PART IX

ELBOW

Section 1: Prevention

Section 2: Diagnosis

Section 3: Treatment

Prevention

Authors: Raul Barco Laakso, Samuel Antuña

QUESTION 1: What are the optimal prophylactic perioperative antibiotics for patients undergoing total elbow arthroplasty (TEA)?

RECOMMENDATION: Patients undergoing primary TEA should receive antibiotics that cover gram-positive and gram-negative organisms specific to the regionally encountered organisms. Peer-reviewed literature supports that cefazolin should be dosed based on body weight. Patients with methicillin-resistant *Staphylococcus aureus* (*S. aureus*) colonization should receive weight-based glycopeptide, preferably in combination with cefazolin. Patients with a true hypersensitivity reaction or adverse reaction that precludes the use of cefazolin should receive vancomycin or clindamycin.

LEVEL OF EVIDENCE: Consensus

DELEGATE VOTE: Agree: 100%, Disagree: 0%, Abstain: 0% (Unanimous, Strongest Consensus)

RATIONALE

A comprehensive literature search of three online databases (PubMed/Medline, Google Scholar and Embase) was performed using the following MeSH search terms: "elbow," "elbow joint," "joint prosthesis," "arthroplasty" and "replacement."

Because of the evolution of TEA techniques, only articles from the last 10 years were selected, published from January 2008 until January 2018. On the basis of the titles and abstracts, two reviewers independently identified potentially relevant articles for review of the full text. The reference lists of the included articles were manually checked to avoid missing relevant articles. When the full text was obtained, the authors independently selected articles. Studies were not blinded for author, affiliation or source.

Inclusion and Exclusion Criteria

The included articles presented original data on patients who had undergone TEA. The diagnoses included the following indications: osteoarthritis, trauma/fracture, post-traumatic osteoarthritis, rheumatoid arthritis, hemophilia and other inflammatory diseases. Studies with a minimum duration of follow-up of two years and a minimum of 10 patients were included. Studies on revision operations were not included. Articles presenting the results of both revision and primary TEA were excluded unless the information for primary TEA could be extracted. Articles presenting the results for interposition arthroplasties, fully-hinged prostheses, hemiarthroplasty or partial resurfacing of the elbow were excluded. Review articles, expert opinions and surgical technique articles were excluded. When possible, studies comparing different groups were analyzed separately. The search was restricted to articles written in English. Some articles that represented institutional historical databases were included only once.

Data Extraction

After the initial assessment for inclusion, two reviewers extracted data from the included articles. The primary goal was to determine the rate of infection after TEA and the pathogen responsible to determine which is potentially the best antibiotic regimen.

The following parameters were recorded when available: numbers of patients and elbows, design of TEA implant, indication for TEA (e.g., primary osteoarthritis, rheumatoid arthritis, fracture, post-traumatic osteoarthritis or other abnormality), whether the prosthesis was linked or unlinked, the rate of infection and the pathogen responsible for the infection (known/unknown, single/multibacterial). When prophylactic antibiotics were reported, they were recorded. No other attempt was made to extract other data regarding other complications.

Data and Statistical Analysis

Different groups were established on the basis of the preoperative regimen and the causative pathogen, when known. The outcome measures were the rate of infection and the distribution according to the pathogen. When sensitivity antibiotic analysis was performed, this information was also analyzed.

Methodological Quality

The two authors assigned the methodological quality of the included studies according to the Center for Evidence-Based Medicine [1].

RESULTS

Articles

After the removal of duplicate articles, our initial search yielded 227 articles from Medline, Embase and Google Scholar. After title and abstract evaluation, a list of 56 articles was created for full review. After full review, 35 studies were deemed suitable for further evaluation and data collection.

Five studies recorded different articles from an institutional database and a national arthroplasty registry, all being level IV evidence. There were no prospective case series or randomized, controlled trials. Two studies were disregarded as they offered duplicate information [2,3]. Data was extracted into a standard worksheet for further analysis.

