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Revision Total Knee Arthroplasty: Infection should be Ruled Out in All Cases

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1 **Revision Total Knee Arthroplasty: Infection should be Ruled Out in All Cases**

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3

4 **Abstract:**

5 We hypothesized that some aseptic revision knee arthroplasty (TKA) failures are indeed due to
6 occult infection. This prospective study recruited 65 patients undergoing revision TKA. Mean
7 follow-up period was 19 months. Collected synovial fluid was analyzed by Ibis T5000 biosensor
8 (a multiplex PCR technology). Cases were considered as infected or aseptic based on the
9 surgeon’s judgment and Ibis findings. Based on Ibis biosensor, 17 aseptic cases were indeed
10 infected that had been missed. Of these 17 cases, 2 developed infection following the index
11 revision. A considerable number of so called aseptic failures seem to be occult infections who
12 were not adequately investigated and/or miss-categorized as aseptic failure. We recommend that
13 all patients undergoing revision arthroplasty need to be investigated for PJI.

14

15 **Key words:** Revision knee arthroplasty, Aseptic failure, Periprosthetic joint infection, Ibis
16 T5000 biosensor, Diagnosis

17

18 **Introduction**

19 Periprosthetic joint infection (PJI), that occurs following 1 to 3% of TKAs [1, 2] is the
20 most common cause of failure after total knee arthroplasty (TKA) [3-5]. Diagnosis of PJI
21 continues to pose a challenge to the medical community because of lack of a “gold standard” [6].
22 It is, however, critical that aseptic cases be distinguished from PJI, as treatment for these
23 conditions is vastly different [7, 8].

24 History taking, physical examination, and radiographic findings can be similar in PJI and
25 aseptic loosening and may not allow distinction in most cases [7]. Joint aspiration and serologic
26 tests such as erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) are usually
27 performed during the work-up of a patient with suspected PJI. Although a very high sensitivity
28 has been reported for ESR and CRP, these laboratory tests have their own limitations in the
29 diagnosis of PJI [9]. Even intraoperative culture and pathology have limited sensitivity in
30 diagnosis of PJI particularly in those receiving antibiotics [10, 11]. It has been demonstrated that
31 intraoperative culture yields false negative results in 6.6% [12] to 17.7% [13] and false positive
32 in 13% of cases [14]. Imaging modalities such as nuclear scans (tc-99, indium 111, gallium) have
33 also been employed in diagnosis of PJI but these tests are also unable to accurately differentiate
34 between aseptic loosening and septic failure after joint arthroplasty [15-17].

35 One of the main reasons for inability to isolate the pathogen relates to the presence of a
36 biofilm [8, 18] and/or internalization of organism by osteoblasts [19]. Biofilm is a complex
37 structure comprising microorganisms enveloped in macromolecules of glycocalyx and other
38 protective films [18, 20]. As a result, it is probable that some of PJIs to be missed and treated as
39 aseptic failure which subsequently cause recurrent failure [21].

40 Using molecular techniques may improve diagnosis of PJI as these methods have high
41 sensitivity and are culture independent [11]. Polymerase chain reaction (PCR) has been used in
42 several studies to diagnose PJI [22-25]. Using a specific PCR or a broad-range (16S ribosomal
43 DNA) PCR which are respectively able to detect only a single microorganism or previously
44 unknown organisms were limitations of these studies. Compared to the specific PCR, the
45 sensitivity and specificity of the broad-range PCR is lower, needs subsequent sequencing for
46 bacterial identification, and fails to detect mixed infections [11]. Recently, the Ibis T5000
47 universal biosensor has been introduced as a sensitive and specific method for identification of
48 bacteria, viruses, fungi, and protozoa. The system operates based on broad-range PCR and high-
49 performance mass spectrometry and seems to be more accurate than conventional PCR. [26]
50 However, it has not yet been approved by the Food and Drug Administration (FDA) for routine
51 use in clinical practice.

52 The hypothesis of this study was that some cases of aseptic failure were indeed due to
53 infection that had either escaped diagnosis using conventional modalities or had not been
54 adequately investigated. This prospective study was set up to examine the postoperative course
55 of a consecutive cohort of patients undergoing revision TKA in whom an intra-articular tissue
56 and/or fluid sample was also sent for analysis by Ibis T5000 biosensor.

