International Orthopaedics (2021) 45:2791–2796
https://doi.org/10.1007/s00264-021-05137-8

ORIGINAL PAPER

Outcomes of patients with unexpected diagnosis of infection at total hip or total knee arthroplasty revisions

Mattia Loppini[1,2] · Alessandro Pisano[1] · Marco Di Maio[1] · Francesco La Camera[2,3] · Maddalena Casana[2] · Guido Grappiolo[2,3]

Received: 6 May 2021 / Accepted: 3 July 2021 / Published online: 22 July 2021

Abstract

Purpose The pre-operative differential diagnosis between periprosthetic joint infections (PJIs) and aseptic failure is challenging particularly in low virulence and biofilm-related infections. This study aimed to assess the incidence and survival of patients with unexpected PJIs in a presumed aseptic revision of total hip (THA) and knee (TKA) arthroplasties.

Methods A retrospective analysis of a prospective cohort of patients was performed with 295 patients undergoing THA ($n=241$) or TKA ($n=54$) revision for presumed aseptic causes. Patients were diagnosed with unexpected PJI taking into account leukocyte count in the synovial fluid, sonicate, synovial culture, and tissue cultures of samples collected during surgery. The primary endpoint was the infection-free implant survival rate at theone year follow-up.

Results The unexpected PJIs were 60 out of 295 (20.3%), whereas 235 (79.7%) were aseptic revisions. In the unexpected PJI group, 6 (11.1%) patients underwent knee revision and 54 (22.4%) hip revision. At the one year follow-up, one patient (1.6%) in the unexpected PJI group and 3 (1.3%) in the aseptic group ($p=1.0$) failed for infection. The infection-free implant survival rate at the one year follow-up was 98.3% (C.I. 95%, 94.9–99.9%) for the unexpected PJI group and 98.7% (C.I. 95%, 97.3–99.9%) ($p=0.82$) for the aseptic group.

Conclusion The incidence of unexpected PJIs in a presumed aseptic revision of THAs and TKAs has been previously underestimated. The infection-free implant survival rate at the one year follow-up in patients with unexpected PJIs was not significantly lower compared with patients undergoing aseptic revision.

Keywords Joint replacement · Failure · Intra-operative cultures · Sonication · Synovial leukocyte count

Introduction

Periprosthetic joint infections (PJIs) are one of the most serious complications in prosthetic surgery and the most frequent cause of early revision [1]. They constitute the cause of failure of the total hip (THA) and knee (TKA) arthroplasties in 15% and 25% of cases, respectively [2, 3].

The correct preoperative diagnosis is crucial to choosing the proper management. The Society of Musculoskeletal Infections (MSIS) developed a definition of PJIs based on the integration of clinical and laboratory data [4]. Subsequently, these criteria have been revised to develop a more effective scoring system providing a sensitivity of 97.7% and a specificity of 99.5% for PJIs [5]. However, the preoperative differential diagnosis between PJI and aseptic failure is still particularly challenging in low-virulence and biofilm-related infections. Biofilm-forming bacteria often remain in a dormant state without significant elicitation of the host response and complicating conventional diagnostic and therapeutic approaches [6]. Since the diagnosis often results from the data collected during surgery, the incidence of PJIs is likely higher than reported by joint registries. Previous authors reported that the rate of PJIs in patients undergoing aseptic

Level of evidence: level IV, case series

✉ Mattia Loppini
mattia.loppini@hunimed.eu

[1] Department of Biomedical Sciences, Humanitas University, Via Rita Levi Montalcini 4, Pieve Emanuele, 20090 Milan, Italy

[2] IRCCS Humanitas Research Hospital, Via Manzoni 56, Rozzano, 20089 Milan, Italy

[3] Fondazione Livio Sciutto Onlus, Università Degli Studi Di Genova, Campus Savona, Via Magliotto 2, 17100 Savona, Italy

revision arthroplasties ranges from 6 to 13.5% [7–13]. However, the outcome of patients with unexpected positive intra-operative cultures during prosthetic revision surgery for presumed aseptic failure is still unclear. Some authors reported a higher risk of re-revision for any causes and infection in patients with unexpected PJIs when compared with patients undergoing culture-negative revision [7, 9]. On the other hand, some authors reported no statistically significant difference in the number of re-revisions between the unexpected PJI group and the aseptic loosening group [11, 13]. Moreover, different classification systems for the diagnosis of PJI have been used among the previous studies preventing a direct comparison of their results.

