Swab Cultures Are Not As Effective As Tissue Cultures for Diagnosis of Periprosthetic Joint Infection

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Abstract

Background While it is accepted accurate identification of infecting organisms is crucial in guiding treatment of periprosthetic joint infection (PJI), there remains no consensus regarding the best method for obtaining cultures.

Questions/purposes We compared the yield of intraoperative tissue samples versus swab cultures in diagnosing PJI.

Methods Tissue and swab cultures (three each) were collected prospectively during a consecutive series of 156 aseptic and septic revision arthroplasties from October 2011 to April 2012. The tissues and swabs were taken from standardized regions of the joint. After excluding 39 reimplantation procedures, we included 117 cases (74 hip, 43 knee; 30 septic, 87 aseptic) for analysis. We used a modified version of the Musculoskeletal Infection Society criteria for defining PJI, requiring three of five rather than four of six criteria. Tissue and swab cultures from septic

and aseptic cases were used to calculate their sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) for identifying PJI.

Results Tissue cultures were positive in a higher percentage of septic cases than swab cultures: 28 of 30 (93%) versus 21 of 30 (70%). Tissue cultures were positive in two of 87 aseptic cases (2%), while swab cultures were positive in 10 of 87 (12%). The sensitivity, specificity, PPV, and NPV were 93%, 98%, 93%, and 98%, respectively, for tissue cultures and 70%, 89%, 68%, and 90%, respectively, for swab cultures.

Conclusions Tissue cultures demonstrated higher sensitivity, specificity, PPV, and NPV for diagnosing PJI than swab cultures. Swab cultures had more false-negative and false-positive results than tissue cultures. Because swab cultures pose a higher risk of not identifying or incorrectly identifying infecting organisms in PJI, we believe their use in obtaining intraoperative culture specimens should be discouraged.

Level of Evidence Level II, diagnostic study. See Guidelines for Authors for a complete description of levels of evidence.

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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Introduction

Isolation of a pathogenic microorganism is essential for diagnosing and treating periprosthetic joint infection (PJI). Yet, there remains no consensus from the American Academy of Orthopaedic Surgeons (AAOS) regarding the best method of obtaining specimens to detect infecting pathogens [14]. Thus, surgeons currently utilize a variety of culture techniques, including tissue sampling, swab cultures, fluid aspiration, and implant sonication during revision surgery.

Swab cultures pose several potential problems during specimen obtainment, including increased risk of contamination, decreased volume of specimen for culture, and inhibition of pathogen growth [8, 19, 27]. Dy Chua et al. [5] reported the superiority of tissue samples over swab cultures in diagnosing infection of implantable cardiac devices. They found patients with clinical infection had positive tissue cultures more frequently than positive swab cultures (69% versus 31%) and patients with no infection had positive tissue cultures with similar frequency to those with positive swab cultures (28% versus 22%).

The new definition for PJI of the Musculoskeletal Infection Society (MSIS) includes isolation of a pathogen from tissue or fluid culture as part of their diagnostic criteria [18]. Nonetheless, due to the ease of their use and low cost, swabs are still frequently utilized to diagnose PJI internationally [27].

Font-Vizcarra et al. [6] compared the accuracy of synovial fluid cultures, tissue cultures, and swab cultures for diagnosing PJI and concluded synovial fluid cultured in blood culture flasks had higher sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) than the other two culture methods. However, that study used unique clinical criteria for defining infection. An acute PJI was defined as presence of local inflammatory signs, purulent drainage through the wound, and elevated C-reactive protein (CRP) levels during the first 6 weeks after total joint arthroplasty (TJA). A chronic PJI was defined when patients had pain, radiographic signs of loosening, elevated inflammatory markers, and (1) a sinus tract communicating with the prosthesis, (2) abnormal spots on leukocytes labeled with technetium-99 m scintigraphy, or (3) a positive culture of synovial fluid obtained using a percutaneous sterile technique. Furthermore, cultures were not taken from standardized sites and only two tissue and swab samples were taken from each case, both of which may have introduced sampling bias.

