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Review Paper
TMJ Disorders

Prevention and detection of prosthetic temporomandibular joint infections—update

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Abstract. Prosthetic joint infections are not only distressing complications for patients and surgeons, but also have an enormous financial impact on healthcare systems. The reported incidence of prosthetic joint infection is likely underestimated due to difficulties in their diagnosis. This unfortunate complication has challenged joint replacement surgeons for years, despite all the advances made in this surgical discipline. Since eradication of these infections can be very difficult, prevention remains the primary objective. Identifying recipient risk factors, adopting a proper surgical technique, appropriate wound care, optimizing the operating room environment, and appropriate postoperative care have become some of the core elements that can help to minimize the overall incidence of this complication. The purpose of this article is to provide the temporomandibular joint replacement surgeon with an update on the prevention and detection of prosthetic joint infections based on a review of the most recent information published in the orthopedic and surgical literature.

Key words: temporomandibular joint replacement (TMJR); prosthetic joint infection (PJI); surgical site infection (SSI).

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Annually, 1.2 million orthopedic joint replacements are performed in the USA. This number is expected to increase 233.33% by the year 2030[1]. Using the same statistical metrics, Onoriobe et al. reported that there should be a 50% increase in temporomandibular joint replacement (TMJR) over the same time period[2]. With these projected increases in the number of joint replacement procedures in both specialties, there is likely to be an increase in prosthetic joint infection (PJI) complications[3].

In 2012, Kurtz et al. estimated that the annual cost of managing orthopedic PJI was US$ 566 million and by 2020 could reach US $ 1.62 billion annually[4]. TMJR statistics demonstrate the incidence of PJI to be uncommon (1.5–2.7%). However, the clinical, psychological, and economic consequences of this complication are substantial[5–7].

In 2017, the American College of Surgeons published updated guidelines for the prevention, detection, and management of a surgical site infection (SSI). These guidelines included pre-hospital, hospital, and post-discharge interventions that could reduce the incidence of SSI[8]. The Centers for Disease Control and Prevention (CDC) and the Healthcare Infection Control Practices Advisory Committee published the *Guideline for the prevention of surgical site infection*, which offers parameters intended to provide new and updated evidence-based recommendations for the prevention of SSI; they recommended that these be incorporated into all comprehensive surgical quality improvement programs[9,10].

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Perry and Hanssen presented a review and update of infection prevention in orthopedic joint replacement in which they listed what they considered the traditional cornerstones for the prevention of PJI: host optimization, reduction of bacteria, and establishment of a proper wound environment in the preoperative, intraoperative, and postoperative periods. They concluded that an institution-based systems approach is critical to implementing standardized, reproducible practices to reduce PJI[11].

Recently, the American Academy of Orthopedic Surgeons produced a systematic literature review on the management of SSI, which in addition to providing practice recommendations, also highlights limitations in the literature and areas that require future research[12].

The purpose of this article is to provide the TMJR surgeon with an update on the prevention and detection of TMJR-related PJI based on a review of the most recent information in the orthopedic and surgical literature.

Prevention (Table 1)

Measures for the prevention of SSI and PJI include (1) preoperative optimization or modification of potential risk factors; (2) reduction of the patients' bacterial burden; (3) the administration of prophylactic antibiotics; (4) the development of prosthetic device coatings that prevent or discourage the formation of biofilms; and (5) the establishment of the proper surgical and postsurgical environments[6,7,11].

Modification of potential PJI risk factors (Table 2)

Evaluating potential at-risk patients in a multidisciplinary clinic prior to performing TMJR is critical in order to identify comorbidities and manage them in a timely and appropriate manner. These assessments can substantially reduce postoperative morbidity[13]. Tan et al. identified and validated risk factors and their relative weights for predicting PJI and developed a risk calculator for PJI for orthopedics[14]. Factors such as the number of prior surgical procedures and other high-risk comorbidities should be discussed when counseling potential TMJR patients about their outcome expectations.

Table 1. Keys to the prevention of surgical site infection (SSI) and prosthetic joint infection (PJI).

Prevention of SSI and PJI
• Preoperative optimization or modification of potential risk factors
• Reduction of the patients' bacterial burden
• Administration of prophylactic antibiotics
• Development of prosthetic device coatings that prevent or discourage the formation of biofilms
• Establishment of the proper surgical and postsurgical environments

Table 2. Potential host risk comorbidities to consider preoperatively and manage before temporomandibular joint replacement.

Host risk comorbidities
• Metabolic diseases (e.g., diabetes[8])
• High inflammatory arthritis
• Depression and anxiety
• Immunosuppressive medications
• Nicotine use (stop 4 to 6 weeks before surgery[8])
• Malnutrition
• Cardiac and pulmonary disease
• Anemia
• Alcohol and drug abuse
• HIV and AIDS

Reduction of the patients' bacterial burden (Table 3)

One of the organisms most commonly isolated from PJIs is *Staphylococcus aureus*. Resistant strains are becoming more prevalent, therefore many hospitals have instituted decolonization protocols based on generalized data[15,16]. However, data on the success of *S. aureus* nasal decolonization programs and their effectiveness in preventing PJI are limited.

Decolonization

An intranasal technique utilizing antimicrobial photo-disinfection therapy combined with chlorhexidine gluconate body wipes demonstrated a significant reduction in SSI rates[17]. The benefits of this approach included excellent patient compliance and easy integration into the preoperative routine. Unfortunately, this option is unavailable in the USA, as it does not to date have Food and Drug Administration (FDA) approval.

Table 3. Components for the reduction of the patients' bacterial burden.

Reduction of the patients' bacterial burden
• Decolonization
• Prophylactic antibiotics
• Prevention of biofilm formation

Clinical practice guidelines from the American Society of Health-System Pharmacists recommend screening and nasal mupirocin decolonization for patients colonized with *S. aureus* before total joint replacement and cardiac procedures. Vancomycin should not be administered as prophylaxis to patients who are negative for methicillin-resistant *S. aureus* (MRSA)[8]. Currently the use of vancomycin or teicoplanin is deemed appropriate in patients who are carriers of MRSA, patients from dialysis units or centers with an outbreak of MRSA, healthcare workers, and patients who are allergic to penicillin[17].