The aim of the present study was to assess the incidence and clinical outcome of patients with unexpected PJIs at the time of presumed aseptic revision of THAs and TKAs. The primary endpoint was the infection-free implant survival rate at the one year follow-up in patients with and without unexpected PJIs. The null hypothesis was that the infection-free implant survival rate at one year would not be higher in the group of unexpected PJIs as compared to the aseptic group.

Patients and methods

All presumed aseptic partial or total one-stage revisions of THA or TKA performed in our academic tertiary referral center in the period 2016–2019 were assessed. All procedures were performed by the same team of experienced, high-volume orthopaedic surgeons. The most common causes of revisions included aseptic loosening (80%), malposition (7%), and polyethylene wear (4%). All causes of revisions are reported in Table 1. The exclusion criteria included previous history of infection in the index joint, pre-operative diagnosis of PJI, intra-operative evidence of visible purulence in the synovial fluid or surrounding the prosthesis, revision surgery for spacer removal and reimplantation, and the use of antibiotic within weeks prior surgery.

Pre-operative assessment included physical examination, laboratory tests including CRP and ESR, and plain radiographs including anterior–posterior (AP) view of the pelvis and axial view of the hip for THA, AP and lateral view of the knee, axial views of patella, and full-length weight-bearing view of bilateral lower extremities for TKA. Bone scintigraphy, CT scan, or MRI was performed according to surgeon preference.

The pre-operative joint aspiration was indicated for CRP and/or ESR elevation, or a high clinical suspicion for PJIs due to multiple surgery or history of surgical site infection in the index joint or prior PJI. In the present study, no patient had preoperative joint aspiration with synovial fluid leukocyte count and culture.

At radiographic assessment, the loosening of the stem has been defined as a progressive axial radiolucency greater than 3 mm, or a varus/valgus deviation from the femoral shaft axis greater than 3° [14]. Loosening of the acetabular cup has been defined by a change greater than 2 mm in the horizontal and/or vertical position with an adjacent radiolucent zone, or a radiolucent zone greater than 3 mm [15]. For the TKA, the loosening was defined as a > 2-mm or progressive zone of radiolucency at the cement-bone or metal-cement or metal-bone interface, and/or an interval change in position of the components [16]. For the THA, the polyethylene wear has been defined by the eccentric position of the femoral head with respect of the acetabular cup in AP and/or lateral view. For TKA, the polyethylene wear has been defined by a not equivalent joint space medially and laterally in the AP view. The presence of heterotopic ossification in THA was evaluated according to Brooker's classification [17].

The malposition of the implant has been defined by prosthetic or bony or soft tissue impingement for THA [18], and over- or under-sizing of components for TKA. In patients with fixed metal on metal implants, revision surgery was performed for a large thick-walled pseudotumour at MRI, or extremely high metal ion levels (> 10–20 ppb) in the serum or whole blood [19].

All procedures were performed by the posterolateral approach with the patient in lateral decubitus for the hip surgery, and through the standard medial parapatellar approach for the knee surgery. The antibiotic prophylaxis with cefazolin or clindamycin was administered in all patients before surgery. Because all patients were eligible for presumed aseptic prosthetic revision, none received antibiotic therapy before the index surgery. Synovial fluid has been collected before to perform capsulotomy to prevent any blood contamination. During surgery, from five up to seven intra-operative periprosthetic tissue samples were obtained for microbiological analysis. The removed prosthesis has been sonicated.

After surgery, all patients received an empiric antibiotic treatment with vancomycin and piperacillin-tazobactam, vancomycin and ciprofloxacin or levofloxacin, or cefazolin until microbiological results were available. The antibiotic regimen was decided on the basis of patient risk factors or intolerance to penicillin. The empiric antibiotic treatment has been interrupted after seven days in patients without evidence of PJIs. In patients with unexpected PJIs, the antibiotic treatment was etiologic in culture-positive cases and empiric in culture-negative cases with duration of three months.