We therefore performed a prospective study comparing tissue samples to swab cultures with regard to (1) the frequency of positive and negative cultures in revision TJA, (2) the sensitivity, specificity, and predictive values of each culture method, and (3) the microorganisms isolated during aseptic and septic revision procedures.

Materials and Methods

We prospectively collected tissue and swab samples from all 156 revision arthroplasty procedures performed at our institution from October 2011 to April 2012. For this study, we excluded 39 revision procedures in which patients had a reimplantation or in which there was incorrect or inadequate specimen collection due to laboratory or nursing

clerical errors. Reimplantation procedures were excluded because they could not be clinically diagnosed as truly aseptic or septic for standards used in calculations. These exclusions left 117 procedures for final data analysis: 74 underwent total hip revision and 43 underwent total knee revision. There were 87 aseptic revisions and 30 septic revisions for PJI (Table 1). The mean age of patients at time of revision was 62 years (range, 24–87 years). There were 53 men and 64 women. Institutional review board approval was obtained before study initiation in September 2011.

The target sample size was chosen to detect a difference between positive tissues and swabs for infected cases. Projections were based on results from the prospective study of Dy Chua et al. [5], which described a positive tissue culture proportion of 69% and a positive swab culture proportion of 31%. A minimum target of 26 procedures with each set of samples had a power of 80% and was based on two-sided significance testing with $\alpha = 0.05$.

The gold standard for PJI was defined according to a modified version of the MSIS criteria [18]. We do not routinely utilize frozen section histology in revision arthroplasty. Tissue and swab culture results were not considered as part of gold standard diagnosis of PJI, as we wanted to remove any variables whose accuracy we were testing as part of the current study. Thus, this modified version of the MSIS criteria was utilized for clinical definition of PJI: (1) there was a sinus tract communicating with the prosthesis; or (2) a pathogen was isolated by culture from two separate fluid samples obtained from the affected prosthetic joint; or (3) when at least three of the following five criteria existed (the MSIS criteria require four of six, but we excluded the criteria of five or more neutrophils on frozen section, thus leaving us with three of five criteria as diagnostic): elevated serum erythrocyte sedimentation rate (ESR) and serum CRP concentration, elevated synovial white blood cell (WBC) count, elevated synovial polymorphonuclear neutrophil percentage (PMN%), presence of purulence in the affected joint, or isolation of a microorganism in one culture of periprosthetic fluid (preoperative

Table 1. Demographic characteristics of study patients included for analysis

Parameter	Septic (n = 30)	Aseptic (n = 87)	p value
Mean age (years)	59.1	62.5	0.29
Sex (number of males/ females)	15/15	38/49	0.67
BMI (kg/m ²)	34.7	31	0.48
Race (% white)	86.7	83.9	1.00
Joint (number of hips/knees)	15/15	60/27	0.08

and/or intraoperative aspirations). An ESR of greater than 30 mm/hour and a CRP of 1.0 mg/dL or greater were used as threshold values as per our institution's laboratory cut-offs. Regarding synovial WBC count and PMN%, thresholds for acute or chronic PJI were 10,700 cells/ μ L or 3000 cells/ μ L and 89% or 80%, respectively [3, 22].

Acute postoperative PJI was diagnosed if infection occurred within 6 weeks of index primary joint arthroplasty [3]. Acute delayed PJI was diagnosed if onset of symptoms occurred abruptly in a previously well-functioning joint [9]. Chronic PJI was suspected when infection was diagnosed after 6 weeks from index primary joint arthroplasty with symptoms of persistent joint pain or discomfort since surgery. Of the 30 septic cases included, 12 (40%) were diagnosed according to the presence of a sinus tract communicating with the prosthesis and 18 (60%) were diagnosed according to the presence of three or more minor MSIS criteria (Table 2). There were 19 chronic PJIs (63%), seven acute postoperative PJIs (23%), and four acute delayed PJIs (13%). For all cases of PJI, mean ESR, CRP, synovial WBC count, and PMN% were 73 mm/hour, 12 mg/dL, 53,976 cells/ μ L, and 85%, respectively.

