with poorer treatment outcomes. Despite the predominance of these forms of infection (71.7 % of the cases) in the present study, the type of infection did not demonstrate a reliable effect on the outcomes of PJI. The data obtained suggest that the decisive role may be played not so much by the clinical scenario of infection manifestation, but by the biological and cultural characteristics of the pathogen. As shown in the work of Lee et al. on the analyzed cases of PJI recurrence after repeated arthroplasty, it is the microbiological profile that has the greatest prognostic significance [33].

A detailed study of the microbial spectrum and an assessment of its impact on the outcomes of orthopedic surgeries are being conducted by Russian colleagues [34]. The authors consider highly resistant gram-negative pathogens as independent factors in the development of infection recurrence and include them in the overall risk scales that determine the appropriateness of rejecting revision arthroplasty in favor of arthrodesis. In the present study, the presence of gram(-) pathogens increased the risk of infection recurrence by almost seven times (OR = 7.1; 95 % CI 1.23–35.77; p = 0.028). Moreover, gram-negative microflora was detected in 37.0 % of patients as a monoculture and in 8.7 % as part of microbial associations. Comparable data are provided by Jhan et al. who found a more than fivefold increase in the risk of PJI recurrence when gram-negative pathogens were detected (OR = 5.68; 95 % CI 1.18–27.4; p = 0.0303) [35]. The identified role of gram-negative microbiological flora in the implementation of infection recurrence emphasizes the importance of targeted antibacterial therapy, which acquires not only prognostic but also practical significance and determines the effectiveness of control over the infectious process at all FTS stages.

The surgical group of factors includes the number of previous debridement surgeries, characteristics of bone loss after primary arthroplasty (according to AORI) and the method of fixation. Two-stage revision arthroplasty is considered the "gold standard" for treating patients with periprosthetic infection after primary arthroplasty [36]. The absence of clinical and laboratory remission

of the infectious process is an indication for an intermediate debridement surgery and reinstallation of the cement spacer. Son et al. showed that performing more than two infection-associated revisions increases the likelihood of changing the surgical tactics to arthrodesis as one of the salvage operations by 1.36 times (95 % CI 1.13–1.64; $p < 0.001$) [37].

In this regard, multiple revision and debridement surgeries are interpreted as a marker of the severity and refractoriness of the infectious process. Attempts at such surgical infection control have another strategic significance. Performing one debridement surgery is associated with a 27 % (OR 0.73; 95 % CI 0.7–0.75; $p < 0.001$), and two or more with a 34 % (OR 0.66; 95 % CI 0.61–0.7; $p < 0.001$) reduction in mortality [37]. Multiple intermediate stages of infection control have orthopedic consequences and cannot be indefinite, since each sequester necrectomy is accompanied by the removal of infected non-viable tissue, and accordingly leads to an even greater bone loss in the femur or tibia. The size of the bone defect subsequently results in the magnitude of residual limb shortening and the functional outcomes of patient treatment in the FTS outcome. The study of our cohort of patients confirms these findings. Thus, five or more debridement surgeries were associated with a fivefold increase in clinically significant residual limb shortening (OR 4.6; 95 % CI 0.904–8.325; $p = 0.003$) and adverse functional outcomes (OR 5.75; 95 % CI 1.003–32.95; $p = 0.05$). Moreover, the severity of bone defects according to AORI had a comparable, and in some cases, more pronounced, effect on these outcomes. It is the severity of bone defects, mediated by the number of debridement surgeries that is the key link in adverse FTS outcomes.

Moreover, the present study noted another associative impact of large-size defects (AORI type III) on the seven-fold increase in the risk of bone fusion failure (OR 6.9; 95 % CI 2.54–10.4; $p = 0.0005$). Similar observational results were presented by Parcel et al., who considered the presence of extensive bone defects as a factor significantly reducing the likelihood of successful ankylosis formation after knee arthrodesis ($p < 0.05$) [38]. However, Yeung et al. did not find that AORI type III bone defects had an impact on delayed fusion or ankylosis failure ($p > 0.05$) [5].

