

Original article

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Microbial landscape in different types of periprosthetic hip joint infection

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Abstract

Introduction Due to the steady increase in the number of primary total hip arthroplasties, the problem of eliminating periprosthetic joint infection (PJI) has become pressing. The rise of antimicrobial-resistant PJI pathogens significantly complicates and prolongs treatment, contributing to the development of chronic infection, sometimes with latent clinical manifestations.

The **aim** of this study was to identify the microbial landscape characteristics in different types of hip joint PJI.

Materials and Methods Microbiological studies of 96 patients with hip joint PJI were analyzed: Group 1 ($n = 16$) with type I PJI; Group 2 ($n = 80$) with type II and type III PJI. Patients in Group 1 underwent the DAIR procedure and those in Group 2 underwent two-stage revision hip replacement.

Results A total of 103 microbial isolates were obtained from 96 patients: 16 (15.5 %) Gr(–) and 87 (84.5 %) Gr(+). Among Gr(+), MRSA, MRSE, and MRSH were detected in 18 isolates, and among Gr(–), ESBL+ was detected in 16 isolates. The predominant pathogens in the PJI structure were *S. aureus* (52.9 %), *S. epidermidis* (19.5 %), *E. cloacae* (37.5 %), *P. aeruginosa* (18.6 %), and *E. coli* (18.6 %). Associations were more common in type 1 PJI (25 %) than in chronic forms (18.4 %). Microbial associations were detected in 20 cases (19.4 %). Culture-negative infection (CNI) was detected in 16 patients (16.7 %) in both groups. Relapse of PJI in patients with microbial associations occurred in three cases (15 %). In CNI cases, recurrence developed in four cases (25 %).

Discussion The growth of Gr(–) flora in early PJI exceeded that in the chronic one: 31.3 % and 9.2 %, respectively. DAIR is ineffective in such conditions. *S. aureus*, as a causative agent of bone and joint infections, exists in a quasi-dormant state which contributes to chronicity.

Conclusion Gram-negative microorganisms and their associations dominate in the etiology of early PJI (type I), while gram-positive pathogens predominated in chronic types (types II and III). Culture-negative infection was a more common cause of early PJI than of chronic types (25.0 % and 16.1 %, respectively). No statistically significant differences were found between the groups in the detection of methicillin-resistant staphylococci or gram-negative bacteria ESBL+.

Keywords: hip joint, periprosthetic joint infection, revision arthroplasty, culture-negative infection, microbial landscape

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INTRODUCTION

Due to the steady increase in the number of primary total joint replacements performed worldwide, the problem of eliminating complications, and primarily of periprosthetic joint infection (PJI), has become pressing [1, 2, 3]. PJI diagnosis is challenging. Identification of specific pathogens is important and is the basis for the targeted use of antibacterial agents [4]. Traditionally, infectious agents are identified through microbiological tests (MBT) of the synovial fluid and intraoperative tissue biopsies. However, the growth of microorganisms during culture tests may be not revealed and this failure reaches 40 % for various reasons:

- biofilm formation;
- inert pathogen formation;
- identification of agents in an appropriate nutrient medium;
- use of antibiotics before tests for pathogens;
- colonization of the osteocyte-lacunar-tubular network of cortical bone [5];

The growth of antimicrobial-resistant pathogens causing PJI significantly complicates and prolongs treatment. These pathogens include staphylococcal strains resistant to three or more classes of drugs, fluoroquinolone- and carbapenem-resistant gram-negative bacteria, and fungal microflora [6, 7, 8].

All of the above contribute to the development of chronic infection, in some cases with latent clinical manifestations. This complicates diagnosis and accounts for a significant rate of treatment failures in patients with orthopedic infection [6, 9].

The **aim** of this study was to identify the microbial landscape characteristics in different types of hip joint PJI.

MATERIAL AND METHODS

Study design A retrospective analysis of the results of MBI punctures and tissue intraoperative biopsies from 96 patients with PJI of the hip joint (ICD-10: Z96.6) treated from 2015 to 2020 at the surgical department for infection of the Sverdlovsk Regional Clinical Psychoneurological Hospital for War Veterans was conducted.