Infection Rates and Pathogen Assessment

A total of 303 infections were recorded out of 6,681 patients, for a mean infection rate of 5.6%. Of these, 301 were considered by the authors to be a deep infection for an infection rate of 5.2%, with the other two corresponding to superficial infection.

A pathogen was identified in only five studies. It was not specified if the infection was mono- or polybacterial in all reported case

series. Large et al. reported four cases of deep infection. Two were positive for *Staphylococcus aureus*, one for *Staphylococcus epidermidis* (*S. epidermidis*) and one with no growing organism but a clinical diagnosis of infection [4]. Antuña et al. reported on the outcome of semiconstrained TEA after fracture of the distal humeral and observed 3 infections in 16 patients, 2 being positive for *S. epidermidis* and 1 having negative cultures [5].

Peden et al. reported on the outcome for TEA for an ankylosed or fused elbow, reporting 3 infections out of 13 cases. One occurred perioperatively and the other occurred at 2 and 15 years. Two cases were diagnosed with *Staphylococcus coagulase negative methicillin-resistant* and *S. aureus* [6]. Tachihara et al. reported on the outcome for TEA for rheumatoid arthritis and reported on three infections positive for *enterobacter*, *pseudomona* and *S. aureus*. In all of those cases, the infection was considered monobacterial [7].

Curiously, in a clinical series reporting on 20 elbows diagnosed with periprosthetic joint infection, Streubel et al. reported that 6 out of 21 infections were polymicrobial [8]. In that series, the most frequent pathogen was S. Coagulase-negative (13 patients) followed by *S. aureus* (9 patients) and *Corynebacterium* (3 patients). These patients were initially treated with vancomycin in 10 cases, cefazolin in 8, rifampin in 3 and ceftriaxone in 1 case [8]. This information is in accordance with other studies, although there is a risk of a partial duplicate patient population. In a group of 51 patients, Zarkadas et al. found 17 cases of *S. aureus*, 11 of *S. epidermidis*, 1 of *Serratia*, 1 of *Costiridium*, 1 of *Mycobacteria*, 1 of *C. acnes*, 10 multiorganism infections and 8 cases in which no bacteria was actually grown [9].

Although they are obviously universally used, only 4 of the 35 studies specified the use of prophylactic antibiotics. Of these, only 2 mentioned in their methods the type and dose of antibiotic (a first-generation and a second-generation cephalosporin prior to skin incision in both) [10,11]. Kodde et al. reported the use of 1 gm of intravenous cefazolin 30 minutes prior to skin incision and extended the use for 48 postoperative hour [10]. Lami et al. reported the use of systematic prophylactic antibiotic at induction using a second-generation cephalosporin with no further description. No other information regarding the duration of perioperative antibiotic therapy has been found.

Discussion

The available information is poor regarding infection as a complication after elbow replacement. Specific information on the pathogen, the type and dose of prophylactic antibiotic or the surgical prepping solutions used in cases complicated with an infection after elbow replacement are almost universally lacking in the analyzed studies. The reasons for this are unclear, but might be related to wording restrictions and focus on other aspects of research. Moreover, a definition of infection was not reported and different authors could have used different definitions.

Even though only four studies specified the use of prophylactic antibiotics, we assume these are universally used. Based on the scarce information found and our own clinical experience, first-generation cephalosporin seems to be the most widely used antibiotic. Other options could be used, based on allergies, intolerance or concomitant diseases. However, no sound conclusion can be extracted from literature on this regard.

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QUESTION 2: What is the evidence and recommendation for the use of antibiotic-laden bone cement (ALBC) in primary total elbow arthroplasty (TEA) or in revision TEA?

RECOMMENDATION: There is inadequate evidence to support the use of ALBC during primary or revision TEA.