Aseptic revision was defined as removal or exchange of any prosthetic components due to loosening of components, instability of joint, polyethylene wear, joint subluxation, arthrofibrosis, or periprosthetic fracture. Diagnosis was confirmed via lack of sinus tract, lack of positive preoperative and intraoperative synovial fluid cultures, normal inflammatory markers (ESR and CRP), normal synovial fluid WBC count and PMN%, and absence of purulence.

All operations were performed by one of five fellow-ship-trained joint reconstruction surgeons using laminar airflow and body exhaust suits. Preoperative prophylactic antibiotic treatment was not delayed in 108 cases of aseptic revision or cases of septic revision where the causative organism was known. Antibiotics were delayed in the remaining nine of 117 patients undergoing revision for PJI where causative organism was unknown.

Three tissue samples and three swabs were collected in a uniformly standardized manner from the same locations after arthrotomy as follows: (1) for revision hip procedures, samples were collected from the acetabular bone, synovial joint capsule, and femoral bone; and (2) for revision knee procedures, samples were collected from the femoral bone, synovial joint capsule, and tibial bone. Tissue samples were obtained utilizing clean instruments, in an approximate size of 1 cm³, and were placed directly into sterile specimen containers without medium for microbiologic analysis. Swabs (CultureSwab™ Plus Amies Gel without Charcoal, Double Swab; Becton, Dickinson and Co, Franklin Lakes, NJ, USA) were applied to the targeted tissue from the same regions as tissue samples and were

placed directly into sterile specimen containers with medium. Because a double swab was used, both aerobic and anaerobic cultures could be set up.

Specimens were transported in sterile containers to the clinical microbiology laboratory from the patient using a courier system or by a hospital pneumatic tube system. A total of 702 samples were processed by the microbiology laboratory. Tissues were exposed to air for an average of 30 minutes during transport and setup. Specimens of solid samples were diced with sterile scalpel blades and either inoculated directly onto appropriate media if small enough or further refined using a disposable hand-held tube and piston tissue homogenizers (Fisher Healthcare Products, Houston, TX, USA). Tissues were ground for 30 to 90 seconds depending on specimen size and toughness, with sterile saline added as necessary to facilitate liquefaction. Swabs were simply plated directly and placed into a thioglycolate broth tube after being used for plating.

Synovial fluid was obtained and used only as a diagnostic adjunct in all 117 cases via needle aspiration either preoperatively or intraoperatively. If the sample was a fluid, it was directly plated using sterile plastic bulb transfer pipettes dispensing one to three drops onto each plate.

Anaerobic media were immediately placed into an anaerobic jar and anaerobic conditions were generated within seconds using an Anoxomat™ system (Advanced Instruments, Inc, Norwood, MA, USA) for evacuating air from the jars, with replacement gas composed of nitrogen, carbon dioxide, and hydrogen. The anaerobic gas mixture was purchased as oxygen free. Inside each jar was about a teaspoon of palladium catalyst pellets to convert traces of oxygen into water using the available hydrogen gas. An indicator of anaerobic conditions was used to ensure anaerobic conditions were achieved. The indicators in each anaerobic jar were checked after 2 hours and again just before opening the jar 48 hours later.

Because the physicians ordered both routine aerobic cultures and anaerobic cultures, we inoculated aerobic media (blood agar, chocolate agar, and MacConkey agar) and specialty anaerobic media (Brucella laked blood agar, phenylethyl alcohol blood agar, Bacteroides bile esculin agar, and laked blood agar with kanamycin and vancomycin) plus thioglycolate broth. These media were obtained from BD Diagnostic Systems (Sparks, MD, USA), except for the prereduced anaerobic enriched Brucella laked blood agar, which was obtained from Hardy Diagnostics Co (San Maria, CA, USA). Incubation was prolonged and anaerobic jars were not opened before 48 hours. Routine incubation for all organism types occurred for the first 5 days. After that, the plates were read on Days 7, 9, and 14 for *Propionibacterium* species.