Administration of prophylactic antibiotics

The use of prophylactic antibiotics is the most important factor in preventing PJI[11,18–22]. In order to reach the minimum inhibitory concentration in the end organs during the operation, the optimum time for weight-adjusted prophylactic antibiotic administration is 1 hour prior to the surgery[8]. A first- or second-generation cephalosporin (cefazolin or cefuroxime) is suggested as routine preoperative surgical prophylaxis, administered within an hour prior to the surgical incision. The timing can be extended up to 2 hours for vancomycin and fluoroquinolones[22]. In certain conditions, such as prolonged surgical duration beyond the half-life of the antibiotic, or when excessive blood loss occurs during the surgery, a second dose of antibiotic is required[8].

Developing prosthetic device coatings to prevent the formation of biofilms

The development of innovative prosthetic coatings to gain antibacterial activity on implant surfaces has been under intense investigation for years[23]. The strategies have involved the release of antimicrobial drugs or use of novel bactericidal metallic nanocrystalline coatings[24–26]. A wide spectrum of substances and technological approaches have been proposed and tested with specific aims: (1) the prevention of bacterial adhesion (anti-adhesive polymers, albumin, superhydrophobic surfaces, nano-patterned surfaces, and hydrogels), and (2) bactericidal activity (inorganic: silver, titanium dioxide, copper, selenium, and zinc; organic: coated or covalent antibiotics, antimicrobial peptides, cytokines, and enzymes; multilayered coatings, positive-charged polymer, and multifunctional smart coatings with nano-containers)[23–26].

Establishing the proper surgical environment (Table 4)

When not part of an MRSA decolonization protocol or specific preoperative surgical protocol, routine preoperative bathing and shampoo with chlorhexidine decreases skin and hair surface pathogen concentrations, but has not been shown to reduce the incidence of SSI[8]. Preoperative hair removal should be avoided unless hair interferes with surgery. If hair removal is necessary, clippers should be used instead of a razor[7,8].

Alcohol-containing preparations should be used unless contraindicated (e.g., fire hazard, surfaces involving mucosa, cornea, or ear). No agent (e.g., chlorhexidine, iodine) appears to be clearly superior when compared to alcohol. If alcohol cannot be included in the preparation, chlorhexidine should be used instead of iodine, unless a contraindication to its use exists[8,10].

The use of a waterless chlorhexidine surgical hand scrub is as effective as traditional water/soap scrub and requires less time. However, it is not superior to traditional surgical hand scrubbing if not used according to manufacturer instructions[8].

Studies have shown that the SSI rate is significantly increased when traditional cloth drapes are used[26,27]. Further, there is no evidence that the use of adhesive drapes, plain or infused with antimicrobials, reduces SSI rates[10,27–29].

Double gloving reduces the risk of glove perforation and wound contamination. In procedures where sharp edges could easily be encountered, double gloving is highly recommended[8,30]. However, with double gloving the inner glove can still be perforated, thereby providing a possible source of contamination. Therefore, some studies have shown that in procedures such as joint replacement, triple gloving is the protocol of choice. Nevertheless, triple gloving has some disadvantages, such as decreased tactile sensation and surgeon dexterity[31,32].

Table 4. Components to consider in regard to a proper surgical environment.

Establishing the proper surgical environment
• Preoperative hair and body cleanse
• Shearing hair from the surgical site
• Surgical attire
• Surgical hand scrub
• Preoperative surgical site preparation
• Double gloving
• Draping
• Soaking prosthetic components in antibiotic solution
• Irrigation
• Blood transfusion
• Intraoperative normothermia and oxygenation
• OR laminar flow and traffic
• OR equipment contamination
• Length of surgery
• Experience of the surgeon

OR, operating room.

There is limited evidence to support recommendations regarding operating room attire. Joint Commission and Association of Perioperative Registered Nurses policies support facility scrub laundering and the use of disposable bouffant hats. American College of Surgeons guidelines support the use of a skull cap only if minimal hair is exposed, removing or covering all jewelry on the head and neck, and professional attire when outside the operating room (no scrubs or clean scrubs covered with a lab-type coat)[8]. Available evidence suggests uncertain trade-offs between the benefits and risks of orthopedic space suits for the prevention of SSI during prosthetic joint replacement surgery and uncertainty regarding the healthcare personnel who should wear them[9].

Maintaining intraoperative normothermia reduces the risk of SSI. Preoperative warming is recommended for all cases, and intraoperative warming methods should be employed for all but short, clean cases. An increased fraction of inspired oxygen (FiO_2) should be administered during surgery and after extubation in the immediate postoperative period for patients with normal pulmonary function undergoing general anesthesia with endotracheal intubation[8].

In the orthopedic literature there are no randomized controlled trials that have evaluated the soaking of prosthetic devices in antimicrobial solutions before implantation to prevent SSI[10]. However, Smith et al. showed that the use of vancomycin as the perioperative prophylactic antibiotic for primary total joint replacements was effective in decreasing the rate of PJI; and in the event that a PJI occurred, the resulting infection occurred with less virulent organisms[33]. It has been recommended that TMJR device components be soaked in a vancomycin solution prior to implantation to decrease the chance of a PJI developing[5–7]. Copious irrigation while cutting and/or shaping host bone and while drilling screw holes, as well as after device implantation, are also fundamental to decreasing the incidence of SSI and PJI[5–7].

Blood transfusion is an independent predictor for PJI. The number of transfused units has a direct link to the likelihood of developing a PJI[34]. The latter statement can be justified because of the modulating effects a transfusion has on the immune system[35]. However, transfusion of blood products should not be withheld from surgical patients as a means to prevent SSI[8]. Strategies to prevent excessive blood loss include meticulous hemostasis, hypotensive anesthesia, and the use of tranexamic acid[36,37].