Unexpected PJIs was established in the absence of visible purulence in the synovial fluid or surrounding the prosthesis, and testing positive for at least one of the following criteria [20]: leukocyte count > 2000/μl or > 70% granulocytes (PMN) in synovial fluid, > 50 CFU/ml in sonication fluid, positive synovial culture, two or more

Table 1 Patient population characteristics

Characteristic	Aseptic revision ($n=235$)	Unexpected PJI ($n=60$)	Total group ($n=295$)	p value
Age, mean ± SD	67.7 ± 11.2	66.5 ± 13.3	67.5 ± 11.6	0.50
Gender, F/M, *n* (%)	153/82 (65.1/34.9)	30/30 (50/50)	183/112 (62/38)	0.03*
Joint				
• Hip (%)	187 (79.6)	54 (90)	241 (81.7)	0.04*
• Knee (%)	48 (20.4)	6 (10)	54 (18.3)	
BMI kg/m^2	27 ± 4.4	26.7 ± 3.9	28.3 ± 4.7	0.72
ASA classification, *n* (%)				
• I	40 (17)	12 (20)	52 (17.6)	0.37
• II	142 (60.4)	31 (51.7)	173 (58.6)	
• III	53 (22.6)	17 (28.3)	70 (23.8)	
CCI score category, *n* (%)				
• 0–1	46 (19.5)	15 (25)	61 (20.7)	0.09
• 2–3	124 (52.7)	33 (55)	157 (53.2)	
• 4–5	63 (26.8)	9 (15)	72 (24.4)	
• ≥ 6	2 (1)	3 (5)	5 (1.7)	
Smoking, *n* (%)	55 (20.7)	7 (22.5)	62 (20.8)	0.74
Diabetes mellitus, *n* (%)	14 (5.3)	2 (6.4)	16 (5.4)	1.0
Rheumatoid arthritis, *n* (%)	11 (4.1)	2 (6.4)	13 (4.4)	0.75
Medical history previous revision, *n* (%)	11 (4.1)	2 (6.4)	13 (4.4)	0.75
Preoperative CRP, mean ± SD	0.6 ± 1.3	0.9 ± 1.3	0.8 ± 1.3	0.22
Preoperative ESR, mean ± SD	23.2 ± 20.9	26.8 ± 24.9	23.6 ± 20.9	0.37
Reason for revision, *n* (%)				
• Aseptic loosening	190 (81.5)	44 (74.3)	238 (80.7)	0.21
• Malposition	16 (6.8)	6 (9.7)	21 (7.1)	0.41
• Recurrent dislocation	5 (2.2)	2 (3.2)	7 (2.3)	0.63
• Polyethylene wear	10 (4.1)	2 (3.2)	12 (4)	1.0
• Metallosis	7 (3.1)	2 (3.2)	9 (3.1)	1.0
• Periprosthetic fracture	1 (0.4)	-	1 (0.3)	-
• Limb length discrepancy	1 (0.4)	2 (3.2)	2 (0.7)	0.11
• Eterotopic ossification	5 (1.5)	2 (3.2)	5 (1.8)	0.63

BMI body mass index, *ASA* American Society of Anesthesiologists physical status classification, *CCI* Charlson Comorbidity Index, *CRP* C-reactive protein, *ESR* erythrocyte sedimentation rate, *SD* standard deviation, *F* female, *M* male

*Statistically significant difference

positive tissue cultures, or only one positive tissue culture for high virulent pathogens (e.g., *Staphylococcus aureus*).

The definition of failure of treatment was performed with a Delphi-based consensus using the following criteria at the one year follow-up: (I) the eradication of infection, characterized by a healed wound without a fistula, drainage, or pain and without recurrence caused by the same organism, (II) no subsequent surgery for persistent or peri-operative infection, (III) no mortality related to the infection, and (IV) no requirement for long term (> 6 months) antibiotic suppression treatment.

Statistical analysis

Descriptive statistics were used for continuous variables, proportions for categorical variables. The Student's T and χ^2 tests were performed to evaluate significant differences between continuous and categorical variables, respectively. The infection-free implant survival rate at the one year follow-up in patients with and without unexpected PJIs was estimated with the Kaplan–Meier curve. Patients undergoing re-revision for aseptic failure or died during the study period were censored. The log-rank test

was performed to compare the survival distributions of the two cohorts of patients.