Gram stain of the direct specimen was performed. If the culture results and Gram stain results matched, cultures

Table 2. Description of the 30 patients diagnosed according to the new MSIS definition for PJI

Infection type	Sinus tract	Fluid aspiration culture	ESR (mm/hour)	CRP (mg/dL)	Synovial WBC count (number of cells/ μ L)	Synovial PMN%	Purulence	Joint
Acute hematogenous (n = 4)	No	MSCoNS	49	4.3	55,891	85	Yes	Hip
	No	MSSA	99	59.2	209	86	Yes	Hip
	No	MSSA	110	22	62,187	88	Yes	Hip
	No	<i>Escherichia coli</i>	112	26.8	59,567	81	Yes	Knee
Acute postoperative (n = 7)	Yes	MSSA	33	19	23,208	78	Yes	Hip
	Yes	MRSA	97	10.3	NA	NA	Yes	Hip
	No	<i>Enterococcus</i>	99	3.7	10,358	87	Yes	Hip
	Yes	Polymicrobial*	38	22.4	NA	NA	Yes	Knee
	Yes	Negative	105	12.1	407	23	Yes	Knee
	Yes	MRCoNS	89	12.5	20,931	89	Yes	Knee
	Yes	Negative	65	7.2	3121	92	No	Knee
Chronic (n = 19)	Yes	MSSA	55	17.2	337,500	93	Yes	Hip
	Yes	MSCoNS	NA	NA	NA	NA	Yes	Hip
	Yes	<i>Propionibacterium acnes</i>	112	5.5	NA	NA	Yes	Hip
	Yes	Negative	107	10.3	2358	72	Yes	Hip
	Yes	NA	13	1	NA	NA	Yes	Hip
	No	MSCoNS	84	8.1	1324	96	Yes	Hip
	No	<i>Streptococcus</i>	NA	NA	35,001	88	Yes	Hip
	No	MSSA	102	8	NA	NA	Yes	Hip
	No	<i>Streptococcus</i>	73	11	266,486	98	Yes	Hip
	Yes	MRSA	> 120	12.2	13,382	91	Yes	Knee
	No	Negative	18	0.9	22,000	93	Yes	Knee
	No	Negative	67	3.7	23,760	90	Yes	Knee
	No	<i>Streptococcus</i>	34	0.1	NA	NA	Yes	Knee
	No	MRSA	55	2.3	82,832	68	Yes	Knee
	No	MSSA	70	8.5	71,993	89	Yes	Knee
	No	MSSA	56	32.9	35,981	94	No	Knee
	No	NA	97	6.2	29,821	95	Yes	Knee
	No	Negative	58	1	NA	87	Yes	Knee
	No	NA	78	11.7	29,170	96	Yes	Knee

* Polymicrobial = *Enterococcus*, *Coryneform*, *Streptococcus*; MSIS = Musculoskeletal Infection Society; PJI = periprosthetic joint infection; ESR = erythrocyte sedimentation rate; CRP = C-reactive protein; WBC = white blood cell; PMN% = polymorphonuclear neutrophil percentage; MSCoNS = methicillin-sensitive coagulase-negative *Staphylococcus*; MSSA = methicillin-sensitive *Staphylococcus aureus*; MRSA = methicillin-resistant *Staphylococcus aureus*; MRCoNS = methicillin-resistant coagulase-negative *Staphylococcus*; NA = not available.

were signed out without subculture of the thioglycolate broth. If the Gram stain results indicated organism morphotypes not already isolated on either the aerobic or anaerobic plates, then the broth was subcultured to aerobic and anaerobic agar plates and rechecked after incubation for new species. Incubation for anaerobic plates was at least a full 48 hours.

In rare cases where Gram stain of the thioglycolate broth indicated organisms that were difficult to cultivate, we would transfer approximately 0.5 mL thioglycolate broth to a chopped meat anaerobic broth, which was incubated a minimum of 3 days and checked for growth.

Bacterial identification systems used where appropriate were the BD PhoenixTM (BD Diagnostic Systems) bacterial identification panels for aerobic gram-positive and gram-negative organisms, augmented where needed with conventional biochemical testing such as coagulase, catalase, oxidase, and specific tubed media. Anaerobic bacteria were identified using the Remel RapIDTM system (Thermo Fisher Scientific-Remel Products, Lenexa, KS, USA) for anaerobes, augmented by conventional anaerobic biochemical identification methods.