The ultimate goal of any operating room design is to diminish patient exposure to infectious organisms. One of the options available to achieve this objective is laminar airflow. However, some studies have reported that laminar flow could even increase the risk of SSIs[38]. The CDC has no comment regarding the use of laminar airflow in reducing SSI. Nevertheless, the CDC has released a guideline for the proper use of laminar airflow[39]. The incidence of SSI is directly related to the operating room traffic. This traffic can increase the environmental airborne microorganism burden in the operating room. Furthermore, more high traffic door openings can interfere with laminar airflow[40,41].

The contamination of surgical equipment can occur during surgery. Givissis et al. reported a 54% suction tip contamination rate[42]. Davis et al. determined the contamination rates of glove tips (28.7%), syringe bags (20.0%), gowns (17.0%), base of light handles (14.5%), body of light handles (14.5%), swabs (13.5), suction tips (11.4%), needles for deep closure (10.1%), surgical skin (9.4%), and deep blades (3.2%)[43]. Beldame et al. reported significantly higher rates of contamination in gloves prior to prosthesis implantation and advised surgeons to change gloves before proceeding with this step[44]. During TMJR, contamination can easily occur if the surgeon and operating room staff do not keep TMJR instrumentation strictly separated from instrumentation used in the oral cavity[7].

There are numerous variables that help promote successful wound healing and avoidance of PJI, but these are difficult to quantify and study (e.g., meticulous surgical technique, accurate wound closure, etc.). However, an increased surgical time has clearly been demonstrated to correlate with an increased incidence of PJI[45,46]. Furthermore, the surgeon's experience and surgical volume also have potential effects on the rate of SSI: surgeons with lower numbers of surgeries tend to have higher rates of infection[47,48].

Detection (Table 5)

While prevention is the most effective strategy, making a clear and timely PJI

Table 5. Established and emerging diagnostics for the detection of prosthetic joint infection.

Detection
Established diagnostics
• Imaging
• Synovial WBC count and neutrophil percentage
• Leukocyte esterase test
• Fluid and tissue cultures
Emerging diagnostics
• Interleukin 6
• Alpha-defensin
• Serum D-dimer
• Next-generation sequencing

WBC, white blood cell.

diagnosis remains critical to successful and directed PJI management. The most challenging aspect of managing a PJI is reaching a definitive diagnosis with identification of the causative organism. PJI is difficult to diagnose before revision or replacement surgery in the absence of uniform and well standardized criteria. This can be further complicated by the difficulty of differentiating a PJI from an adverse local tissue reaction (ALTR) to particulate wear without the presence of purulence[49].

In 2011, The Musculoskeletal Infection Society (MSIS) developed criteria for PJI that resulted in improvements in diagnostic confidence and research collaboration. This was presented and discussed in the TMJR literature[50]. However, with the emergence of new diagnostic tests and the lessons learned from the past using the MSIS definition, Parvizi et al. have developed an updated, evidence-based and validated version of the MSIS criteria[51].

PJI culture-negative infections range between 27% and 55%. These are biofilms that cannot easily be identified using conventional culture methodology. Therefore, strategies have been recommended for improving the yield of cultures, such as withholding antibiotics before taking culture samples, culturing synovial fluid in blood culture bottles, and holding cultures for longer periods[52]. The latter recommendation is especially germane when potentially dealing with a *Propionibacterium acnes* PJI[53].

Established diagnostic tests

Imaging

There is limited evidence to support the use of medical imaging in the diagnostic evaluation of patients with a suspected SSI and/or PJI[12].

Synovial fluid white cell counts and neutrophil percentage

There is strong evidence that joint fluid aspiration for the assessment of the synovial white blood cell (WBC) count and neutrophil differential (PMN %), along with tissue cultures, are invaluable for the detection of acute and chronic PJIs[12]. However, any useful fluid aspirant from a TMJR articulation is very difficult or impossible to secure. Also, the WBC count and PMN differential may be unreliable in the setting of a failed metal-on-metal bearing or corrosion reaction[54]. Traumatic aspirations should also be corrected to determine the true level of synovial cells in bloody joint fluid by using a validated formula that adjusts for synovial red blood cell (RBC), serum RBC, and serum WBC counts[55]. Also, as with other routine tests, the diagnostic utility of the synovial fluid WBC count and PMN % can be negatively impacted by prior antibiotic dosage[56].

Leukocyte esterase test

Leukocyte esterase (LE) is an enzyme produced by activated neutrophils at the site of infection. The reasons for its widespread usage and inclusion within the standard PJI diagnostic algorithm is that it can be measured quickly and easily with a colorimetric strip (urinalysis dipstick), provide immediate results, and is inexpensive[57]. The LE test has a sensitivity of 81% and specificity of 97%[58].

One disadvantage of the LE test is the potential for blood in the aspirant to compromise the color change of the test strip[59]. To prevent this, it is recommended that the aspirant be centrifuged for at least 2 min[60]. When this protocol is followed, LE has been shown to be an effective diagnostic tool for PJI. However, the difficulty in aspirating sufficient uncompromised fluid from a TMJR articulation makes utilization of this test or its results questionable.

Intraoperative cultures, duration of incubation, and number of samples

While cultures have historically been used as a standard reference for the identification of PJI pathogens, there are several limitations to their use, and it has been reported that up to 30% of patients with a PJI are culture-negative[61,62]. The current literature suggests that prophylactic antibiotics should be withheld only in cases of PJI where the infecting organism has yet to be identified. A prospective, randomized study demonstrated that prophylactic preoperative antibiotics do not decrease the sensitivity of traditional intraoperative cultures[63].

A consensus suggests that at least three, but not more than six, intraoperative samples should be sent for culture[64]. Further, it is recommended that to achieve the best results from traditional cultures, they should be incubated for a minimum of 5–14 days, with a longer duration of >14 days considered in cases of suspected culture-negative PJI or where slow-growing and fastidious organisms such as *P. acnes* are suspected[53,61].

The existence of two positive cultures is considered to be diagnostic for PJI, since a single positive culture is a possible consequence of a contaminating organism[65]. Culture results are not only helpful for the detection of PJI, but also for the selection of appropriate antimicrobials effective in the management of PJI.