LEVEL OF EVIDENCE: Consensus

DELEGATE VOTE: Agree: 96%, Disagree: 0%, Abstain: 4% (Unanimous, Strongest Consensus)

RATIONALE

The response to the question regarding the value of ALBC in a primary and revision setting of TEA requires an understanding of several issues:

1. The specific answer to these questions referable to the elbow cannot be directly answered from the available literature addressing the elbow. Very little information exists for the

elbow, regardless of the level of evidence [1].

2. The clinical features of elbow pathology by definition place all TEAs "at risk," including the underlying diagnosis (a systemic inflammatory disorder or failed intervention for a post-traumatic condition). Primary osteoarthritis is not an indication for TEA as it is effectively treated with debridement. TEA for primary arthrosis was only performed in 18 patients over a 20-year period at the Mayo Clinic, representing about a 2% incidence in our institution [2].
3. Even the less common inflammatory etiology is at particular risk due to the virtual universal management with the immunocompromising disease remitting agents.
4. The subcutaneous location of the joint with little or no muscle protection places it at risk for wound healing problems, which has been documented to increase the likelihood of infection [3,4].
5. The subcutaneous nature and the less robust osseous structure of the elbow increases the complication rate of revision for infection, especially compromising triceps function in more than 25% of patients. In other words, the management of infection by surgical means is poorly tolerated at the elbow (level 4 and 5 evidence) [4].
6. The above observations are supported by the documented infection rate of the primary TEA to be around 5% (3) compared to 1–2% associated with primary hip or knee replacement, but similar to the infection rate of the revision procedures on these joints [4,5].
7. Finally, all the higher-quality literature on the subject relates only to knee and hip replacement with the preponderance of data relating to the knee.

Methodology

The question was addressed in the context of the above and the current literature relating to hip and knee surgery, primarily over the last 10 years. A PubMed literature review was conducted exploring level 1 and 2 randomized control trials, meta-analyses and national registry data. As noted above, all such studies relate only to hip and knee replacement. This review prompted a need for more detail in some instances, followed by level 3 and 4 case series and reports being included.

RESULTS

Use of ALBC in the Primary Total Knee Arthroplasty

- Currently, no conclusive evidence exists regarding the efficacy of antibiotic-loaded cement at the knee in uncomplicated, non-risk patients [6–11].
- Currently, based on the highest-level studies, no recommendation can be made regarding the routine use of antibiotic-loaded cement in primary knee arthroplasty.
- The justification is further weakened by poor cost-effectiveness data for primary knee [12,13], yet primary hip replacement may be cost-effective [14].
- As noted above, this recommendation has no bearing on the question at hand, as by definition all primary TEAs occur in an at-risk population.
- Consensus does exist that ALBC should be used in patients with a high risk of infection (Obesity, body mass index > 35, diabetes mellitus, revision total joint arthroplasty, operative time > 150 minutes, rheumatoid arthritis, a prior history of periprosthetic joint infection, organ transplantation and hemophilia) [5,6,15].

Use of ALBC in Hip Replacement Surgery

- Evidence [16–18], and consensus [19,20] is strong indicating that ALBC does statistically lessen the likelihood of infection after a primary hip replacement, independent of the at-risk patient [21–23].
- Evidence also indicates that ALBC decreases the incidence of deep infections at the hip and at the knee [24] and in hemi-replacement of the hip after fracture [25].
- Therefore, should antibiotic-impregnated cement be used:
  - **A. For primary TEA? Yes, based on:**
    1. Strong evidence supporting its use in primary hip replacement
    2. Strong consensus for ALBC in the at-risk patient and the features of the elbow defining it as an at-risk joint

    Confidence: Extrapolated: moderate; subjective: strong. 100%.
  - **B. For revision TEA? Yes, based on:**
    1. Moderate evidence for effectiveness in revision knee and hip surgery [5,26]
    2. Infection rate of revision TEA exceeds hip and knee revision, as well as increased difficulty and complication rates when treating an infected TEA [27]

    Confidence: Strong. 100%.