Inclusion criteria Patients with PJI clinical and laboratory signs who underwent surgical treatment in a hospital setting.

Exclusion criteria Patient without PJI signs

The study was approved by the institutional ethics committee of the War Veterans' Hospital (Yekaterinburg, protocol dated November 9, 2015, No. 9.2/2015) and conducted in accordance with the 1975 Helsinki Declaration (revised in 2008). All patients signed informed consent. Detailed information that would identify the patients included in the study is not available.

According to the classification of deep infection after total hip arthroplasty (Coventry – Fitzgerald – Tsukayama [10]), the subjects were divided into two groups. Group 1 included 16 patients with early PJI, corresponding to type I according to the Tsukayama classification. Group 2 included 80 (83.3 %) patients with chronic PJI, of which 39 cases (48.75 %) were type II and 41 cases (51.25 %) were type III. Our study did not include patients with PJI type IV.

In most cases, patients in group 1 underwent the DAIR (Debridement, Antibiotics, and Implant Retention) procedure. Group 1 also included patients with extensive musculoskeletal defects from previous surgeries and severe medical conditions, for whom revision hip replacement

was not possible. These patients underwent resection hip arthroplasty and removal of implant components.

Patients in group 2 underwent two-stage revision hip arthroplasty.

The study groups were comparable in terms of age and gender characteristics ($p > 0.05$) (Table 1). The analysis revealed no statistically significant differences between the early ($n = 16$) and chronic PJI ($n = 80$) groups. Stratification by age < 65 years and ≥ 65 years, did not find statistically significant differences ($p = 0.059$).

Table 1

Age and gender of included patients

Parameter for comparison		Group 1	Group 2	P-value
		Early PJI ($n = 16$)	Chronic PJI ($n = 80$)	
Males	n	10	42	0.464
	%	62.5	52.5	
Females	n	6	38	
	%	37.5	47.5	
Age, years ($M \pm SD$)		63.7 ± 11.1	57.9 ± 12.2	0.656
< 65 year old	n	8	59	0.059
	%	50.0	73.8	
≥ 65 year old	n	8	21	
	%	50.0	26.2	

Pyoinflammatory complications after previous revision procedures developed in eight (50 %) patients in group 1 and 41 (51.3 %) patients in group 2.

In 41 (83.7 %) of 49 revision procedures, pathogens were detected in tissue biopsies during the previous stages of treatment with MBI tests.

After the first stage of two-stage revision arthroplasty, recurrent infection occurred in seven (8.8 %) patients in Group 2. Recurrent infection after the DAIR procedure was observed in one (6.25 %) patient in Group 1.

In 15 patients (18.75 %) in group 2, negative-pressure wound therapy (NPWT) was used at stage 1 of revision arthroplasty due to severe purulent soft tissue destruction, necrosis, and sclerotic changes in bone tissue [11–14]. One case of recurrent PJI was identified in this group of patients (6.7 %).

Upon admission to the hospital, all patients had their complaints and anamnestic data collected, a general and local examination was performed, and local signs of inflammation were identified. To identify implant instability and pathological changes in adjacent bone structures, all patients underwent radiographic studies of the affected joints, and X-ray fistulography was performed in the presence of external fistulas [1, 5].

Laboratory tests included determination of the white blood cell count, ESR, and C-reactive protein levels in the blood and serum [15, 16]. For bacteriological and cytological examination of the puncture, a diagnostic puncture of the periprosthetic cavity was performed regardless of the presence of a fistula [17, 18].

Microbiological (culture) study

Biomaterial obtained through diagnostic puncture of the periprosthetic cavity and intraoperative tissue biopsies were analyzed. Biopsies were homogenized before seeding. Biomaterial was collected in a sterile container according to sample collection guidelines and delivered to the laboratory within two hours.

After vortexing, 10 µl of the puncture fluid was plated onto culture media with a sterile calibrated loop using the depletion seeding method.