57

58 **Materials and Methods**

59 After approval of the Institutional Review Board of the Thomas Jefferson University, all
60 patients who underwent TKA revision from February 2009 to May 2010 were recruited for this
61 study. The study consists of 65 patients of whom 33 were men. The mean age of the patients was

62 65 ± 11 years. All patients underwent appropriate preoperative work-up based on the
63 recommendation of the treating surgeon and then categorized as infected or uninfected based on
64 these investigations and surgeon's judgment. In our center, patients who are suspicious for PJI
65 are evaluated by measurement of serum erythrocyte sedimentation rate (ESR) and C-reactive
66 protein (CRP), intraoperative culture and synovial fluid analysis. However, frozen section isn't
67 use as a part of PJI work-up in our institute. Intraoperatively tissue and/or fluid samples were
68 collected and analyzed using the Ibis T5000 biosensor. After discharging from the hospital,
69 patients are followed-up based on the protocol which is used routinely in our institution at 6
70 weeks, 6 months and 2 years after the revision surgery. In this study, all patients were followed-
71 up for a minimum of six months with a mean follow-up of 19 months (range; 12 to 26). In
72 particular, "aseptic" patients in whom the Ibis T5000 biosensor had detected an infecting
73 pathogen were followed-up closely for development of subsequent failure after the index
74 revision.

75 *Preoperative work-up*

76 Detailed history taking, examination, and routine radiographs were performed in all
77 patients in this cohort. It is institutional policy that all patients undergoing revision arthroplasty
78 at our institution have preoperative Erythrocyte Sedimentation Rate (ESR) and C-Reactive
79 Protein (CRP) measured. In addition, and based on the findings of serology, majority of patients
80 (n=57) underwent joint aspiration with the fluid sent for analysis for neutrophil count, neutrophil
81 differential, and culture. As this was an observational and not interventional study, we did not
82 make any changes to the preoperative work-up of any patients. Collection of synovial fluid
83 and/or tissue sample for analysis by Ibis T5000 biosensor was a requirement of the study.

84 *Sample collection and the Ibis T5000 method*

85 Joint fluid and/or tissue were collected intraoperatively. Joint fluid was aspirated prior to
86 the arthrotomy and was also sent for WBC count (if indicated) and culture. Tissue-sampling was
87 performed from areas that were considered by the surgeon that to be most suggestive of
88 infection. In addition to the Ibis analysis, tissues were sent for histopathologic assessment and
89 culture. The samples were not sent for measurement of inflammatory markers for this study.
90 Samples then processed appropriately for later analysis by Ibis T5000 in batches. Appropriate
91 cryogenic vials were used to store fluid samples in a Styrofoam container. The vials were
92 transferred in ice bags from the operating room to liquid nitrogen. About 0.5 to 1 mL of the
93 liquid was stored for further analysis in liquid nitrogen. The syringe was changed in order to
94 minimize possibility of accidental microbial contaminations before synovial fluid was transferred
95 to the labeled vials. These vials were transferred to -140o F freezer where they were stored until
96 they were shipped in batch to the Center for Research and Genomic Studies in Allegheny, PA.

97 For DNA extraction, 1 ml of the aspirate was centrifuged at 10,000 rpms for 3 min and
98 900uL of supernatant was removed. Then, ATL lysis buffer and proteinase K were added and the
99 samples were incubated at 56°C until lysis occurred. The Qiagen DNeasy Tissue kit (Qiagen. Inc.
100 cat # 69506) was used to extract nucleic acid from the lysed sample. After DNA was extracted,
101 10 uL of sample was loaded per well into each of 16 wells on the BAC detection PCR plate that
102 each contained a different primer pair (Abbott Molecular. cat # PN 05N13-01). The BAC
103 detection plate is a 96 well, 6 sample plate which contains 16 primers that identify all bacterial
104 organisms, Candida species, and determines the presence of several key antibiotic resistance
105 markers such as van-A and van-B (vancomycin resistance) in Enterococcus species, KPC
106 (carbapenem resistance) in Gram-negative bacteria, and mec-A (methicillin resistance) in

107 *Staphylococcus* species. Once PCR was completed, the plate was loaded onto the Ibis T5000
108 machine. The products from the PCRs were desalted in a 96-well plate format and sequentially
109 electrosprayed into the time-of-flight mass spectrometer. The resultant spectral signals were then
110 processed to determine the masses of each of the PCR products present with sufficient accuracy
111 that the base composition of each amplicon could be unambiguously deduced. Using combined
112 base compositions from multiple PCRs, the identities of the pathogens and their relative
113 concentrations in the starting sample were determined.