Intramedullary implants for arthrodesis of the knee joint after arthroplasty failure have been used by foreign colleagues since the late 1980s [39]. The apparent potential of the method influenced the early results obtained by the authors, both used alone [40, 41] and in comparison with other fixation methods [16]. Functional results and patient satisfaction after surgery using the intramedullary osteosynthesis method significantly exceeded the effectiveness of the Ilizarov apparatus ($p > 0.05$). An analysis of more recent literature sources allows us to conclude that there are no significant differences in daily functioning and quality of life in the patients treated with the methods [42]. We came to a similar conclusion in our previous studies [17]. However, including the categorical variable of defects according to AORI in the analysis of functional results, we revealed an advantage of using the Ilizarov apparatus for type III bone defects ($p = 0.018$). This allowed us to delve into this factor in more detail and conclude that an intramedullary nail is a predictor of functional limitations in FTS procedure (OR = 10.67; 95 % CI 1.201–15.72; $p = 0.034$). We have not encountered similar results and conclusions in the available literature.

A probable reason for such an impact on the functional parameters of patients with an intramedullary nail is the impossibility of creating a biomechanically correct position of the operated limb. The technical characteristics of a long nail for arthrodesis of the knee joint do not provide for its valgus deviation of about 5° in the frontal plane at the level of the knee joint, but have only an antecurvatum bending. Of interest is the idea of Solomin et al. to turn the technical disadvantage of this design into an advantage by rotating the nail inward by 45° [43]. In practice, the use of this technique revealed a range of problems for our team of authors associated with locking, conflict of the distal end of the nail with the posterior cortical wall of the tibia and the risk of its splitting during further advancement of the nail, and malpositioning of the foot in internal rotation when

the nail is jammed in the tibial canal. Given the above, achieving an optimal mechanical axis, and therefore the correct axial load distribution, becomes a difficult task. Existing biomechanical studies of gait confirm the negative impact of an ankylosed knee joint on the "survival" of adjacent joints [44]. The resulting, even minor, varus deformity of the limb at the level of the knee joint leads to distortion of the biomechanical axis of the lower limb, pathological overload of the ankle and hip joints, progression of deforming arthrosis, chronic pain syndrome, and limitation in the quality of life and daily activities of patients. It is important to consider the magnitude of the true bone defect, which directly affects the residual shortening of the limb. In turn, the difference in leg length affects both the patient's functioning and their mental state. The Ilizarov method is more "flexible" for eliminating or leveling this difference and biomechanically aligning the limb axis [45].

In the world literature, the most widespread and structural complications after arthrodesis of the knee joint were analyzed by Carr et al. based on the national database of the United States [46]. The authors indicate a rate of systemic complications of 25.9 % (n = 683/2634) and in-hospital mortality of 2.1 % (n = 55/2634). It is worth noting the fact that colleagues do not consider the influence of the fixation method on the obtained results. Our study showed a sevenfold effect of an intramedullary nail for fixation on the development of systemic complications and in-hospital mortality (OR = 6.69; 95 % CI 1.33–9.9; p = 0.035). Mention of critical events associated with the use of a long nail for knee arthrodesis is found in the work of Brown et al. on a small sample of patients. The authors present data on a two-year mortality rate of 33 % of cases (n = 6/18), including one case (5.5 %) of death in the early postoperative period [2].

The pathogenesis of systemic complications is associated with the formation of numerous free fatty acids during reaming of the medullary canal of the femur and tibia and their entry into the bloodstream during insertion of the intramedullary implant due to a sharp increase in intramedullary pressure. The contents of the medullary canal have a direct cytotoxic effect on the vascular endothelium, leading to a systemic inflammatory response. The additional release of thromboplastic factors leads to a prothrombotic state, clinically manifested as pulmonary embolism, respiratory failure, and multiple organ failure [47].