Culture tests were performed on the following culture media:

- 5 % sheep blood agar (Columbia Agar base, Bio-Rad, France; defibrinated sheep blood, E&O Laboratories, Scotland),
- chocolate agar (Columbia Agar base, Bio-Rad, France; defibrinated sheep blood, E&O Laboratories, Scotland),
- yolk-salt agar (nutrient agar for microbial cultivation GRM-agar, State Research Center for Applied Microbiology and Biotechnology, Russia),
- Sabouraud agar with 2 % glucose and chloramphenicol (SIFIN diagnostics, Germany).

To enrich and isolate anaerobes, 100 µl of puncture fluid was inoculated into thioglycollate medium in tall-column tubes (State Research Center for Applied Microbiology and Biotechnology, Russia). The inoculated Petri dishes were then placed in an aerobic incubator at $37 \pm 1^\circ\text{C}$. Blood and chocolate agar dishes were incubated in an atmosphere containing 5 % CO_2 . The cultures were incubated for up to 72 hours and their growth was assessed after 24, 48, and 72 hours.

Identification of the grown colonies was performed using phenotypic methods (Gram staining, oxidase and catalase tests, etc.) and a WalkAway 40 Plus bacteriological analyzer (Beckman Coulter, USA).

Antibiotic susceptibility was determined by the disk diffusion method according to the standard procedure described by EUCAST, as well as using a WalkAway 40 Plus bacteriological analyzer (Beckman Coulter, USA).

Susceptibility categories were interpreted according to the current EUCAST criteria: Clinical breakpoints — bacteria (<https://www.eucast.org/>).

Statistical analysis was performed using Jamovi software (version 2.6.17, Australia) and Microsoft Excel (version 16.75.2, USA). The mean and standard deviation ($M \pm SD$) were used to describe quantitative data with a normal distribution, and the median and interquartile range (IQR) corresponding to the lower (Q1) and upper (Q3) quartiles were used for non-normally distributed data. The normality of data distribution was tested using the Shapiro-Wilk test. Categorical data were described using absolute values and percentages (n, %). Comparison of groups by quantitative indicator with a normal data distribution was performed using the Student's t-test or the Mann – Whitney U test for non-normally distributed data. To assess differences between groups based on categorical characteristics, 2×2 contingency tables were constructed. In cases where the expected frequency exceeded 5, the Pearson χ^2 test was used. In cases where the expected frequencies were low (< 5), the Fisher exact test was used. Differences between the groups were considered statistically significant at $p < 0.05$.

RESULTS

Analysis of the clinical PJI manifestations upon admission to the hospital (Table 2) revealed a high rate of fistulas and wounds, which were detected in 93.8 % of patients in group 1 with early PJI and in 80.0 % of patients in group 2 with chronic PJI. Hyperemia of the skin in the area of the affected joint was recorded in 87.5 % of cases in group 1 and in 67.5 % of cases in group 2. Pain in the involved joint was reported in the majority of patients in both groups. An increase in body temperature to febrile values was relatively rare. No statistically significant differences in these clinical manifestations were found between the groups ($p > 0.05$).

Table 2

Detection of diagnostically significant clinical manifestations of PJI upon admission to hospital

Clinic Exact Fisher's test al manifestations	Group 1		Group 2		P-value Exact Fisher's test
	Early PJI (n = 16)		Chronic PJI (n = 80)		
	a6c.	%	a6c.	%	
Sinuses/wounds	15	93.8	64	80.0	0.289
Hyperemia of the skin in the area of the affected joint	14	87.5	54	67.5	0.139
Pain in the affected joint	13	81.3	71	88.8	0.415
Body temperature rise to febrile levels	2	12.5	18	22..5	0.510

Recurrence of PJI after stage I was observed in seven (8.8 %) patients in group 2. Stage II revision hip arthroplasty was performed in 64 (80 %) patients.

One patient with type I PJI in group 1 underwent two-stage revision hip arthroplasty after DAIR, which yielded a positive result.

Two or more comorbidities (diabetes mellitus, systemic diseases, obesity, HIV infection, hepatitis B and C, injection drug abuse, etc.), which are risk factors for PJI [1], were observed in nine (56.3 %) cases in group 1 and in 58 (72.5 %) observations in group 2.