Additional Questions to Consider

1. **Which antibiotics(s) should be used?**
   - For primary and revision, combination therapy is recommended (total of 2 gm/40 gm monomer).
   - An aminoglycide, either 1 gm/40 gm cement gentamycin or tobramycin (tobramycin is much more expensive) and 1 gm/40 gm vancomycin.
   - Target likely-offending organisms [6]. Over the last 15 years in 231 infected elbows treated at Mayo Clinic: Coag – Staph – 22%; Staph A. 14% (data generated for this review – JSS).
   - A single low-dose gentamycin cement (1 gm/40 gm cement) may actually select an increase in coag – infections [6].
2. **Which cement should be used?**
   Palacos has better elution properties, but this does not seem to matter clinically.
3. **Will bacterial resistance develop?**
   No evidence of this to date [28].
4. **Will the altered mechanical properties of the cement affect loosening rate**?
   No evidence of this to date.

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QUESTION 3: Does previous surgery (arthroscopic, fracture fixation, other non-arthroplasty) increase the risk of subsequent elbow periprosthetic joint infection (PJI) after total elbow arthroplasty (TEA)?

RECOMMENDATION: There is an apparent increase in the percentage of infections among patients with a previous operation in the affected elbow joint, though the association is not robust and needs to be further analyzed.

LEVEL OF EVIDENCE: Limited

DELEGATE VOTE: Agree: 100%, Disagree: 0%, Abstain: 0% (Unanimous, Strongest Consensus)

RATIONALE

A comprehensive literature search of three online databases (PubMed/Medline, the Cochrane database for clinical trials, and Embase) was performed using the following MeSH search terms: "elbow," "elbow joint," "joint prosthesis," "arthroplasty," "replacement," "elbow replacement," "elbow arthroplasty" and "elbow prosthesis."

Because of the evolution of TEA techniques, only articles published from January 2000 until September 2018 were reviewed. By the titles and abstracts, two reviewers independently identified potentially relevant articles for review of the full text. The reference lists of the included articles were manually checked to avoid missing relevant articles. When the entire text was obtained, the authors independently selected articles. Studies were not blinded for author, affiliation or source.

Inclusion and Exclusion Criteria

The included articles presented original data on patients who had undergone TEA. The diagnoses included the following indications: osteoarthritis, trauma/fracture, post-traumatic osteoarthritis, rheumatoid arthritis, hemophilia and other inflammatory diseases. Studies with a minimum duration of follow-up of two years and a minimum of five patients were included. Studies on revision operations were not included. Articles presenting the results of both revision and primary TEA were excluded unless the information for primary TEA could be extracted. Articles presenting the results for interposition arthroplasties, fully-hinged prostheses, hemiarthroplasty or partial resurfacing of the elbow were reviewed if they included information regarding the outcome of further treatment

with TEA with extractable outcome data. Review articles, expert opinions and surgical technique articles were excluded. When possible, studies comparing different groups were analyzed separately. The search was restricted to articles written in English, Spanish and French. Some articles that represent institutional historical databases were included only once.

Data Extraction

After the initial assessment for inclusion, two reviewers extracted data from the included articles. The primary goal was to determine the rate of infection after TEA and the pathogen responsible for determining the best potential antibiotic regimen.

The following parameters were recorded when available: numbers of patients and elbows, sex, age, design of TEA implant, indication for TEA (e.g., primary osteoarthritis, rheumatoid arthritis, fracture, post-traumatic osteoarthritis or other abnormality), whether the prosthesis was linked or unlinked, the rate of infection and the pathogen responsible. When prophylactic antibiotics were reported, they were recorded. Specific information regarding previous operations prior to arthroplasty was searched, as it was the focus of this review.

No other attempt was made to extract other data regarding other complications. Data regarding the number and type of surgical procedures before index TEA was collected and outcomes of these TEAs were extracted when available. Revision for infection was defined as removal of all or part of the arthroplasty or loosening that required removal regardless of the indication, or if a new TEA was implanted or excised.