The software IBM SPSS Statistics 21 (IBM Corp, Armonk, NY, USA) was used for the statistical analysis. A value $p < 0.05$ has been considered significant.

Results

In the index period, 295 patients underwent presumed aseptic revision of joint arthroplasty. Demographic characteristics are reported in Table 1. Fifty-four patients (18.3%) underwent knee revision and 241 patients (81.7%) hip revision. The median age was 67.5 years (range, 32.6–90.2). The average follow-up was 19.2 months (range, 12–40.8).

In patients undergoing TKA revision, 52 out of 54 (96.3%) received a total revision, and two (3.7%) had replacement of the patella. In patients undergoing THA revision, 87 out 241 (36.1%) received a total revision, 122 (50.6%) had a cup revision, 12 (5%) had a stem revision, and the remaining 20 (8.3%) had revision of the mobile components. All TKA revisions were cemented. Among the THA revisions, 211 out of 221 (95.48%) were cementless, five (2.26%) were cemented, and five (2.26%) were hybrid/reverse hybrid. In all the THA revisions, the cement was without antibiotic. Among TKA revisions, the cement was with antibiotic in 28 out of 54 (51.8%), and without antibiotic in 26 (48.2%).

The number of unexpected PJIs was 60 out of 295 (20.3%), whereas 235 patients (79.7%) were negative for infections. Among the 60 patients diagnosed with unexpected PJI, six patients underwent knee revision (11.1% of TKA revisions) and 54 hip revision (22.4% of THA revisions).

Nine patients had leukocyte count > 2000/μl or > 70% granulocytes (PMN) in synovial fluid, 21 patients had > 50 CFU/ml in sonication fluid, six patients had two or more positive tissue samples, and only one patient had one positive tissue culture for *S. aureus*. Twenty-three patients were positive for more than one of the above criteria (Table 2). Among the 21 different pathogens isolated, 18 were gram-positive, two were gram-negative, and one was a fungus. Among these, five were polymicrobial infections. Nine (15%) out of 60 patients had an unexpected culture-negative PJI. Table 3 shows the microbiological findings in patients with unexpected PJIs.

Table 3 Microbiological findings in patients with unexpected PJIs

Pathogen isolated	*N* of patients ($n = 51$)	Stain
Aspergillus fumigatus	2	-
Bacillus	1	Gram positive
Corynebacterium species	1	Gram positive
Corynebacterium striatum	1	Gram positive
Enterococcus faecium	2	Gram positive
Microbacterium species	1	Gram positive
Propionibacterium acnes	7	Gram positive
Pseudomonas aeruginosa	1	Gram negative
Ralstonia pickettii	2	Gram negative
Staphylococcus aureus	3	Gram positive
Staphylococcus capitis	3	Gram positive
Staphylococcus caprae	1	Gram positive
Staphylococcus epidermidis	17	Gram positive
Staphylococcus lugdunensis	1	Gram positive
Staphylococcus warneri	1	Gram positive
Streptococcus agalactiae	1	Gram positive
Streptococcus bovis group	1	Gram positive
Polymicrobial infections	5	-

At the one year follow-up, one patient with THA revision in the unexpected PJI group, and two patients with THA revision and one with TKA revision in the aseptic group failed for infection (1.6% versus 1.3% $p = 1.0$). The patient in the unexpected group is scheduled for a two-stage revision. In the aseptic group, two patients were managed with an early debridement, antibiotics and implant retention (DAIR), and one with a two-stage revision. The infection-free implant survival rate at the one year follow-up was 98.3% (C.I. 95%, 94.9–99.9%) for the unexpected PJI group and 98.7% (C.I. 95%, 97.3–99.9%) ($p = 0.82$) for the aseptic group.