Emerging diagnostic tests

Interleukin 6

Interleukin 6 (IL-6) is a cytokine produced as part of the inflammatory response by activated monocytes and macrophages. Serum levels have been shown to rise to 30–340 pg/ml in infection, trauma, and the postoperative setting[66]. There is also robust evidence that C-reactive protein (CRP) is a strong rule-in and rule-out marker for patients with suspected SSI[12]. However, IL-6 lies upstream of CRP markers, therefore it may be a more rapid and more sensitive responding marker for the detection of PJI[67].

Two meta-analyses have demonstrated the diagnostic potential of IL-6 in the context of PJI. IL-6 was found to have a higher diagnostic odds ratio than CRP, and synovial fluid IL-6 was shown to have a higher diagnostic value for PJI than the serum CRP test[67,68].

While IL-6 has shown significant promise for the early detection of PJI, it is not currently being used widely in the clinical setting, nor has it found a place in the current diagnostic guidelines due to the variability and lack of consistency in the results[69]. Therefore, further investigations are required to validate routine use and the costs associated with IL-6 testing.

Alpha-defensin

Alpha-defensin is a naturally occurring antimicrobial peptide released from activated neutrophils as part of the innate immune response to pathogens[70]. Its

mechanism of action is its effect on the permeability of the microorganism cell membrane[71]. It has been shown to rise in response to low virulence organisms and is unaffected by prior antibiotic administration[72]. Unlike LE, alpha-defensin testing is very expensive. However, it has proven to be highly accurate for the early detection and diagnosis of PJI[73]. A meta-analysis demonstrated excellent sensitivity of 100% with specificity of 96% in the diagnosis of PJI[74].

ALTR secondary to a failed metal-on-metal bearing or corrosion may confound the interpretation of alpha-defensin results, as it does with the synovial fluid WBC count[54]. A multicenter cohort study of patients with an ALTR who underwent alpha-defensin testing revealed that 31% had a false-positive alpha-defensin result, but were otherwise negative per the MSIS criteria for the diagnosis of PJI[75].

Serum D-dimer

D-dimer is a fibrin degradation product released into the blood following fibrin clot breakdown by plasmin. D-dimer is a non-specific serum marker that aids in the screening for venous thromboembolism and has recently shown promise as a biomarker for the diagnosis of PJI, as well as the timing of reimplantation[76].

D-dimer has a more rapid rise and fall in the early joint replacement postoperative period than either CRP or the serum erythrocyte sedimentation rate (ESR), and there is limited strength evidence that does not support the use of ESR alone to rule in or rule out SSI due to conflicting data[12]. Lee et al. showed that in contrast to serum CRP and ESR, which remained elevated until postoperative day 5 and day 3, respectively, D-dimer levels generally decreased to baseline levels on postoperative day 2, before reaching a second peak in postoperative week 2[77].

In a prospective study of primary and revision arthroplasty patients, serum D-dimer outperformed both ESR and serum CRP, with a sensitivity of 89.5% and specificity of 92.8%. A threshold of 850 ng/ml was calculated to be the optimal cut-off value of serum D-dimer for the diagnosis of PJI in that study[76].

Measurement of serum D-dimer is a widely available and accessible test that may be an effective screening tool for the early detection of PJI. However, further validation is required to reproduce and confirm the relative test performance of D-dimer versus other more established serum markers[78].

Next-generation sequencing

While microbiological culture remains the 'gold standard' for pathogen identification in PJI, molecular technologies such as next-generation sequencing (NGS) are becoming feasible in the clinical setting. The American Academy of Microbiology cited NGS as having the potential to significantly revolutionize clinical microbiology by ''replacing current time-consuming and labor-intensive techniques with a single, all-inclusive diagnostic test''[79].

NGS refers to a collection of non-Sanger-based high-throughput DNA sequencing methods that can produce data in vastly larger amounts, at greatly lower cost, in a shorter time, and with less manual intervention than previous methods[79]. Unlike methods based upon polymerase chain reaction (PCR), NGS can be used in 'open' mode, which does not rely on a set of parameters or a panel of PCR primer targets. It is therefore capable of characterizing all microbial DNA present within a given clinical sample and providing a complete picture of the microbial profile without the need for preconceived ideas of the possible responsible pathogen. NGS searches all known microbial databases for a match—including bacteria, viruses, yeast, fungi, and parasites—without the need for additional individual testing. NGS also has the potential to suggest antimicrobial resistance through the identification of known resistance genes[80].

In a recently published report, NGS was useful for pathogen detection in 81.8% of culture-negative PJIs where intraoperative tissue samples were analyzed[81]. In a series of 86 synovial fluid samples, high concordance with microbiological culture was seen with NGS of synovial fluid alone[82].

Shotgun metagenomic sequencing has also shown recent promise in sonicate fluid samples, with a 43.9% detection rate of potential pathogens in culture-negative PJI[83] and species-level sensitivity of 88%[84].

However, there remain significant issues with host DNA contamination and the overall cost of this methodology. Ultimately, multicenter clinical studies and clinical trials examining patient outcomes will be necessary to validate and reinforce the benefits as well as cost savings of using NGS-based tests for the diagnosis of PJI and targeting antimicrobial treatment[58].

Postoperative considerations

Antibiotic coverage in the immediate post-implantation period

The 2016 updated SSI guidelines of the American College of Surgeons and Surgical Infection Society state that there is no evidence that prophylactic antibiotic administration after incision closure decreases the risk of SSI, hence prophylactic antibiotics should be discontinued at the time of incision closure; however, exceptions to this include joint replacement[8]. The oral and maxillofacial surgery literature recommends 7–10 days of oral post-TMJR antibiotic prophylaxis due to the proximity of the surgical wounds to potential contamination from the ear, parotid, and oral cavity[5–7].