Discriminant analysis showed that the occurrence of an adverse FTS outcome is statistically significantly (p < 0.001) dependent on the patient's risk factors, particularly their cumulative factors. Among patients in the study cohort, those with four or more risk factors had adverse outcomes in 72.2 % of cases, compared to 22.2 % of those with two or three risk factors. Among patients with one risk factor, an adverse outcome was observed in 10 % of cases.

Limitations of the study

The small sample size limits the statistical power of the study and increases the risk of wide confidence intervals for a number of factors. Univariate regression analysis was used in the study, which does not exclude the potential influence of hidden confounding variables. To minimize bias in future results, multivariate regression analysis for potential confounders is necessary.

CONCLUSION

The study demonstrated a statistically significant direct association between adverse outcomes of femorotibial synostosis in the conditions of periprosthetic infection with the patient's comorbid background, gram-negative microbiological profile of the infection, large bone defects, five or more previous debridement surgeries, and the chosen fixation method. As the number of risk factors identified in a patient grows, the likelihood of an adverse outcome significantly increased.

Conflict of Interest *The authors declare no obvious or potential conflicts of interest related to the research conducted and the publication of this article.*

Source of Funding *The authors declare that they received no external funding for the study and publication.*

Ethical approval *The study was approved by the local ethics committee of the Regional Clinical Hospital for War Veterans, Yekaterinburg (protocol No. 2/2025, dated February 25, 2025).*

Informed consent *All patients provided written informed consent to participate and publish their findings without a dtailed information to identify the patients included in the study.*