Table 2 Criteria for the diagnosis of unexpected PJI

	Yes *n* (hip:knee)	No *n* (hip:knee)	Unknown *n* (hip:knee)	Positivity % (hip:knee)	Unknown % (hip:knee)
WBCs > 2000/μl or > 70% PMNs in synovial fluid	14 (12:2)	12 (10:2)	34 (32:2)	53.8 (22.2:33.3)	56.7 (59.3:33.3)
Positive tissue cultures ≥ 2	28 (26:2)	32 (28:4)	-	46.7 (48.1:50)	-
Positive tissue cultures < 2	7 (7:0)	53 (47:6)	-	11.7 (13:0)	-
> 50 CFU/ml in sonication fluid	43 (39:4)	10 (9:1)	7 (6:1)	81.1 (72.2:66.6)	11.7 (11.1:16.7)
Positive synovial fluid culture	8 (8:0)	36 (31:5)	16 (15:1)	18.2 (14.8:0)	26.7 (27.8:20)

Among patients undergoing TKA revision, none out of six patients in the unexpected PJI group and one out of 48 in the aseptic group failed due to infection (0 versus 2%, $p=0.12$). The infection-free implant survival rate at the one year follow-up was 100% for the unexpected PJI group and 97.9% (C.I. 95%, 93.7–99.9%) ($p=0.72$) for the aseptic group. Among patients undergoing THA revision, one out of 54 patients in the unexpected PJI group and two out of 187 in the aseptic group failed due to infection (1.8% versus 1%, $p=0.2$). The infection-free implant survival rate at the one year follow-up was 98.1% (C.I. 95%, 94.5–99.9%) for the unexpected PJI group and 98.9% (C.I. 95%, 97.3–99.9%) ($p=0.66$) for the aseptic group.

At the one year follow-up, 5 out of 295 (1.7%) patients had further surgery for aseptic reasons: one patient in the unexpected PJI group (1.6%) and four in the aseptic group (1.7%) ($p=1.0$). The causes of failure included patellar tendon rupture in the replaced knee for the unexpected group, and hip dislocation ($n=3$) and great trochanter fracture ($n=1$) in the aseptic group.

Discussion

The present study reported no statistically significant difference in terms of infection-free implant survival rate at the one year follow-up between the aseptic and unexpected PJI groups. In this respect, unexpected PJIs seem to be low-grade infections successfully managed with one-stage revision followed by long antibiotic therapy according with the isolated pathogen. Some authors previously reported no statistically significant difference in the number of re-revisions between the unexpected PJI group and the aseptic loosening group [11, 13]. On the other hand, Fernandez-Sampedro et al. [8] reported a greater number of implant failure at the two year follow-up in the PJI group compared with the aseptic loosening group (37.5% versus 1.1%, $p<0.0001$). Jacobs et al. [9] demonstrated a significantly lower infection-free implant survival rate at two years in the PJI group compared to the aseptic group in patients who underwent TKA revision (88% versus 98%, $p=0.001$). Following THA revision, no significant difference has been found between PJI and aseptic groups (92% versus 94%, $p=0.31$).

Our results suggest that the diagnosis of unexpected PJI in both hip and knee presumed aseptic revisions does not affect the survival at the one year follow-up. In previous studies [8, 9], only half of patients received a long post-operative antibiotic therapy. Although the authors did not report a significantly lower risk of implant failure in patients with longer post-operative antibiotic regimens, the numbers were small to achieve meaningful conclusions. In our study, all patients with unexpected PJI received three months of etiologic or empiric antibiotic therapy. Therefore, we could hypothesize that the long post-operative antibiotic therapy may explain the excellent survival in both hip and knee procedures with respect to the literature. Further studies should investigate the proper schedule for the post-operative antibiotic therapy in these patients in order to avoid overtreatment.

The present study reported an incidence of unexpected PJIs of 20%. This value is higher compared to what previously reported in the literature [7–13], particularly for the THA revision (22.4% versus 12.1%) compared with TKA revision (11.1% versus 7.9%) [9]. The discrepancy is mostly due to the heterogeneity of the criteria for defining an unexpected PJI. The majority of the published studies mainly considered positive intra-operative tissue cultures for the diagnosis of PJI. On the other hand, in the present study further criteria have been taken into account, such as positive sonication fluid, synovial fluid culture, or increased white blood cell count. In this respect, 15% of the unexpected PJIs were culture-negative. To our knowledge, this is the first study taking into account a wide spectrum of PJIs also including the culture-negative patients.