114 The isolated microorganism from the Ibis biosensor was considered as an “orthopedic pathogen”
115 based on extensive search of the available literature. In other words, if there was any evidence
116 even a case report that shows the isolated microorganism is able to cause bone and/or joint
117 infection, that microorganism was defined as an “orthopedic pathogen”. However, Ibis biosensor
118 results did not change the treatment strategy and all patients were treated based on results
119 obtained from conventional diagnostic tests and surgeon’s judgment.

120 **Results**

121 Based on preoperative investigations and surgeon’s judgment, of the 65 patients recruited
122 for this study, 21 patients were undergoing revision arthroplasty for PJI and the remaining 44
123 patients had aseptic failure. Among the 21 patients with PJI, synovial culture was negative in 11
124 cases. In the remaining 10 patients the isolated organisms were coagulase negative
125 *Staphylococcus* (5 cases), *Staphylococcus aureus* (3 patients), *Streptococcus mitis* plus
126 *Streptococcus sanguis* (1 case) and *Peptostreptococcus* species (1 case). Ibis identified a
127 pathogen with confidence ≥ 0.7 in total of 36 cases. Ibis T5000 isolated an organism in 19 PJI
128 cases and failed to isolate any organism in 2 cases that were categorized as infected. The isolated
129 organism by Ibis was coagulase negative *Staphylococcus* in 10 patients and *Staphylococcus*

130 *aureus* in 4 patients. In the PJI group, comparison of the isolated organisms from the culture and
131 the detected organism by the Ibis T5000 biosensor showed the same pathogens in 9 cases
132 samples whereas in 11 cases, the Ibis biosensor found additional pathogen. Table 1 demonstrates
133 comparison between isolated organism by culture and Ibis T5000 results in patients with PJI. On
134 the other hand, the Ibis T5000 found additional non-pathogen organisms in 3 cases in which the
135 Ibis T5000 had also detected an orthopedic pathogen.

136 All cultures in the aseptic group were negative whereas in 17 cases the Ibis T5000 found
137 orthopedic pathogens. In 27 patients, the biosensor failed to find any orthopedic pathogens.
138 Table 2 demonstrates more details on aseptic cases. During the follow-up period, 2 patients
139 failed and needed re-revision who were both initially revised for aseptic failure. The cause of
140 failure in these 2 patients was subsequent PJI with the same organism (Coagulase negative
141 *Staphylococcus*) as one isolated by the Ibis T5000. At the latest follow-up which ranged from 12
142 to 26 months after the index revision, all the remaining patients appear to be doing well with no
143 evidence of infection.

144

145 **Discussion**

146 Given the completely different management of aseptic loosening and PJI as well as the
147 importance of early diagnosis of PJI for establishment of a more effective treatment,
148 distinguishing between these two conditions needs special attention. Absence of a “gold
149 standard” for diagnosis of PJI [27] in addition to various defensive mechanisms of pathogens
150 such as biofilm production [8] make this differentiation more difficult. The infecting organism
151 that segregate in biofilm evade detection by conventional culture as the latter relies on isolation
152 of planktonic organisms. As a result it is suggested that some cases of PJI escape detection and

153 erroneously are categorized as aseptic failures [8]. Although many factors contribute to
154 development of PJI after revision surgery, the latter point may be considered as one of the
155 contributing factor for the much higher incidence of PJI after revision arthroplasty than that after
156 primary replacement.

157 The Ibis T5000 universal biosensor is a promising technology that has been used to
158 identify a wide spectrum of pathogens in sepsis [28] and it may cover limitations of PCR method
159 for diagnosis of PJI. Because of reliance on mass spectrometry and further “purification” of
160 DNA it is assumed that Ibis does not suffer the same extreme sensitivity as conventional PCR.
161 Further, because of pan-genomic amplification, Ibis may be able to detect infecting organisms
162 that could be missed by conventional PCR.