REFERENCES

1. Mabry TM, Jacofsky DJ, Haidukewych GJ, Hanssen AD. Comparison of intramedullary nailing and external fixation knee arthrodesis for the infected knee replacement. *Clin Orthop Relat Res*. 2007;464:11-15. doi: 10.1097/BLO.0b013e31806a9191.
2. Brown NM, Balkissoon R, Saltzman BM, et al. Knee Arthrodesis With an Intramedullary Antegrade Rod as a Salvage Procedure for the Chronically Infected Total Knee Arthroplasty. *J Am Acad Orthop Surg Glob Res Rev*. 2020;4(9):e20.00082-6. doi: 10.5435/JAAOSGlobal-D-20-00082.
3. Röhner E, Windisch C, Nuetzmann K, et al. Unsatisfactory outcome of arthrodesis performed after septic failure of revision total knee arthroplasty. *J Bone Joint Surg Am*. 2015;97(4):298-301. doi: 10.2106/JBJS.N.00834.
4. Robinson M, Piponov HI, Ormseth A, et al. Knee Arthrodesis Outcomes After Infected Total Knee Arthroplasty and Failure of Two-stage Revision With an Antibiotic Cement Spacer. *J Am Acad Orthop Surg Glob Res Rev*. 2018;2(1):e077. doi: 10.5435/JAAOSGlobal-D-17-00077.
5. Yeung CM, Lichstein PM, Varady NH, et al. Knee Arthrodesis Is a Durable Option for the Salvage of Infected Total Knee Arthroplasty. *J Arthroplasty*. 2020;35(11):3261-3268. doi: 10.1016/j.arth.2020.06.034.
6. Schnetz M, Maluki R, Ewald L, et al. Above-knee amputation shows higher complication and mortality rates in line with lower functional outcome compared to knee arthrodesis in severe periprosthetic joint infection. *Bone Joint J*. 2024;106-B(7):669-679. doi: 10.1302/0301-620X.106B7.BJJ-2023-0978.R2.
7. Fedorka CJ, Chen AF, McGarry WM, et al. Functional ability after above-the-knee amputation for infected total knee arthroplasty. *Clin Orthop Relat Res*. 2011;469(4):1024-1032. doi: 10.1007/s11999-010-1577-0.
8. Benvenuti L, Digennaro V, Panciera A, et al. Knee arthrodesis with intramedullary nail in end-stage periprosthetic joint infection with extensor mechanism failure: a retrospective outcome and reinfection rate analysis of a case series. *Musculoskelet Surg*. 2025;109(4):455-461. doi: 10.1007/s12306-025-00896-8.
9. Trouillez T, Faure PA, Martinot P, et al. Above-the-knee amputation versus knee arthrodesis for revision of infected total knee arthroplasty: Recurrent infection rates and functional outcomes of 43 patients at a mean follow-up of 6.7 years. *Orthop Traumatol Surg Res*. 2021;107(4):102914. doi: 10.1016/j.otsr.2021.102914.
10. Prokhorenko VM, Zlobin AV, Mamedov AA, Baitov VS. Treatment of the paraprosthetic infection of the knee joint. *Modern problems of science and education*. 2015;(6). URL: https://science-education.ru/ru/article/view?id=23231. (In Russ.)
11. Kliushin NN, Ermakov AN, Ababkov IuV, Koiushkov AN. True efficiency of arthrodesis in the treatment of periprosthetic knee infection. *Genij Ortopedii*. 2019;25(2):156-161. doi: 10.18019/1028-4427-2019-25-2-156-161.
12. Mercurio M, Gasparini G, Cofano E, et al. Knee Arthrodesis for Periprosthetic Knee Infection: Fusion Rate, Complications, and Limb Salvage-A Systematic Review. *Healthcare (Basel)*. 2024;12(7):804. doi: 10.3390/healthcare12070804.