The most common organisms in culture-positive PJIs were low-virulence bacteria such as *Staphylococcus epidermidis* (33%) and *Propionibacterium acnes* (14%), as previously reported [9]. However, high-virulence bacteria such as *Staphylococcus aureus* (6%) and *Pseudomonas aeruginosa* (2%) were also isolated suggesting that these pathogens can also determine low-grade or very low-grade infection. Moreover, 5% of culture-positive unexpected PJIs were polymicrobial. Although polymicrobial PJIs reported poorer outcome compared with monomicrobial infections [21], no difference in terms of infection-free implant survival rate at the one year follow-up was found between high- and low-virulence monomicrobial and polymicrobial infections.

Nevertheless, some limitations are present in this study. The follow-up period was short. Although the vast majority of infections appeared within one year, some late failures could be missed. Then, since all unexpected PJI patients received three months of antibiotic therapy we were not able to compare short versus long post-operative antibiotic therapy, and we cannot determine whether certain patients were unnecessarily treated. In addition, heterogeneity of the antibiotic regimens was present. Lastly, some difference was also present among the surgical procedures since we included both partial and total revisions, but this was useful in order to enlarge the study groups.

In conclusion, the incidence of unexpected PJIs at the time of presumed aseptic revision of total hip and knee arthroplasties has been previously underestimated. The infection-free implant survival rate at the one year follow-up in patients with unexpected PJIs was not significantly lower compared with patients undergoing aseptic revision.

Author contribution All the authors of the present manuscript (1) significantly contributed to the conception or design of the study or the collection, analysis, or interpretation of the data; (2) drafted the work or revised it critically for important intellectual content; and (3) approved the final version for the publication.

Data availability Not applicable.

Declarations

Ethics approval The present retrospective analysis was based on medical records of a prospective cohort of patients included in a registry of orthopedic surgical procedures. The study protocol for the development of this registry was approved by the Ethical Committee of Humanitas Research Hospital (approval number 618/17) and in strict accordance with the Helsinki Declaration.

Consent to participate and for publication All individual participants signed a written informed consent before the surgical procedure and a written informed consent to be included in the registry of orthopedic surgical procedures.

Conflict of interest Mattia Loppini received a research grant from the Italian Ministry of Health (GR-2018–12367275), as well as financial support for attending symposia and educational programs from Zimmer Biomet. He is also the Scientific Director of Livio Sciutto Foundation Biomedical Research in Orthopaedics – ONLUS. Guido Grappiolo received honoraria for speaking at symposia, financial support for attending symposia and educational programs from Zimmer Biomet, and royalties from Zimmer Biomet and Innomed. Francesco La Camera received financial support for attending symposia and educational programs from Zimmer Biomet. Alessandro Pisano, Marco Di Maio, and Maddalena Casana have no conflict of interest.