Analysis of laboratory parameters of inflammatory activity upon admission (Table 3) revealed no statistically significant differences between the groups ($p > 0.05$). The mean white blood cell count was higher in the early PJI group ($p = 0.298$). The ESR level was also higher in group 1, but the differences did not reach statistical significance ($p = 0.130$). The C-reactive protein concentration tended to be higher in early PJI ($p = 0.055$).

Table 3

Laboratory parameters of inflammatory activity in patients with early and chronic periprosthetic joint infection

Parameter	Group 1	Group 2	P-value
	Early PJI (n = 16)	Chronic PJI (n = 80)	
White blood cell count, 10 ⁹ /l	7.85 ± 1.97	7.30 ± 2.60	0.298
ESR, mm/hour	41.25 ± 20.20	30.68 ± 18.65	0.130
C-reactive protein, mg/L	115.63 ± 44.73	74.97 ± 55.94	0.055

A total of 103 microbial isolates were obtained by the MBT from 96 patients with PJI, including 16 (15.5 %) gram-negative and 87 (84.5 %) gram-positive microorganisms (Table 4; Figures 1 and 2).

Table 4

Structure of the microbial landscape in the isolates of the studied groups

Agent/group	Group 1		Group 2		Total (n = 103)	
	Early PJI (n = 17)		Chronic PJI (n = 86)			
	n	%	n	%	n	%
Gram-positive microorganisms	11	64.7	76	88.4	87	84.5
<i>Staphylococcus aureus</i>	7	41.2	39	45.3	46	44.7
<i>Staphylococcus epidermidis</i>	1	5.9	16	18.6	17	16.5
<i>Enterococcus faecalis</i>	1	5.9	7	8.1	8	7.8
Other CNI**	2	11.8	12	13.9	14	13.6
Gram-negative microorganisms	6*	35.3*	10*	11.6*	16	15.5
<i>Enterobacter cloacae</i>	4	23.5	2	2.3	6	5.8
<i>Pseudomonas aeruginosa</i>	1	5.9	2	2.3	3	2.9
Other gram-negative pathogens***	1	5.9	6	7.0	7	6.8

Note: * – differences between groups are statistically significant ($\chi^2 = 6.06$; Pearson criterion $p = 0.014$); ** – the category “Other coagulase-negative staphylococci (CNS)” includes: *Staphylococcus hominis*, *S. capitis*, *S. warneri*, *S. intermedius*; *** – the category “Other gram-pathogens” includes: *Escherichia coli*, *Acinetobacter baumannii*, *Klebsiella pneumoniae*, *Proteus mirabilis*.

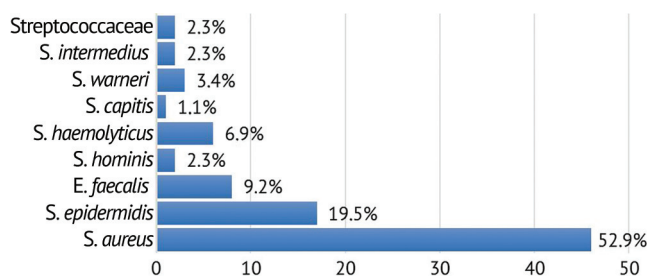


Fig. 1 Species structure of gram-positive bacteria (%)

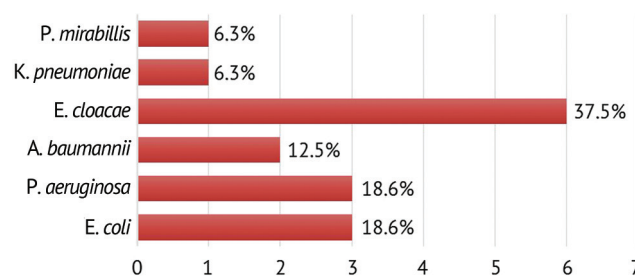


Fig. 2 Species structure of gram-negative bacteria (%)

Analysis of the microbial composition of the isolates (Table 4) revealed statistically significant differences between early and chronic PJI ($\chi^2 = 6.06$; $p = 0.014$). In the early PJI group ($n = 17$ isolates), gram-negative microorganisms were isolated in 35.3 % of cases, compared with only 11.6 % in the chronic one ($n = 86$ isolates). In contrast, gram-positive flora prevailed in chronic PJI.