Antibiotic prophylaxis prior to invasive dental, genitourinary, gastrointestinal, and aerodigestive procedures

In 2014, a panel of experts was convened by the American Dental Association Council on Scientific Affairs and developed an evidence-based clinical practice guideline for the use of prophylactic antibiotics in patients with prosthetic joints undergoing dental procedures. The panel made the following clinical recommendation: ''In general, for patients with prosthetic joint implants, prophylactic antibiotics are not recommended prior to dental procedures to prevent prosthetic joint infection. The practitioner and patient should consider possible clinical circumstances that may suggest the presence of a significant medical risk in providing dental care without antibiotic prophylaxis, as well as the known risks of frequent or widespread antibiotic use. As part of the evidence-based approach to care, this clinical recommendation should be integrated with the practitioner's professional judgment and the patient's needs and preferences.''[85]

Postoperative prophylaxis after orthopedic joint replacement and before invasive dental, urologic, gastrointestinal, and aerodigestive procedures, although questioned in published studies[86–88], might be important in TMJ TJR, because the tips of the condylar component ramus fixation screws lie in the pterygomandibular space where they could be contaminated during inferior alveolar nerve anesthesia administration techniques[5]. Therefore, TMJR surgeons should consider the use of prophylactic antibiotics for patients undergoing inferior alveolar nerve blocks.

In conclusion, this article presents an updated overview of the recent validated, evidence-based criteria for preventing and detecting SSI and PJI published in the surgical and orthopedic literature. However, despite extensive research, the detection of TMJR PJI remains uncertain in many cases. These patients may benefit

from the use of emerging biomarkers or novel techniques such as NGS. Further research is needed into obtaining appropriate synovial fluid from presumed TMJR PJI cases in order to use and correlate the results of these new tests with patient outcomes and to justify their clinical use and expense.

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Ethical approval

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Patient consent

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References

1. Kurtz SM, Lau E, Schmier J, Ong KL, Zhao K, Parvizi J. Infection burden for hip and knee arthroplasty in the United States. *J Arthroplasty* 2008;**23**:984–91.
2. Onoriobe U, Miloro M, Sukotjo C, Mercuri LG, Lotesto A, Eke R. How many temporomandibular joint total joint replacements will be performed in the United States by 2030? *J Oral Maxillofac Surg* 2016;**74**:1531–8.
3. Kurtz SM, Ong KL, Lau E, Bozic KJ, Berry D, Parvizi J. Prosthetic joint infection risk after TKA in the medicare population. *Clin Orthop Relat Res* 2010;**468**:52–6.
4. Kurtz SM, Lau E, Watson H, Schmier JK, Parvizi J. Economic burden of periprosthetic joint infection in the United States. *J Arthroplasty* 2012;**27**(Suppl). 61–65.e1.
5. Mercuri LG, Psutka D. Peri-operative, post-operative and prophylactic use of antibiotics in alloplastic total temporomandibular joint replacement surgery: a survey and preliminary guidelines. *J Oral Maxillofac Surg* 2011;**69**:2106–11.
6. Mercuri LG. Avoiding and managing temporomandibular joint total joint replacement surgical site infections. *J Oral Maxillofac Surg* 2012;**70**:2280–9.
7. Mercuri LG. Complications associated with TMJ TJR: management and prevention. In: Mercuri LG, editor. *Temporomandibular joint total joint replacement—TMJ TJR—a comprehensive reference for researchers, material scientists and surgeons*. New York: Springer International Publishing; 2016 . p. 187.
8. Ban KA, Minei JP, Laronga C, Harbrecht BG, Jensen EH, Fry DE, Itani KM, Dellinger EP, Ko CY, Duane TM. American College of Surgeons and Surgical Infection Society: surgical site infection guidelines, 2016 update. *J Am Coll Surg* 2017;**224**:59–73.
9. Berríos-Torres SI, Umscheid CA, Bratzler DW, Leas B, Stone EC, Kelz RR, Reinke CE, Morgan S, Solomkin JS, Mazuski JE, Dellinger EP, Itani KMF, Berbari EF, Segreti J, Parvizi J, Blanchard J, Allen G, Kluytmans JAJW, Donlan R, Schecter WP, Healthcare Infection Control Practices Advisory Committee. Centers for Disease Control and Prevention guidelines for the prevention of surgical site infection. *JAMA Surg* 2017;**152**:784–91.