163 This prospective study was designed to examine the possibility of escaping some cases of
164 TKA failures which are assumed to be “aseptic” from conventional diagnostic tests. These cases
165 may be indeed infections. that have escaped diagnosis and have been miss-categorized as
166 “aseptic” failures. The study relied on Ibis T5000 for isolation of organism. Although we did not
167 accept Ibis as the “gold standard” for diagnosis of PJI, we were interested to know in what
168 percentage of patients with aseptic failure Ibis T5000 biosensor was able to isolate a pathogen.
169 Further, we sought to examine the correlation between conventional culture and Ibis in terms of
170 their ability for isolation of a pathogen and its resistance profile.

171 At our institution since 2006, we have utilized an algorithmic approach for work-up of
172 patients with failed arthroplasty which includes determination of ESR and CRP prior to revision
173 arthroplasty and selective aspiration of the failed joint in those with abnormal serology or high
174 index of suspicion for PJI [7]. In addition, intraoperative culture is performed for all cases

175 undergoing revision arthroplasty. In spite of employing such a comprehensive and strict
176 approach, the present study revealed that a few PJIs cannot be detectable by using routine
177 diagnostic tools. It appears that reliance on conventional investigations is likely to miss occult
178 PJI at least in 30% of patients (13 out of 44 if *Enterococcus faecalis* cases were considered as
179 contamination). The 2 patients who were originally assumed to have aseptic failure, developed
180 infection shortly after the index revision by organisms that had been isolated by the Ibis T5000
181 but failed to be detected by conventional culture. The infecting organism in one case was low-
182 virulence, but a recognized pathogen [29, 30] namely *Staphylococcus Caprae*. Although these
183 patients did not receive any treatment for isolated additional pathogens from the Ibis biosensor,
184 our findings may indirectly indicate the clinical importance of isolated pathogens from the Ibis
185 biosensor. However, we are not able to make a statement about effect of treatment on outcome of
186 these patients with negative culture in whom the Ibis biosensor isolates additional pathogens. It
187 is possible that the conventional culture may have identified these organisms if supplemented
188 culture was utilized or the culture was kept for an extended period of time.

189 PCR has been used previously for the purpose of isolating organism in cases of suspected
190 PJI [22, 23, 31]. However, PCR methods suffer several limitations, most important of which is
191 the high incidence of false positive results [11]. The technique is so sensitive that it may amplify
192 contaminating and non-infecting organism such as those residing on the skin that may have been
193 picked up by aspirating needle [25]. Ibis T5000 is a multiplex PCR technology that was designed
194 to overcome some of the limitations of conventional PCR.

195 Compared to conventional PCR, the Ibis T5000 utilizes a pan-genomic amplifier that is
196 capable of isolating atypical bacteria and even non-bacterial pathogens such as fungi. Unlike
197 conventional PCR, Ibis does not rely on universal primers for amplification of DNA which may

198 detect contaminating organism. Instead Ibis T5000 biosensor uses multiple pairs of species-
199 specific primers to amplify regions of an organism's genome. This process is followed by the
200 identification of that region's base composition using mass spectrometry, the results of which are
201 compared to a database which matches it to the closest microorganism [26]. The Ibis T5000
202 universal biosensor technology combines nucleic acid amplification to high-performance
203 electrospray ionization mass spectrometry and base-composition analysis. The system can
204 identify and quantify all known bacteria, all major groups of pathogenic fungi, and the major
205 families of pathogen viruses in humans and animals. Moreover, the system is capable of
206 detecting virulence factors and antibiotic resistance markers [26].

207 Despite its appeal, Ibis T5000 may still be a victim of high sensitivity. Ibis isolated a
208 "pathogen" in 17 cases (38%) of "aseptic" cases. Of the latter 2 patients have failed so far due to
209 infection which we believe was missed during the index revision arthroplasty. It is possible that
210 occult PJI may have been present in a few more cases that were either eradicated during index
211 revision arthroplasty, effectively with the patient undergoing a one stage exchange arthroplasty,
212 or are likely to manifest a failure with further follow-up. It is unlikely that the isolated organism
213 by Ibis in all 17 aseptic cases represent a true pathogen. Thus, this technology, despite its appeal,
214 should be reserved for patients in whom high index of suspicion or PJI exists but no organism
215 can be isolated. In other words the indication for use of Ibis, in our opinion, is for cases of
216 culture negative PJI.