Data and Statistical Analysis

Different groups were established by the preoperative regimen and the causative pathogen, when known. The outcome measures were the rate of infection and the distribution according to the pathogen. When sensitivity antibiotic analysis was performed, this information was also analyzed.

Methodological Quality

The two authors assigned the methodological quality of included studies according to the Center for Evidence-Based Medicine [1].

RESULTS

Articles

After the removal of duplicate articles, our initial search yielded 227 articles from Medline, Embase and Google Scholar. After title and abstract evaluation, a list of 56 articles was created for full review. After a full review, 35 studies were deemed suitable for further assessment and data collection.

There were no prospective case series and no randomized controlled trials. All were level IV evidence. Data were extracted into a standard worksheet for further analysis.

Prior procedures

Reporting of previous surgery before TEA was only available in six studies. Two hundred and one patients out of 291 (69%) were reported to have had prior surgery before TEA. The average rate of infection in these six studies was 11%, which is almost double to the reported rate of 5.5% in our concurrent systematic review (Table 1).

Kodde et al. reported on a series of 17 patients treated for post-traumatic arthritis with a cemented semi-constrained prosthesis, with a mean follow-up of 32 months. Fourteen patients had a prior operation consisting mainly in open reduction and internal fixation (nine cases, 64%), two patients had radial head resection, two had radial head prostheses implantation and one case had a medial epicondyle resection [2]. There was one case of infection (1%), but information is lacking regarding to which group it pertained. Additionally, the follow-up was short so that longer follow-up could increase the described rate of infection.

Baksi et al. reported on the use of a sloppy-hinge TEA for the treatment of fresh elbow fractures and non-unions. Eleven of the 41 cases reported had a previous failed internal fixation [3]. One of these patients suffered an infection that was treated with resection arthroplasty (1%) compared to one infection in 30 cases that did not undergo prior procedures (0.03%).

Throckmorton et al. reported on 84 patients with post-traumatic arthritis undergoing a semi-constrained TEA with a mean follow-up of nine years. The majority of this group of patients (90%) had prior surgery and the authors report seven deep infections without further information regarding the risk of preoperative surgery. The mean number of preoperative surgeries was three, so this group of patients may not be comparable to other studies [4].

Cil et al. reported the outcomes of a semi-constrained TEA for post-traumatic arthritis in 92 patients, of which 76 had previous surgery [5]. Of note, eight patients had a history of prior infection. At latest follow-up, five patients had an infection, all of which had had a previous operation. Interestingly, three of these patients had had a previous infection, so it is difficult to interpret if these were indeed a new episode or a reactivation of a latent infection.

Peden et al. reported on the outcome for TEA for an ankylosed or fused elbow, reporting 3 infections out of 13 cases [6]. One occurred perioperatively and the other happened at 2 and 15 years. Two of the three cases had previous surgery, but the type of surgery is not explicitly stated.

Sorbie et al. reported on a series of 44 unlinked TEA for hemophilic arthritis, rheumatoid arthritis or posttraumatic arthritis [7]. Sixteen patients had had a previous operation in the elbow and one of the seven infections occurred in a patient with post-traumatic arthritis and history of a previous operation. Once more, no reference to the number or type of previous operations was provided.

In a landmark paper, Morrey et al. reported on the outcome of 14 patients with an infection after TEA out of a group of 156 patients (9%) [8]. The rate of infection was 8 out of 99 patients without previous surgery compared to 6 out of 49 patients that had prior surgery (8% vs. 12.2%). This relationship was not statistically significant, alone. If only patients with previous surgery and rheumatoid arthritis were analyzed, the authors found a significant association, but the number of patients is so small that these findings should be interpreted with caution. Additionally, two of the patients with rheumatoid arthritis and prior surgery were on steroids.

The authors defined infection as deep sepsis that included different clinical and laboratory findings.