Among gram-positive bacteria, MRSA (methicillin-resistant staphylococcus *aureus*), MRSE (methicillin-resistant staphylococcus *epidermidis*), and MRSH (methicillin-resistant staphylococcus *hominis*) were found in 18 (20.7 %) isolates (two isolates (11.1 %) in group 1, and 16 (88.9 %) in group 2). In the structure of gram-negative bacteria, ESBL+ were found in 16 (25 %) cases (two (12.5 %) in group 1, and 14 (87.5 %) in group 2, respectively).

Microbial associations were detected in 20 (19.4 %) cases from the total number of microorganisms ($n = 103$): associations of Gr(+) and Gr(−) bacteria were found in seven cases (35 %); Gr(+) associations in 10 (50 %); Gr(−) associations in three (15 %) cases. Four associations (20 %) containing three or more pathogens were detected.

In 16 patients (16.7 %) of both groups, despite the clinical and laboratory picture of PJI, the MBT results were negative.

Relapses of PJI in patients with microbial associations were noted in three (15 %) of 20 cases. Recurrence was recorded in four (25 %) patients with culture-negative infection (CNI).

Figure 3 shows a comparative assessment of the microbial landscape of the pathogens in groups 1 and 2.

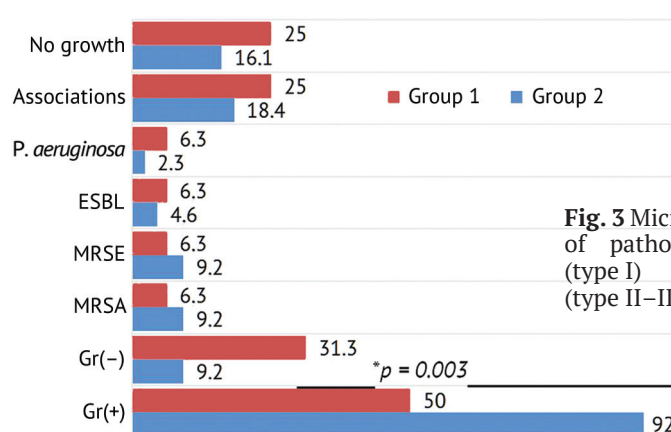


Fig. 3 Microbial landscape of pathogens of early (type I) and chronic (type II–III) PJI %

Analysis of the microbial landscape among patients also revealed significant differences in the distribution of pathogens between early and chronic periprosthetic joint infection ($\chi^2 = 8.94$, $p = 0.003$). In the early PJI group ($n = 16$), gram-negative bacteria were detected in 31.3 % of cases ($n = 5$), which is significantly more frequent compared to chronic PJI ($n = 80$), where gram-negative bacteria were found in only 9.2 % of cases ($n = 7$). In contrast, gram-positive bacteria predominated in chronic infection — 92 % ($n = 74$) versus 50 % ($n = 8$) of cases in the early type.

These findings confirm that gram-negative bacteria have a significant impact on the development of early PJI, while the chronic disease is predominantly associated with gram-positive bacteria.

In patients in group 2 who underwent NPWT at stage 1 of revision arthroplasty ($n = 15$), only gram-positive flora was detected in intraoperative MBT. A total of 12 microbial isolates were obtained in this group. Three cases (20 %) had CNI. Associations were obtained in one case (6.7 %), and MRSA/MRSE was detected in three cases (20 %).

Among patients with revision interventions at previous treatment stages ($n = 49$), microbial associations were detected in 12 (24.5 %) (four (33.3 %) in group 1 and eight (66.7 %) in group 2). Three (25 %) of these patients experienced recurrent PJI. Two patients subsequently underwent repeat debridement with cement spacer change. Recurrent infection was observed in four (25 %) patients with CNI in group 2.