13. White CJ, Palmer AJR, Rodriguez-Merchan EC. External Fixation vs Intramedullary Nailing for Knee Arthrodesis After Failed Infected Total Knee Arthroplasty: A Systematic Review and Meta-Analysis. *J Arthroplasty*. 2018;33(4):1288-1295. doi: 10.1016/j.arth.2017.10.055.
14. Corona PS, Jurado M, Scott-Tennent A, et al. Uniplanar versus biplanar monolateral external fixator knee arthrodesis after end-stage failed infected total knee arthroplasty: a comparative study. *Eur J Orthop Surg Traumatol*. 2020;30(5):815-825. doi: 10.1007/s00590-020-02633-2.
15. Aparicio G, Otero J, Bru S. High Rate of Fusion but High Complication Rate After Knee Arthrodesis for Infected Revision Total Knee Replacement. *Indian J Orthop*. 2020;54(5):616-623. doi: 10.1007/s43465-020-00163-x.
16. Iacono F, Raspugli GF, Bruni D, et al. Arthrodesis After Infected Revision TKA: Retrospective Comparison of Intramedullary Nailing and External Fixation. *HSS J*. 2013;9(3):229-235. doi: 10.1007/s11420-013-9349-5.
17. Bugaev GA, Vinogradsky AE, Prokopyev DS, Borzunov DYu. Comparative analysis of femoro-tibial synostosis results in periprosthetic infection. *Genij Ortopedii*. 2025;31(5):574-586. doi: 10.18019/1028-4427-2025-31-5-574-586.
18. Tsukayama DT, Estrada R, Gustilo RB. Infection after total hip arthroplasty. A study of the treatment of one hundred and six infections. *J Bone Joint Surg Am*. 1996;78(4):512-523. doi: 10.2106/00004623-199604000-00005.
19. Khan Y, Arora S, Kashyap A, et al. Bone defect classifications in revision total knee arthroplasty, their reliability and utility: a systematic review. *Arch Orthop Trauma Surg*. 2023;143(1):453-468. doi: 10.1007/s00402-022-04517-y.
20. Ratter J, Pellekooren S, Wiertsema S, et al. Content validity and measurement properties of the Lower Extremity Functional Scale in patients with fractures of the lower extremities: a systematic review. *J Patient Rep Outcomes*. 2022;6(1):11. doi: 10.1186/s41687-022-00417-2.
21. Denyer S, Hoyt AK, Schneider AM, Brown NM. Knee Arthrodesis: An Analysis of Surgical Risk Factors and Complications Using a National Database. *Arthroplast Today*. 2023;20:101098. doi: 10.1016/j.artd.2023.101098.
22. Yue C, Cui G, Ma M, et al. Associations between smoking and clinical outcomes after total hip and knee arthroplasty: A systematic review and meta-analysis. *Front Surg*. 2022;9:970537. doi: 10.3389/fsurg.2022.970537.
23. Boyce L, Prasad A, Barrett M, et al. The outcomes of total knee arthroplasty in morbidly obese patients: a systematic review of the literature. *Arch Orthop Trauma Surg*. 2019;139(4):553-560. doi: 10.1007/s00402-019-03127-5.
24. Podmore B, Hutchings A, van der Meulen J, et al. Impact of comorbid conditions on outcomes of hip and knee replacement surgery: a systematic review and meta-analysis. *BMJ Open*. 2018 Jul 11;8(7):e021784. doi: 10.1136/bmjopen-2018-021784.
25. Dimitriou D, Ramokgopa M, Pietrzak JRT, et al. Human Immunodeficiency Virus Infection and Hip and Knee Arthroplasty. *JBJS Rev*. 2017;5(9):e8. doi: 10.2106/JBJS.RVW.17.00029.
26. Ferraro SL, Zhao AY, Mahindroo S, et al. AIDS but not asymptomatic HIV is associated with lower 2-10-year implant survivorship following total knee arthroplasty. *Knee*. 2024;48:76-82. doi: 10.1016/j.knee.2024.02.012.