Conclusions

There is insufficient information regarding the influence of previous surgery on the incidence of infection after total elbow arthroplasty. Inadequate reporting regarding the number of procedures, the type of procedures and other patient-associated factors makes achieving definitive conclusions difficult. In a landmark paper, Morrey et al. highlighted the association of prior operation with the development of a periprosthetic joint infection after TEA. However, even though there is an apparent increase in the percentage of infections among patients with a previous operation, the association is not robust and needs to be further analyzed.

TABLE 1. Summary of information regarding the rate of infection after TEA when having prior surgery

Author, Year	Indication	Arthroplasty	Number of Cases	Number of Infections	% Infection	Number of Previous Surgeries	Additional Information
Kodde et al., 2013	PT	Coonrad-Morrey	17	1	5.8	14	None
Baksi et al., 2011	PT	Baksi sloppy hinge	41	2	4.9	11	1 infection in 11 PTs w/ prior surgery vs. 1/30 w/o prior surgery
Throckmorton et al., 2010	PT	Coonrad-Morrey	84	7	8.3	76	None
Sorbie et al., 2011	RhA/ PT/ Hemophilia	Sorbie	44	7	17%	16	1 infection with prior surgery (PT)/ 6 had infection immuno-suppression (RhA)
Peden et al., 2009	10 PT/ 3 RhA	Coonrad-Morrey	13	3	23%	8	2 of 3 infected had prior surgery
Cil et al., 2008	PT	Coonrad-Morrey	92	5	5.4	76	All 5 infections had prior surgery (3 had infection prior to index TEA)

PT, post-traumatic; RhA, rheumatoid arthritis; TEA, total elbow arthroplasty

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Diagnosis

Authors: Ilya Voloshin, Theodore Blaine

QUESTION 1: Is there a role for preoperative joint aspiration in the evaluation of the painful elbow arthroplasty for periprosthetic joint infection (PJI)?

RECOMMENDATION: Preoperative joint aspiration can play a role in the evaluation of the painful total elbow arthroplasty (TEA) suspected for infection.

LEVEL OF EVIDENCE: Limited

DELEGATE VOTE: Agree: 100%, Disagree: 0%, Abstain: 0% (Unanimous, Strongest Consensus)

RATIONALE

In a patient with painful TEA and the presence of prosthetic loosening on the radiographs, PJI is high on the list of differential diagnosis. PJI remains one of the major failure modes for TEA. Joint aspiration has not been evaluated at length as a diagnostic test in TEA, with only a few studies examining its role and usefulness in the identification of infection of the joint [1–3]. Although joint aspiration has not been specifically evaluated as a diagnostic test in TEA, the value of this diagnostic approach has been proven in the workup of patients with hip and knee arthroplasty [4].

Gille et al. reported that in five of six infected elbows, positive joint aspiration cultures were found, and cultures of the sixth elbow, which had previously been treated with antibiotics, tested positive for infection at the time of revision [2]. There is little data on the role of joint aspiration in evaluating infection in TEA, however, it has been shown to be useful in identifying patients with PJI in hip and knee arthroplasty patients [4].

When aspirated, the obtained synovial fluid should be sent for white blood cell (WBC) count, with particular attention to the differential (% polymorphonuclear neutrophils). In addition, the fluid should be sent for aerobic and anaerobic cultures. Elevated synovial fluid WBC count is highly suggestive of PJI [5]. The hip and knee arthroplasty literature demonstrated excellent sensitivity and specificity of synovial WBC for the diagnosis of chronic PJI [6–11]. Based on that literature, the proceedings of the International Consensus on PJI recommends the following thresholds for synovial fluid tests for chronic PJI: WBC > 3,000 cell/microL and % PMN of 80% [12]. For acute PJI, the recommended thresholds are the following: WBC > 10,000 cell/microL and % PMN of 90% [12].