10. O'Hara LM, Thom KA, Preas MA. Commentary on update to the Centers for Disease Control and Prevention and the Healthcare Infection Control Practices Advisory Committee guideline for the prevention of surgical site infection (2017): a summary, review, and strategies for implementation. *Am J Infect Control* 2018;**46**:602–9.
11. Perry KI, Hanssen AD. Orthopaedic infection: prevention and diagnosis. *J Am Acad Orthop Surg* 2017;**25**(Suppl 1):S4–6.
12. Lundy D, McLaren A, Sturm PF, Reddy S, Stacy GS, Lee G-C, Basmajian H, Fleeter T, Schoenfeld A, Schoenfeld A, Anderson P, Nelson SB, Chillag K, Cassidy C, Shaffer WO, Cummins D, Murray J, Schulte D, Mohiuddin M, DeMars M, Sevarino K, Shores P, Woznica A. *Systematic literature review on the management of surgical site infections. Adopted by the American Academy of Orthopaedic Surgeons Board of Directors June 9, 2018*. Rosemont, IL: AAOS; 2018.
13. Kamal T, Conway RM, Littlejohn I, Ricketts D. The role of a multidisciplinary pre-assessment clinic in reducing mortality after complex orthopaedic surgery. *Ann R Coll Surg Engl* 2011;**93**:149–51.
14. Tan TL, Maltenfort MG, Chen AF, Shahi A, Higuera CA, Siqueira M, Parvizi J. Development and evaluation of a preoperative risk calculator for periprosthetic joint infection following total joint arthroplasty. *J Bone Joint Surg Am* 2018;**100**:777–85.
15. Schweizer M, Perencevich E, McDanel J, Carson J, Formanek M, Hafner J, Braun B, Herwaldt L. Effectiveness of a bundled intervention of decolonization and prophylaxis to decrease Gram positive surgical site infections after cardiac or orthopedic surgery: systematic review and meta-analysis. *BMJ* 2013;**346**. f2743.
16. Chen AF, Wessel CB, Rao N. *Staphylococcus aureus* screening and decolonization in orthopaedic surgery and reduction of surgical site infections. *Clin Orthop Relat Res* 2013;**471**:2383–99.
17. Bryce E, Wong T, Forrester L, Masri B, Jeske D, Barr K, Errico S, Roscoe D. Nasal photodisinfection and chlorhexidine wipes decrease surgical site infections: a historical control study and propensity analysis. *J Hosp Infect* 2014;**88**:89–95.
18. Fogelberg EV, Zitzmann EK, Stinchfield FE. Prophylactic penicillin in orthopaedic surgery. *J Bone Joint Surg Am* 1970;**52**:95–8.
19. Pavel A, Smith RL, Ballard A, Larsen IJ. Prophylactic antibiotics in clean orthopaedic surgery. *J Bone Joint Surg Am* 1974;**56**:777–82.
20. Meehan J, Jamali AA, Nguyen H. Prophylactic antibiotics in hip and knee arthroplasty. *J Bone Joint Surg Am* 2009;**91**:2480–90.
21. Mauerhan DR, Nelson CL, Smith DL, Fitzgerald Jr RH, Slama TG, Petty RW, Jones RE, Evans RP. Prophylaxis against infection in total joint arthroplasty. One day of cefuroxime compared with three days of cefazolin. *J Bone Joint Surg Am* 1994;**76**:39–45.
22. Rezapoor M, Parvizi J. Prevention of periprosthetic joint infection. *J Arthroplasty* 2015;**30**:902–7.
23. Gallo J, Holinka M, Moucha CS. Antibacterial surface treatment for orthopaedic implants. *Int J Mol Sci* 2014;**15**:13849–80.
24. Pan CJ, Dong YX, Zhang YY, Nie YD, Zhao CH, Wang YL. Enhancing the antibacterial activity of biomimetic HA coatings by incorporation of norvancomycin. *J Orthop Sci* 2011;**16**:105–13.
25. Gosau M, Haupt M, Thude S, Strowitzki M, Schminke B, Buergers R. Antimicrobial effect and biocompatibility of novel metallic nanocrystalline implant coatings. *J Biomed Mater Res B Appl Biomater* 2016;**104**:1571–9.
26. Norambuena GA, Patel R, Karau M, Wyles CC, Jannetto PJ, Bennet KE, Hanssen AD, Sierra RJ. Antibacterial and biocompatible titanium–copper oxide coating may be a potential strategy to reduce periprosthetic infection: an in vitro study. *Clin Orthop Relat Res* 2017;**475**:722–32.
27. Blom AW, Gozzard C, Heal J, Bowker K, Estela CM. Bacterial strike-through of reusable surgical drapes: the effect of different wetting agents. *J Hosp Infect* 2002;**52**:52–5.
28. Blom A, Estela C, Bowker K, MacGowan A, Hardy JR. The passage of bacteria through surgical drapes. *Ann R Coll Surg Engl* 2000;**82**:405–7.
29. Webster J, Alghamdi AA. Use of plastic adhesive drapes during surgery for preventing surgical site infection. *Cochrane Database Syst Rev* 2007;**4**:CD006353.
30. Tanner J, Parkinson H. Double gloving to reduce surgical cross-infection. *Cochrane Database Syst Rev* 2002;**3**:CD003087.
31. Carter AH, Casper DS, Parvizi J, Austin MS. A prospective analysis of glove perforation in primary and revision total hip and total knee arthroplasty. *J Arthroplasty* 2012;**27**:1271–5.
32. Demircay E, Unay K, Bilgili MG, Alataca G. Glove perforation in hip and knee arthroplasty. *J Orthop Sci* 2010;**15**:790–4.
33. Smith EB, Wynne R, Joshi A, Liu H, Good RP. Is it time to include vancomycin for routine perioperative antibiotic prophylaxis