Differences in the proportion of positive cultures between tissues and swabs for septic and aseptic cases were

determined using Fisher's exact test. Results of cultures from septic and aseptic cases were used to calculate the sensitivity, specificity, PPV, and NPV for both types of samples. The gold standard for defining infection was the modified MSIS criteria described previously. Multivariate logistic regression was used to determine the strength of association of two or more positive cultures of a given sample type and true diagnosis of PJI.

Results

False-positive and false-negative culture results occurred more often with swab cultures than with tissue cultures. In infected cases, tissues (28 of 30, 93%) produced a positive culture more frequently ($p = 0.042$) than swabs (21 of 30, 70%). In aseptic cases, swabs (10 of 87, 12%) produced a positive culture more frequently ($p = 0.032$) than tissues (two of 87, 2%). Synovial fluid was obtained for culture in 27 of 30 septic cases. Fluid culture was positive in 21 of 27 infected cases where fluid was available (78%).

Using septic and aseptic culture results, the sensitivity, specificity, PPV, and NPV were all higher for tissues than for swabs when one or more positive culture were evaluated for diagnosis of PJI and were equal to or higher for tissues than for swabs when two or more positive cultures were evaluated (Table 3). Positive tissue culture was more strongly associated with true diagnosis of PJI (odds ratio, 57; 95% CI, 18–182) than positive swab culture (odds ratio, 5; 95% CI, 2–13). Both tissues and swabs were associated with ($p < 0.001$) a diagnosis of PJI.

With regard to infecting microorganisms, 37% of PJIs were caused by *Staphylococcus aureus*, 27% by coagulase-negative staphylococcal species, 13% by streptococcal species (including *Enterococcus*), 10% by gram-negative organisms, 7.0% were polymicrobial, and 7.0% were culture negative (Table 4). Eight of the 11 culture-positive aseptic cases grew coagulase-negative staphylococcal species, one case grew *Propionibacterium acnes*, and one case grew *Pantoea agglomerans* (formerly *Enterobacter agglomerans*). Both tissue and swab samples were able to diagnose PJI at high rates when infected with

Staphylococcus aureus species (Table 4). Swab samples were often falsely negative in infections with streptococcal species. Swabs were most often falsely positive with contamination from coagulase-negative staphylococcal species.

Discussion

Accurate diagnosis of PJI is crucial in guiding ensuing treatment, and identification of infecting microorganisms has always been considered paramount in making this diagnosis. A lack of definitive data confirming the best method to isolate pathogens has led to a wide variety of techniques being utilized in evaluating periprosthetic material for infection [1–3, 6]. While periprosthetic tissue and fluid samples are considered the ideal specimens by some authors [3, 6, 18], swab cultures continue to be used due to their ease of use and low cost [27]. However, it is unclear whether swab cultures and tissue cultures result in similarly positive and negative cultures. We therefore (1) compared the frequency of positive and negative tissue and swab cultures in PJI; (2) determined the sensitivity, specificity, PPV, and NPV of each method using standardized MSIS criteria to define septic and aseptic revisions; and (3) identified the microorganisms isolated by each culture method.

Our study has some limitations. First, the standard duration of culture used in our study was 5 days as per our institution's microbiology laboratory protocol. Some studies have reported culture incubation for 2 weeks captures low-virulence infecting organisms such as *Propionibacterium acnes* [21]. To prevent inflation of false-negative results, septic cases with no initial growth were cultured additionally for up to 14 days in our study. However, we opted to grow cultures from aseptic cases for less than 2 weeks due to concerns of contaminant growth and thus overly inflated false-positive results. Second, several studies [11, 17, 20] have recently debated categorizing all aseptic revisions as truly aseptic, especially if there is positive intraoperative culture growth and subsequent need for rerevision due to infection. Although it is

Table 3. Sensitivity, specificity, PPV, NPV, and likelihood ratios for tissue and swab cultures

Number of positive cultures considered diagnostic	Intraoperative test	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Positive diagnostic likelihood ratio	Negative diagnostic likelihood ratio
≥ 1	Tissue culture	93.3 (79–98)	97.7 (92–99)	93.3 (79–98)	97.7 (92–99)	40.6 (10.2–160.3)	0.07 (0.02–0.26)
	Swab culture	70.0 (52–83)	88.5 (80–93)	67.7 (50–81)	89.5 (81–94)	6.1 (3.2–11.4)	0.34 (0.20–0.59)
≥ 2	Tissue culture	63.3 (46–78)	97.7 (92–99)	90.5 (71–97)	88.5 (81–94)	27.6 (6.8–111.4)	0.38 (0.23–0.60)
	Swab culture	53.3 (36–70)	97.7 (92–99)	88.9 (67–97)	85.9 (78–91)	23.2 (5.6–95.0)	0.48 (0.33–0.70)

The 95% CIs are reported in parentheses; PPV = positive predictive value; NPV = negative predictive value.