References

1. American Joint Replacement Registry (AJRR) (2020) Annual report. American Academy of Orthopaedic Surgeons (AAOS), Rosemont, IL. https://www.aaos.org/registries/publications/ajrr-annual-report/. Accessed 8 Apr 2021
2. Bozic KJ, Kurtz SM, Lau E et al (2010) The epidemiology of revision total knee arthroplasty in the United States. Clin Orthop Relat Res 468:45–51. https://doi.org/10.1007/s11999-009-0945-0
3. Bozic KJ, Kurtz SM, Lau E et al (2009) The epidemiology of revision total hip arthroplasty in the United States. J Bone Joint Surg Am 91:128–133. https://doi.org/10.2106/JBJS.H.00155
4. Zmistowski B, Della Valle C, Bauer TW et al (2014) Diagnosis of periprosthetic joint infection. J Arthroplasty 29:77–83. https://doi.org/10.1016/j.arth.2013.09.040
5. Parvizi J, Tan TL, Goswami K et al (2018) The 2018 Definition of periprosthetic hip and knee infection: an evidence-based and validated criteria. J Arthroplasty 33:1309-1314.e2. https://doi.org/10.1016/j.arth.2018.02.078
6. Shoji MM, Chen AF (2020) Biofilms in periprosthetic joint infections: a review of diagnostic modalities, current treatments, and future directions. J Knee Surg 33:119–131. https://doi.org/10.1055/s-0040-1701214
7. Milandt NR, Gundtoft PH, Overgaard S (2019) A single positive tissue culture increases the risk of rerevision of clinically aseptic THA: a national register study. Clin Orthop Relat Res 477:1372–1381. https://doi.org/10.1097/CORR.0000000000000609
8. Fernandez-Sampedro M, Salas-Venero C, Fariñas-Álvarez C et al (2015) 26Postoperative diagnosis and outcome in patients with revision arthroplasty for aseptic loosening. BMC Infect Dis 15:232. https://doi.org/10.1186/s12879-015-0976-y
9. Jacobs AME, Bénard M, Meis JF et al (2017) The unsuspected prosthetic joint infection : incidence and consequences of positive intra-operative cultures in presumed aseptic knee and hip revisions. Bone Joint J 99-B:1482–1489. https://doi.org/10.1302/0301-620X.99B11.BJJ-2016-0655.R2
10. Ribera A, Morata L, Moranas J et al (2014) Clinical and microbiological findings in prosthetic joint replacement due to aseptic loosening. J Infect 69:235–243. https://doi.org/10.1016/j.jinf.2014.05.003
11. Moojen DJF, van Hellemondt G, Vogely HC et al (2010) Incidence of low-grade infection in aseptic loosening of total hip arthroplasty. Acta Orthop 81:667–673. https://doi.org/10.3109/17453674.2010.525201
12. Barrack RL, Aggarwal A, Burnett RSJ et al (2007) The fate of the unexpected positive intraoperative cultures after revision total knee arthroplasty. J Arthroplasty 22:94–99. https://doi.org/10.1016/j.arth.2007.03.029
13. Boot W, Moojen DJF, Visser E et al (2015) Missed low-grade infection in suspected aseptic loosening has no consequences for the survival of total hip arthroplasty. Acta Orthop 86:678–683. https://doi.org/10.3109/17453674.2015.1086942
14. Kim Y-H, Kim J-S, Oh S-H, Kim J-M (2003) Comparison of porous-coated titanium femoral stems with and without hydroxyapatite coating. J Bone Joint Surg Am 85:1682–1688. https://doi.org/10.2106/00004623-200309000-00005
15. Kim Y-H, Oh S-H, Kim J-S (2003) Primary total hip arthroplasty with a second-generation cementless total hip prosthesis in patients younger than fifty years of age. J Bone Joint Surg Am 85:109–114. https://doi.org/10.2106/00004623-200301000-00017
16. Math KR, Zaidi SF, Petchprapa C, Harwin SF (2006) Imaging of total knee arthroplasty. Semin Musculoskelet Radiol 10:47–63. https://doi.org/10.1055/s-2006-934216
17. Brooker AF, Bowerman JW, Robinson RA, Riley LH (1973) Ectopic ossification following total hip replacement. Incidence and a method of classification. J Bone Joint Surg Am 55:1629–1632
18. Vigdorchik JM, Sharma AK, Madurawe CS et al (2020) Does prosthetic or bony impingement occur more often in total hip arthroplasty: a dynamic preoperative analysis. J Arthroplasty 35:2501–2506. https://doi.org/10.1016/j.arth.2020.05.009
19. Reito A, Lainiala O, Elo P, Eskelinen A (2016) Prevalence of failure due to adverse reaction to metal debris in modern, medium and large diameter metal-on-metal hip replacements–the effect of novel screening methods: systematic review and metaregression analysis. PLoS ONE 11:e0147872. https://doi.org/10.1371/journal.pone.0147872
20. Renz N, Yermak K, Perka C, Trampuz A (2018) Alpha defensin lateral flow test for diagnosis of periprosthetic joint infection: not a screening but a confirmatory test. J Bone Joint Surg Am 100:742–750. https://doi.org/10.2106/JBJS.17.01005
21. Wimmer MD, Friedrich MJ, Randau TM et al (2016) Polymicrobial infections reduce the cure rate in prosthetic joint infections: outcome analysis with two-stage exchange and follow-up ≥two years. Int Orthop 40:1367–1373. https://doi.org/10.1007/s00264-015-2871-y