in total joint arthroplasty patients? *J Arthroplasty* 2012;**27**:55–60.
34. Koval KJ, Rosenberg AD, Zuckerman JD, Aharonoff GB, Skovron ML, Bernstein RL, Su E, Chakka M. Does blood transfusion increase the risk of infection after hip fracture? *J Orthop Trauma* 1997;**11**:260–5.
35. Innerhofer P, Klingler A, Klimmer C, Fries D, Nussbaumer W. Risk for postoperative infection after transfusion of white blood cell-filtered allogeneic or autologous blood components in orthopedic patients undergoing primary arthroplasty. *Transfusion* 2005;**45**:103–10.
36. Alshryda S, Sarda P, Sukeik M, Nargol A, Blenkinsopp J, Mason JM. Tranexamic acid in total knee replacement: a systematic review and meta-analysis. *J Bone Joint Surg Br* 2011;**93**:1577–85.
37. Yang ZG, Chen WP, Wu LD. Effectiveness and safety of tranexamic acid in reducing blood loss in total knee arthroplasty: a meta-analysis. *J Bone Joint Surg Am* 2012;**94**:1153–9.
38. Gastmeier P, Breier AC, Brandt C. Influence of laminar airflow on prosthetic joint infections: a systematic review. *J Hosp Infect* 2012;**81**:73–8.
39. Sehulster L, Chinn RY. Guidelines for environmental infection control in health-care facilities. Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC). *MMWR Recomm Rep* 2003;**52**:1–42.
40. Andersson AE, Bergh I, Karlsson J, Eriksson BI, Nilsson K. Traffic flow in the operating room: an explorative and descriptive study on air quality during orthopedic trauma implant surgery. *Am J Infect Control* 2012;**40**:750–5.
41. Young RS, O'Regan DJ. Cardiac surgical theatre traffic: time for traffic calming measures? *Interact Cardiovasc Thorac Surg* 2010;**10**:526–9.
42. Givissis P, Karataglis D, Antonarakos P, Symeonidis PD, Christodoulou A. Suction during orthopaedic surgery. How safe is the suction tip? *Acta Orthop Belg* 2008;**74**:531–3.
43. Davis N, Curry A, Gambhir AK, Panigrahi H, Walker CR, Wilkins EG, Worsley MA, Kay PR. Intraoperative bacterial contamination in operations for joint replacement. *J Bone Joint Surg Br* 1999;**81**:886–9.
44. Beldame J, Lagrave B, Lievain L, Lefebvre B, Frebourg N, Dujardin F. Surgical glove bacterial contamination and perforation during total hip arthroplasty implantation: when gloves should be changed. *Orthop Traumatol Surg Res* 2012;**98**:432–40.
45. Ong KL, Lau E, Manley M, Kurtz SM. Effect of procedure duration on total hip arthroplasty and total knee arthroplasty survivorship in the United States Medicare population. *J Arthroplasty* 2008;**23**:127–32.
46. Urquhart DM, Hanna FS, Brennan SL, Wluka AE, Leder K, Cameron PA, Graves SE, Cicuttini FM. Incidence and risk factors for deep surgical site infection after primary total hip arthroplasty: a systematic review. *J Arthroplasty* 2010;**25**:1216–22.
47. Muilwijk J, van den Hof S, Wille JC. Associations between surgical site infection risk and hospital operation volume and surgeon operation volume among hospitals in the Dutch nosocomial infection surveillance network. *Infect Control Hosp Epidemiol* 2007;**28**:557–63.
48. Ravi B, Jenkinson R, Austin PC, Croxford R, Wasserstein D, Escott B, Paterson JM, Kreder H, Hawker GA. Relation between surgeon volume and risk of complications after total hip arthroplasty: propensity score matched cohort study. *BMJ* 2014;**348**:g3284. http://dx.doi.org/10.1136/bmj.g3284.
49. Deirmengian C, Kardos K, Kilmartin P, Cameron A, Schiller K, Parvizi J. Diagnosing periprosthetic joint infection: has the era of the biomarker arrived? *Clin Orthop Relat Res* 2014;**472**:3254–62.
50. Mercuri LG. Temporomandibular joint replacement periprosthetic joint infections: a review of early diagnostic testing options. *Int J Oral Maxillofac Surg* 2014;**43**:1236–42.
51. Parvizi J, Tan TL, Goswami K, Higuera C, Della Valle C, Chen AF, Shohat N. The 2018 definition of periprosthetic hip and knee infection: an evidence-based and validated criteria. *J Arthroplasty* 2018;**33**. 1309–1314.e2.
52. Shanmugasundaram S, Ricciardi BF, Briggs TW, Sussmann PS, Bostrom MP. Evaluation and management of periprosthetic joint infection—an international, multicenter study. *HSS J* 2014;**10**:36–44.
53. Khader R, Tingey J, Sewall S. Temporomandibular prosthetic joint infections associated with *Propionibacterium acnes*: a case series, and a review of the literature. *J Oral Maxillofac Surg* 2017;**75**:2512–20.
54. Kwon Y-M, Antoci V, Leone WA, Tsai TY, Dimitriou D, Liow MH. Utility of serum inflammatory and synovial fluid counts in the diagnosis of infection in taper corrosion of dual taper modular stems. *J Arthroplasty* 2016;**31**:1997–2003.
55. Yi PH, Cross MB, Moric M, Levine BR, Sporer SM, Paprosky WG, Jacobs JJ, Della Valle CJ. Do serologic and synovial tests help diagnose infection in revision hip arthroplasty with metal-on-metal bearings or corrosion. *Clin Orthop* 2015;**473**:498–505.
56. Shahi A, Deirmengian C, Higuera C, Chen A, Restrepo C, Zmistowski B, Parvizi J. Premature therapeutic antimicrobial treatments can compromise the diagnosis of late periprosthetic joint infection. *Clin Orthop* 2015;**473**:2244–9.
57. Parvizi J, Jacovides C, Antoci V, Ghanem E. Diagnosis of periprosthetic joint infection: the utility of a simple yet unappreciated enzyme. *J Bone Joint Surg Am* 2011;**93**:2242–8.
58. Goswami K, Parvizi J, Maxwell Courtney P. Current recommendations for the diagnosis of acute and chronic PJI for hip and knee-cell counts, alpha-defensin, leukocyte esterase, next-generation sequencing. *Curr Rev Musculoskelet Med* 2018;**11**:428–38. http://dx.doi.org/10.1007/s12178-018-9513-0.
59. Wetters NG, Berend KR, Lombardi AV, Morris MJ, Tucker TL, Della Valle CJ. Leukocyte esterase reagent strips for the rapid diagnosis of periprosthetic joint infection. *J Arthroplasty* 2012;**27**:8–11.
60. Aggarwal VK, Tischler E, Ghanem E, Parvizi J. Leukocyte esterase from synovial fluid aspirate: a technical note. *J Arthroplasty* 2013;**28**:193–5.
61. Parvizi J, Erkocak OF, Della Valle CJ. Culture-negative periprosthetic joint infection. *J Bone Joint Surg Am* 2014;**96**:430–6.
62. McLawhorn AS, Nawabi DH, Ranawat AS. Management of resistant, atypical and culture-negative periprosthetic joint infections after hip and knee arthroplasty. *Open Orthop J* 2016;**10**:615–32.
63. Burnett RSJ, Aggarwal A, Givens SA, McClure JT, Morgan PM, Barrack RL. Prophylactic antibiotics do not affect cultures in the treatment of an infected TKA: a prospective trial. *Clin Orthop* 2010;**468**:127–34.
64. Atkins BL, Athanasou N, Deeks JJ, Crook DW, Simpson H, Peto TE, McLardy-Smith P, Berendt AR. Prospective evaluation of criteria for microbiological diagnosis of prosthetic-joint infection at revision arthroplasty. The OSIRIS Collaborative Study Group. *J Clin Microbiol* 1998;**36**:2932–9.
65. Proceedings of the International Consensus Meeting on Periprosthetic Joint Infection. Foreword. *J Orthop Res* 2014;**32**(Suppl 1):S2–3.
66. Song M, Kellum JA. Interleukin-6. *Crit Care Med* 2005;**33**:S463–5.
67. Xie K, Dai K, Qu X, Yan M. Serum and synovial fluid interleukin-6 for the diagnosis of periprosthetic joint infection. *Sci Rep* 2017;**7**:1496.
68. Berbari E, Mabry T, Tsaras G, Spangehl M, Erwin PJ, Murad MH, Steckelberg J, Osmon D. Inflammatory blood laboratory levels as markers of prosthetic joint infection: a systematic review and meta-analysis. *J Bone Joint Surg Am* 2010;**92**:2102–9.
69. Ettinger M, Calliess T, Kielstein JT, Sibai J, Brückner T, Lichtinghagen R, Windhagen H, Lukasz A. Circulating biomarkers for discrimination between aseptic joint failure, low-grade infection, and high-grade septic failure. *Clin Infect Dis* 2015;**61**:332–41.
70. Ganz T. Defensins antimicrobial peptides of innate immunity. *Nat Rev Immunol* 2003;**3**:710–20.
71. Lehrer RI, Barton A, Daher KA, Harwig SS, Ganz T, Selsted ME. Interaction of human defensins with *Escherichia coli*. Mechanism of bactericidal activity. *J Clin Invest* 1989;**84**:553–61.
72. Deirmengian C, Kardos K, Kilmartin P, Gulati S, Citrano P, Booth Jr RE. The alpha-defensin test for periprosthetic joint in-