Table 4. Microorganisms encountered by each tissue and swab sample for septic and aseptic cases

Microorganism	Number of cases	Number of tissue samples			Number of swab samples		
		+	–	% positive	+	–	% positive
Septic cases							
MSSA	6	15	3	83.3	11	7	61.1
MRSA	5	12	3	80.0	15	0	100.0
MSCoNS	3	4	5	44.4	3	6	33.3
MRCoNS	5	6	9	40.0	8	7	53.3
<i>Streptococcus</i> *	4	8	4	66.7	4	8	33.3
Gram negatives [†]	3	7	2	77.8	5	4	55.6
Polymicrobial	2	5	1	83.3	3	3	50.0
Culture negative	2	0	6	0.0	0	6	0.0
Total	30	57	33	63.3	49	41	54.4
Aseptic cases							
MSCoNS	7	2	19	9.5	9	12	42.9
MRCoNS	1	0	3	0.0	1	2	33.3
<i>Propionibacterium acnes</i>	2	0	6	0.0	2	4	33.3
<i>Pantoea agglomerans</i>	1	2	1	66.7	0	3	0.0
Culture negative	76	0	228	0.0	0	228	0.0
Total	87	4	257	1.5	12	249	4.6

* *Streptococcus* group includes *Enterococcus* species; [†] gram negatives include *Escherichia coli*, *Pseudomonas aeruginosa*, and *Serratia marcescens*; MSSA = methicillin-sensitive *Staphylococcus aureus*; MRSA = methicillin-resistant *Staphylococcus aureus*; MSCoNS = methicillin-sensitive coagulase-negative *Staphylococcus*; MRCoNS = methicillin-resistant coagulase-negative *Staphylococcus*.

never possible to definitively recognize a revision as truly aseptic, all of our aseptic cases were grouped as such based on their failure to meet the modified MSIS criteria for PJI previously outlined. Further, in presumed aseptic cases with positive culture growth, it is not possible to determine whether the joint was previously infected or whether the growth represented a contaminant. Third, we utilized a modified version of the new definition of PJI proposed by the MSIS to standardize the criteria for diagnosing septic TJA [18]. Our institution does not have reliable resources for analyzing histologic frozen sections, and thus this criterion was eliminated when categorizing our revisions as septic. This elimination, however, did not deflate the number of septic cases in our study as, even if frozen sections were always positive in our aseptic cohort, they would still not meet the combinatorial criteria for PJI. Before publication of the MSIS criteria [16], there was no consensus as to the true definition of PJI and thus no consistent means for comparison of diagnostic modalities and treatment outcomes in clinical practice or across studies. For example, when evaluating methods for microbiologic diagnosis of PJI, Atkins et al. [2] used only histologic findings suggestive of PJI as the gold standard for comparison with culture results. In addition, Schäfer et al. [21] used the presence of two or more positive cultures or one positive culture and one positive histology specimen as diagnostic for PJI. The MSIS criteria reflect a

consensus from a number of institutions. To be as close to the 66% (four of six) of minor criteria as possible, rather than eliminating just one of the criteria from the denominator (four of five or 80% of minor criteria) and potentially missing some infections due to overly high specificity and lower sensitivity, we opted for inclusion of three of five (60%) criteria to ensure diagnostic sensitivity and specificity as close as possible to those of the original publication. Thus, in the current study, we used a prospective study design with standardized culture sites and a modified version of the MSIS criteria to improve the validity of comparison between previously published literature on tissue and swab culture diagnostic effectiveness.