217 The study suffers a few limitations. Perhaps the most important limitation of this study is
218 the relatively short follow-up. As mentioned above, it is possible that with longer surveillance we
219 are likely to encounter more patients who may fail. Although plausible, the latter is unlikely to
220 alter the message of this study. The study highlights the importance of routine preoperative

221 work-up using conventional serology for all and selected aspiration for some, in line with the
222 recent American Academy of Orthopedic Surgeons guidelines for diagnosis of PJI [6, 32]. It also
223 highlights the fact that a sophisticated technology is available for use by orthopedic surgeons to
224 isolate the infecting organism in cases of culture negative PJI. Another limitation of the study
225 relates to lack of a “standard” definition for PJI. It is possible that using a different diagnostic
226 criteria, some of the PJI cases in our cohort may have been considered as uninfected and vice
227 versa. The latter is unfortunately a limitation inherent to any studies related to topic of PJI as
228 various definitions for PJI exist and depending on the definition used the percent of infected
229 versus uninfected cases in a given cohort may change. It is hoped that orthopedic societies in
230 collaboration with other organizations may be able to address this shortfall in the future.

231 Despite the aforementioned limitations, the present study demonstrated that some aseptic
232 loosening are not “truly” aseptic and are low grade PJIs that remain undiagnosed using
233 conventional modalities. Some of these cases may fail early for a subsequent infection. This may
234 explain the relatively high incidence of infection following revision arthroplasty, compared to
235 primary, and also the high rate of early failure of revision cases. It is thus recommended that all
236 patients undergoing revision for failed arthroplasty should be subjected to routine conventional
237 work-up which includes routine serology (ESR and CRP) and joint aspiration in patients with
238 abnormal serology tests and high index of suspicion for PJI. With further refinements of
239 molecular techniques such as multiplex PCR, the true nature of some of these so called “aseptic”
240 failures is likely to be revealed.

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243 **References**

- 244 1. Della Valle CJ, Zuckerman JD, Di Cesare PE. Periprosthetic sepsis. *Clin Orthop Relat Res*
245 2004; 420: 26.
- 246 2. Phillips JE, Crane TP, Noy M, et al. The incidence of deep prosthetic infections in a specialist
247 orthopaedic hospital: a 15-year prospective survey. *J Bone Joint Surg Br* 2006; 88: 943.
- 248 3. Sharkey PF, Hozack WJ, Rothman RH, et al. Insall Award paper. Why are total knee
249 arthroplasties failing today? *Clin Orthop Relat Res* 2002; 7.
- 250 4. Bozic KJ, Kurtz SM, Lau E, et al. The epidemiology of revision total knee arthroplasty in the
251 United States. *Clin Orthop Relat Res* 2010; 468: 45.
- 252 5. Mortazavi SM, Molligan J, Austin MS, et al. Failure following revision total knee
253 arthroplasty: infection is the major cause. *Int Orthop* 2010 Oct 21. [Epub ahead of print];
- 254 6. Parvizi J, Della Valle CJ. AAOS Clinical Practice Guideline: diagnosis and treatment of
255 periprosthetic joint infections of the hip and knee. *J Am Acad Orthop Surg* 2010; 18: 771.
- 256 7. Parvizi J, Ghanem E, Menashe S, et al. Periprosthetic infection: what are the diagnostic
257 challenges? *J Bone Joint Surg Am* 2006; 88 Suppl 4: 138.
- 258 8. Nelson CL, McLaren AC, McLaren SG, et al. Is aseptic loosening truly aseptic? *Clin Orthop*
259 *Relat Res* 2005; 25.
- 260 9. Greidanus NV, Masri BA, Garbuz DS, et al. Use of erythrocyte sedimentation rate and C-
261 reactive protein level to diagnose infection before revision total knee arthroplasty. A prospective
262 evaluation. *J Bone Joint Surg Am* 2007; 89: 1409.
- 263 10. Bare J, MacDonald SJ, Bourne RB. Preoperative evaluations in revision total knee
264 arthroplasty. *Clin Orthop Relat Res* 2006; 446: 40.