fection responds to a wide spectrum of organisms. *Clin Orthop* 2015;**473**:2229–35.
73. Alvand A, Rezapoor M, Parvizi J. The role of biomarkers for the diagnosis of implant-related infections in orthopaedics and trauma. *Adv Exp Med Biol* 2017;**971**:69–79.
74. Wyatt MC, Beswick AD, Kunutsor SK, Wilson MJ, Whitehouse MR, Blom AW. The alpha-defensin immunoassay and leukocyte esterase colorimetric strip test for the diagnosis of periprosthetic infection: a systematic review and meta-analysis. *J Bone Joint Surg Am* 2016;**98**:992–1000.
75. Okroj KT, Calkins TE, Kayupov E, Kheir MM, Bingham JS, Beauchamp CP, Parvizi J, Della Valle CJ. The alpha-defensin test for diagnosing periprosthetic joint infection in the setting of an adverse local tissue reaction secondary to a failed metal-on-metal bearing or corrosion at the head–neck junction. *J Arthroplasty* 2018;**33**:1896–8.
76. Shahi A, Kheir MM, Tarabichi M, Hosseinzadeh HRS, Tan TL, Parvizi J. Serum D-dimer test is promising for the diagnosis of periprosthetic joint infection and timing of reimplantation. *J Bone Joint Surg Am* 2017;**99**:1419–27.
77. Lee YS, Koo K-H, Kim HJ, Tian S, Kim TY, Maltenfort MG, Chen AF. Synovial fluid biomarkers for the diagnosis of periprosthetic joint infection: a systematic review and meta-analysis. *J Bone Joint Surg Am* 2017;**99**:2077–84.
78. Saleh A, George J, Faour M, Klika AK, Higuera CA. Serum biomarkers in periprosthetic joint infections. *Bone Joint Res* 2018;**7**:85–93.
79. Goldberg B, Sichtig H, Geyer C, Ledeboer N, Weinstock GM. Making the leap from research laboratory to clinic: challenges and opportunities for next-generation sequencing in infectious disease diagnostics. *MBio* 2015;**6**. e01888-15.
80. Dunne WM, Westblade LF, Ford B. Next-generation and whole genome sequencing in the diagnostic clinical microbiology laboratory. *Eur J Clin Microbiol Infect Dis* 2012;**31**:1719–26.
81. Tarabichi M, Shohat N, Goswami K, Alvand A, Silibovsky R, Belden K, Parvizi J. Diagnosis of periprosthetic joint infection: the potential of next-generation sequencing. *J Bone Joint Surg Am* 2018;**100**:147–54.
82. Tarabichi M, Shohat N, Goswami K, Parvizi J. Can next generation sequencing play a role in detecting pathogens in synovial fluid? *Bone Joint J* 2018;**100-B**:127–33.
83. Thoendel M, Jeraldo P, Greenwood-Quaintance KE, Chia N, Abdel MP, Steckelberg JM, Osmon DR, Patel R. A possible novel prosthetic joint infection pathogen, *Mycoplasma salivarium*, identified by metagenomic shotgun sequencing. *Clin Infect Dis* 2017;**65**:332–5.
84. Street TL, Sanderson ND, Atkins BL, Brent AJ, Cole K, Foster D, McNally MA, Oakley S, Peto L, Taylor A, Peto TEA, Crook DW, Eyre DW. Molecular diagnosis of orthopaedic device infection direct from sonication fluid by metagenomic sequencing. *J Clin Microbiol* 2017;**55**:2334–47.
85. Sollecito TP, Abt E, Lockhart PB, Truelove E, Paumier TM, Tracy SL, Tampi M, Beltrán-Aguilar ED, Frantsve-Hawley J. The use of prophylactic antibiotics prior to dental procedures in patients with prosthetic joints: evidence-based clinical practice guideline for dental practitioners—a report of the American Dental Association Council on Scientific Affairs. *J Am Dent Assoc* 2015;**146**. 11–16.e8.
86. Berbari EF, Osmon DR, Carr A, Hanssen AD, Baddour LM, Greene D, Kupp LI, Baughan LW, Harmsen WS, Mandrekar JN, Therneau TM, Steckelberg JM, Virk A, Wilson WR. Dental procedures as risk factors for prosthetic hip or knee infections: a hospital-based prospective case–control study. *Clin Infect Dis* 2010;**50**:8–16.
87. Whal MJ. Myths of dental-induced prosthetic joint infections. *Clin Infect Dis* 1995;**20**:1420–5.
88. Marculescu CE, Osmon DR. Antibiotic prophylaxis in orthopedic prosthetic surgery. *Infect Dis Clin North Am* 2005;**19**:931–46.

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