A critical part of culture obtainment is maximizing positive results in septic cases and minimizing positive results in aseptic cases. We found a lower false-positive rate for tissue cultures in aseptic cases than Font-Vizcarra et al. [6] (two of 87 [2%] versus 21 of 63 [33%]). This was likely in part due to our protocol for not delaying preoperative prophylactic antibiotic administration in aseptic cases, which is in accordance with AAOS clinical practice guidelines for PJI [14]. The authors of that study reported antibiotics were delayed for all cases until after culture collection. However, in clinical practice, prophylactic antibiotics are administered for the very reason that previously aseptic joints may in fact become contaminated during revision surgery itself and therefore result in more

Table 5. Comparison of tissue and swab results of our study and previous studies

Study	Number of cases	Tissue cultures		Swab cultures	
		Sensitivity (%)	Specificity (%)	Sensitivity (%)	Specificity (%)
Font-Vizcarra et al. [6]	150	69	81	61	99
Spangehl et al. [23]	18	94	97	76	99
Current study*	117	63	98	53	98

* When two or more cultures are considered diagnostic for PJI.

false-positive culture specimens. Further efforts to decrease the burden of specimen contamination have been advocated in the literature, including taking three or more samples for culture, using clean instruments when obtaining periprosthetic material, and placing specimens directly into sterile containers for transport to the microbiology laboratory [2, 21].

Given the difficulties identifying PJI, a wide range of sensitivities (60%–94%) and specificities (81%–100%) has been reported in the literature [2, 6, 7, 10, 12, 13, 15, 21, 23, 25, 26]. We found tissue cultures (93% sensitivity, 98% specificity) outperformed swab cultures (70% sensitivity, 89% specificity) for all measured parameters. As expected, when two or more positive cultures were considered diagnostic for true PJI, the sensitivity of both culture methods decreased (63% for tissues; 53% for swabs), and the specificity of swabs increased (98% for tissues; 98% for swabs). Only two previous studies have included separate data analyses on cultures obtained from tissue and swab specimens (Table 5). The study by Font-Vizcarra et al. [6] was performed retrospectively and the same standardized intraarticular regions for both tissue and swab specimen collections were not used, thus jeopardizing the validity of the comparison between groups. The study by Spangehl et al. [23] included only 18 cases of PJI in the calculations, and swabs cultures were taken only of explanted prostheses, again limiting the strength of direct comparison to tissue cultures.

Accurate identification of microorganisms in PJI is an important endeavor that many authors [1, 4, 24, 25] have begun to investigate. While we found the majority of infections were caused by staphylococcal species, a large percentage of the culture-negative results were due to staphylococcal and streptococcal microorganisms. It is now well accepted based on work by Costerton and others [4, 24] that a majority of the culture-negative cohort can be attributed to the ability of bacteria to form matrix-enclosed biofilms on prosthetic and bone surfaces, allowing evasion of traditional culture methods, host defenses, and even antibiotic therapy. Trampuz et al. [25] published one of the initial studies showing sonicate fluid cultures had higher sensitivity (60.8% versus 78.5%) and specificity (99.2% versus 98.8%) than periprosthetic tissue cultures [25].

Particularly, sonication is able to dislodge adhering biofilm from implants to substantially increase the diagnostic yield of cultures taken from patients who have received antibiotics within 2 weeks of revision surgery [1, 25]. While novel investigations such as these show initial promise in enhancing bacteriologic identification in PJI, their widespread use into practice has been limited by high costs, time-consuming protocols, and need for additional resources [25].

In summary, when compared using a standardized protocol, periprosthetic tissue cultures demonstrated superior microorganism identification compared to swab cultures taken from the same sites. This study was the first to use both a prospective study design and previously published validated diagnostic criteria in calculating statistical parameters to evaluate tissue and swab cultures. Therefore, we recommend against the use of swab cultures in diagnosis of PJI, as they add no advantage to synovial fluid aspiration or intraoperative tissue specimens and may confuse the clinical picture due to contamination. Continued efforts to improve microbiologic diagnosis of PJI must focus on not only increasing sensitivity and specificity of results but also improving cost-effectiveness and efficiency of diagnostic methods to enable widespread use among the orthopaedic and infectious disease community.

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