- 265 11. Achermann Y, Vogt M, Leunig M, et al. Improved diagnosis of periprosthetic joint infection
266 by multiplex PCR of sonication fluid from removed implants. *J Clin Microbiol* 2010; 48: 1208.
- 267 12. Berbari EF, Marculescu C, Sia I, et al. Culture-negative prosthetic joint infection. *Clin Infect*
268 *Dis* 2007; 45: 1113.
- 269 13. Trampuz A, Piper KE, Jacobson MJ, et al. Sonication of removed hip and knee prostheses for
270 diagnosis of infection. *N Engl J Med* 2007; 357: 654.
- 271 14. Barrack RL, Harris WH. The value of aspiration of the hip joint before revision total hip
272 arthroplasty. *J Bone Joint Surg Am* 1993; 75: 66.
- 273 15. Reing CM, Richin PF, Kenmore PI. Differential bone-scanning in the evaluation of a painful
274 total joint replacement. *J Bone Joint Surg Am* 1979; 61: 933.
- 275 16. Weiss PE, Mall JC, Hoffer PB, et al. ^{99m}Tc-methylene diphosphonate bone imaging in the
276 evaluation of total hip prostheses. *Radiology* 1979; 133: 727.
- 277 17. Gelman MI, Coleman RE, Stevens PM, et al. Radiography, radionuclide imaging, and
278 arthrography in the evaluation of total hip and knee replacement. *Radiology* 1978; 128: 677.
- 279 18. Costerton JW, Montanaro L, Arciola CR. Biofilm in implant infections: its production and
280 regulation. *Int J Artif Organs* 2005; 28: 1062.
- 281 19. Jevon M, Guo C, Ma B, et al. Mechanisms of internalization of *Staphylococcus aureus* by
282 cultured human osteoblasts. *Infect Immun* 1999; 67: 2677.
- 283 20. Gristina AG, Costerton JW. Bacterial adherence and the glycocalyx and their role in
284 musculoskeletal infection. *Orthop Clin North Am* 1984; 15: 517.
- 285 21. Parvizi J, Suh DH, Jafari SM, et al. Aseptic Loosening of Total Hip Arthroplasty: Infection
286 Always Should be Ruled Out. *Clin Orthop Relat Res* 2011; 469: 1401.

- 287 22. Tunney MM, Patrick S, Curran MD, et al. Detection of prosthetic hip infection at revision
288 arthroplasty by immunofluorescence microscopy and PCR amplification of the bacterial 16S
289 rRNA gene. *J Clin Microbiol* 1999; 37: 3281.
- 290 23. Mariani BD, Martin DS, Levine MJ, et al. The Coventry Award. Polymerase chain reaction
291 detection of bacterial infection in total knee arthroplasty. *Clin Orthop Relat Res* 1996; 11.
- 292 24. Levine MJ, Mariani BA, Tuan RS, et al. Molecular genetic diagnosis of infected total joint
293 arthroplasty. *J Arthroplasty* 1995; 10: 93.
- 294 25. Panousis K, Grigoris P, Butcher I, et al. Poor predictive value of broad-range PCR for the
295 detection of arthroplasty infection in 92 cases. *Acta Orthop* 2005; 76: 341.
- 296 26. Ecker DJ, Sampath R, Massire C, et al. Ibis T5000: a universal biosensor approach for
297 microbiology. *Nat Rev Microbiol* 2008; 6: 553.
- 298 27. Della Valle CJ, Bogner E, Desai P, et al. Analysis of frozen sections of intraoperative
299 specimens obtained at the time of reoperation after hip or knee resection arthroplasty for the
300 treatment of infection. *J Bone Joint Surg Am* 1999; 81: 684.
- 301 28. Andrade SS, Bispo PJ, Gales AC. Advances in the microbiological diagnosis of sepsis.
302 *Shock* 2008; 30 Suppl 1: 41.
- 303 29. Arciola CR, Campoccia D, An YH, et al. Prevalence and antibiotic resistance of 15 minor
304 staphylococcal species colonizing orthopedic implants. *Int J Artif Organs* 2006; 29: 395.
- 305 30. Shuttleworth R, Behme RJ, McNabb A, et al. Human isolates of *Staphylococcus caprae*:
306 association with bone and joint infections. *J Clin Microbiol* 1997; 35: 2537.
- 307 31. Tarkin IS, Henry TJ, Fey PI, et al. PCR rapidly detects methicillin-resistant staphylococci
308 periprosthetic infection. *Clin Orthop Relat Res* 2003; 89.

309 32. Della Valle C, Parvizi J, Bauer TW, et al. Diagnosis of periprosthetic joint infections of the
310 hip and knee. J Am Acad Orthop Surg 2010; 18: 760.

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