DISCUSSION

Analyzing the microbial landscape, one can note the leading role of gram-positive flora in the causes of PJI development (group 1 — 50 %; group 2 — 92 %) [6, 19–22]. The growth of gram-negative flora in early PJI significantly exceeded similar indicators for chronic infection: 31.3 % and 9.2 %, respectively. These microorganisms represent a serious problem for all orthopedists involved in primary and revision arthroplasty due to the steadily increasing resistance of microflora to many antibacterial drugs [23]. The involvement of gram-negative bacteria in the etiology of PJI complicates and prolongs the treatment process [24]. The effectiveness of the DAIR technique in such conditions may decrease significantly.

The incidence of *P. aeruginosa* in the early PJI was 6.3 % and 2.3 % in the chronic PJI. *P. aeruginosa* can be the cause of early/postoperative nosocomial infections [25]. According to various authors, *P. aeruginosa* is the cause of nosocomial infections in more than 15 % of cases [26–28].

Microbial associations pose a challenge in treating patients with PJI. In our study, the incidence of polymicrobial infections in PJI type I was 25 %, and in PJI types II–III, it was 18.4 %. Microbial associations complicate the choice of etiotropic antibiotic therapy, which often leads to worse treatment outcomes compared to monomicrobial microflora [29, 30].

In chronic PJI, *Staphylococcus aureus* is isolated in 52.9 % of cases, characterized by the growth of resistant strains [6, 19–22]. The numbers of MRSA/MRSE/MRSH strains in our study were comparable.

Methicillin resistance is not a decisive virulence factor. However, methicillin-resistant *S. aureus* (MRSA) strains often express higher levels of virulence factors that facilitate their survival and dissemination [31].

In clinically complex cases with severe soft tissue destruction, we used NPWT at the first stage of revision arthroplasty [11]. *S. aureus* was found in 83.3 % of isolates from this group of patients. Several significant features of *S. aureus* contribute to tissue damage, particularly in PJI. *S. aureus* is capable of producing a number of toxins, including alpha-toxin, exfoliative toxins (ETA, ETB, ETC), enterotoxins, and Panton-Valentine leukocidin. Moreover, *S. aureus* has many secreted enzymes and cell wall proteins that mediate tissue invasion, such as coagulase, DNase, hyaluronidase, collagenase, and fibronectin-binding proteins. Most virulence factors are encoded by additional genes, which may or may not be present in a given *S. aureus* strain. In vitro studies also show that *S. aureus* strains rapidly aggregate in the presence of human synovial fluid and develop into macroscopic colonies within 24 hours, which ultimately transform into a biofilm resistant

to antibiotics [32]. Synovial fluid components such as fibrinogen, fibronectin, and free DNA may induce bacterial aggregation, which is thought to play a role in the pathogenesis of PJI.

Proctor et al. studied *S. aureus* due to its frequent association with bone and joint infections and its well-characterized ability to exist in a quasi-dormant state (the so-called small-colony SCV phenotype), which potentially contributes to the chronicity of the disease [33].

In our study, culture-negative PJI was detected in 25 % of cases in group 1 and in 16.1 % of group 2. This is consistent with global data, according to which culture-negative PJI occurs in 5 % to 42 % of cases [21, 34–38]. This fact often complicates the choice of antimicrobial drugs. Currently, molecular methods, including polymerase chain reaction (PCR) and sequencing, are recommended for diagnosis. These methods have demonstrated improved microbial identification in culture-negative PJI [37, 38]. Moreover, often undetected but present cultures in traditional tests are the result of microorganisms in a biofilm state. It has been found that culturing puncture fluid and removed implants treated with ultrasound increases the exit of microbes due to the destruction of the bacterial biofilm and the sensitivity of PCR [37].

CONCLUSION

Gram-negative microorganisms and their associations dominated in the etiology of early PJI (type I), while gram-positive pathogens prevailed in chronic types (types II and III). Culture-negative infection was a more common cause of early PJI than of chronic types (25.0 % and 16.1 %, respectively). No statistically significant differences were found between the groups in the detection of methicillin-resistant staphylococci or gram-negative bacteria ESBL+.

Conflict of interest Not declared.

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