27. Tryapichnikov AS, Ermakov AM, Klyushin NM, et al. Treatment outcomes of periprosthetic joint infection in HIV-positive patients. *Traumatology and Orthopedics of Russia*. 2019;25(4):117-125. doi: 10.21823/2311-2905-2019-25-4-117-125.
28. Opportunistic Infections Project Team of the Collaboration of Observational HIV Epidemiological Research in Europe (COHERE) in EuroCoord; Young J, Psichogiou M, Meyer L, et al. CD4 cell count and the risk of AIDS or death in HIV-Infected adults on combination antiretroviral therapy with a suppressed viral load: a longitudinal cohort study from COHERE. *PLoS Med*. 2012;9(3):e1001194. doi: 10.1371/journal.pmed.1001194.
29. Lenguerrand E, Whitehouse MR, Beswick AD, et al. Risk factors associated with revision for prosthetic joint infection following knee replacement: an observational cohort study from England and Wales. *Lancet Infect Dis*. 2019;19(6):589-600. doi: 10.1016/S1473-3099(18)30755-2.
30. Dudareva M, Hotchen A, McNally MA, et al. Systematic review of risk prediction studies in bone and joint infection: are modifiable prognostic factors useful in predicting recurrence? *J Bone Jt Infect*. 2021;6(7):257-271. doi: 10.5194/jbji-6-257-2021.
31. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. *J Chronic Dis*. 1987;40(5):373-383. doi: 10.1016/0021-9681(87)90171-8.
32. Klemt C, Tirumala V, Smith EJ, et al. Development of a Preoperative Risk Calculator for Reinfection Following Revision Surgery for Periprosthetic Joint Infection. *J Arthroplasty*. 2021;36(2):693-699. doi: 10.1016/j.arth.2020.08.004.
33. Lee DW, Han HS, Ro DH. Risk factors of recurrent periprosthetic joint infection of the knee after two-stage reimplantation. *Knee Surg Relat Res*. 2025;37(1):4. doi: 10.1186/s43019-025-00258-5.
34. Preobrazhensky PM, Bozhkova SA, Kazemirsky AV. Staged revision knee arthroplasty in patients with periprosthetic joint infection: when to stop? *Traumatology and Orthopedics of Russia*. 2025;31(4):28-40. (In Russ.) doi: 10.17816/2311-2905-17733.
35. Jhan SW, Lu YD, Lee MS, et al. The risk factors of failed reimplantation arthroplasty for periprosthetic hip infection. *BMC Musculoskelet Disord*. 2017;18(1):255. doi: 10.1186/s12891-017-1622-1.
36. Insall JN, Thompson FM, Brause BD. Two-stage reimplantation for the salvage of infected total knee arthroplasty. *J Bone Joint Surg Am*. 1983;65(8):1087-1098.
37. Son MS, Lau E, Parvizi J, et al. What Are the Frequency, Associated Factors, and Mortality of Amputation and Arthrodesis After a Failed Infected TKA? *Clin Orthop Relat Res*. 2017;475(12):2905-2913. doi: 10.1007/s11999-017-5285-x.
38. Parcel TW, Levering M, Polikandriotis JA, et al. Failure analysis of knee arthrodesis with the WichitaFusion Nail. *Orthopedics*. 2013;36(11):e1336-9. doi: 10.3928/01477447-20131021-11.
39. Wilde AH, Stearns KL. Intramedullary fixation for arthrodesis of the knee after infected total knee arthroplasty. *Clin Orthop Relat Res*. 1989;(248):87-92.
40. McQueen DA, Cooke FW, Hahn DL. Intramedullary compression arthrodesis of the knee: early experience with a new device and technique. *J Arthroplasty*. 2005;20(1):72-78. doi: 10.1016/j.arth.2004.09.022.
41. Bargiotas K, Wohlrab D, Sewecke JJ, et al. Arthrodesis of the knee with a long intramedullary nail following the failure of a total knee arthroplasty as the result of infection. *J Bone Joint Surg Am*. 2006;88(3):553-8. doi: 10.2106/JBJS.E.00575.
42. Suda AJ, Brachtendorf X, Tinelli M, et al. Low complication rate and better results for intramedullary nail - arthrodesis for infected knee joints compared to external fixator-a series of one hundred fifty two patients. *Int Orthop*. 2021;45(7):1735-1744. doi: 10.1007/s00264-021-05054-w.
43. Solomin LN, Shchepkina EA, Korchagin KL, Sabirov FK. Comparative Analysis of Knee Joint Fusion with Long Locking Nail and Ilizarov Apparatus in Patients with Deep Infection after Arthroplasty. *Traumatology and Orthopedics of Russia*. 2020;26(3):109-118. (In Russ.) doi: 10.21823/2311-2905-2020-26-3-109-118.
44. Wagener N, Böhle S, Kirschberg J, et al. Knee Arthrodesis Affects Gait Kinematics More in the Ankle Than in the Hip Joint. *Medicina (Kaunas)*. 2022;58(6):696. doi: 10.3390/medicina58060696.
45. Birch JG, Samchukov ML. Use of the Ilizarov method to correct lower limb deformities in children and adolescents. *J Am Acad Orthop Surg*. 2004;12(3):144-154. doi: 10.5435/00124635-200405000-00002.
46. Carr JB 2nd, Werner BC, Browne JA. Trends and Outcomes in the Treatment of Failed Septic Total Knee Arthroplasty: Comparing Arthrodesis and Above-Knee Amputation. *J Arthroplasty*. 2016;31(7):1574-1577. doi: 10.1016/j.arth.2016.01.010.
47. Pape HC, Grimme K, Van Griensven M, et al. Impact of intramedullary instrumentation versus damage control for femoral fractures on immunoinflammatory parameters: prospective randomized analysis by the EPOFF Study Group. *J Trauma*. 2003;55(1):7-13. doi: 10.1097/01.TA.0000075787.69695.4E.

The article was submitted 27.01.2025; approved after reviewing 16.02.2026; accepted for publication 06.04.2026.

Information about the authors:

Gleb A. Bugaev — Orthopaedic Surgeon, glebbugaev97@gmail.com, https://orcid.org/0000-0002-0176-0090;

Alexander E. Vinogradsky — Candidate of Medical Sciences, Orthopaedic Surgeon, Assistant Professor, vinalexc@mail.ru, https://orcid.org/0000-0003-2912-6291;

Dmitry Yu. Borzunov — Doctor of Medical Sciences, Professor, Orthopaedic Surgeon, Professor of the Department, borzunov@bk.ru, https://orcid.org/0000-0003-3720-5467.