Gram stains lack sensitivity and specificity, and are not routinely recommended [13]. Cultures remain the most effective method for specific organism identification. However, despite a high specificity, culture has poor sensitivity and a negative culture does not rule out the diagnosis of PJI [14–18]. For isolation of the infecting organism, aerobic and anaerobic cultures of the obtained samples should be performed [19,20]. The addition of Acid-Fast Bacilli (AFB) and fungal cultures can also be considered in patients with atypical infection and a possibility for these infections. Additionally, incubating cultures for a longer period (21 days) may assist in identifying fastidious, slow-growing organisms such as *Cutibacterium acnes* [21].

Despite the lack of adequate studies in the TEA literature, and borrowing from the hip and knee arthroplasty, we recommend that aspiration of elbow joint suspected of infection should be part of the diagnostic work up. The synovial fluid obtained should be sent for routine culture (which may need to be kept for 14-21 days), WBC count, determination of neutrophil percentage and possibly molecular analyses for identification of the infective organisms.

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QUESTION 2: What is the role for serum erythrocyte sedimentation rate (ESR), C-reactive protein (CRP) or white blood cell (WBC) count in the evaluation of an elbow arthroplasty for periprosthetic joint infection (PJI)?

RECOMMENDATION: ESR, CRP and WBC play a role in screening and monitoring for PJI, though evidence is limited regarding specific thresholds and strategies to guide the surgeon when interpreting these values.

LEVEL OF EVIDENCE: Consensus

DELEGATE VOTE: Agree: 95%, Disagree: 0%, Abstain: 5% (Unanimous, Strongest Consensus)

RATIONALE

When in the evaluation stage of a suspected PJI, these laboratory markers are often combined with the clinical findings and joint aspiration to increase confidence of PJI [1–9]. In isolation, ESR and CRP may be difficult to interpret, especially in the setting of a medically complex patient with underlying conditions such as rheumatoid arthritis or with atypical infectious organisms such as fungi [2,3]. In monitoring for resolution of an infection after initial explantation, these laboratory markers are utilized again in concert with clinical factors, and it is important to trend these over time [5]. If the values have not normalized at the time of subsequent surgery with plans to reimplant, a repeat debridement and washout is advised along with the trending of values over time.

Despite the lack of multiple randomized clinical trials reflecting the utility of ESR, CRP and WBC measurement and monitoring in the patient with PJI of the elbow, several retrospective studies demonstrate the usefulness of integrating these values into the treatment plan. Also, the importance of these markers has been incorporated into the recommendations of the American Academy of Orthopaedic Surgeons for the treatment of PJI in the hip and knee [7,10]. This recommendation is rated as "limited" due to the lack of large, high-quality studies addressing PJI in the elbow specifically, rather than adapting already-published data from other joints, though these results are useful as they may be extrapolated to the management of elbow PJI.

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QUESTION 3: What is the role of intraoperative histology examination in the evaluation of an elbow arthroplasty for periprosthetic joint infection (PJI)?

RECOMMENDATION: Intraoperative histology for the evaluation of elbow PJI in isolation is not sufficient for the diagnosis of infection.

LEVEL OF EVIDENCE: Limited

DELEGATE VOTE: Agree: 92%, Disagree: 4%, Abstain: 4% (Super Majority, Strong Consensus)

RATIONALE

There are a number of studies related to the use of histologic examination for the diagnosis of PJI in hip and knee arthroplasty [1–4]. The available literature suggests that although histology cannot be used as a standalone test for the diagnosis of PJI, it does provide valuable information in the work-up of patients with suspected PJI (in fact, the MusculoSkeletal Infection Society (MSIS) workgroup included histological examination as a criterion for its diagnosis) [5,6]. The controversy that exists is what constitutes a positive histology [4]. Currently, based on the MSIS criteria, the presence of more than five neutrophils in more than five high-power fields is indicative of positive histology. The latter is based on examination of periarticular tissues for the diagnosis of infection and the role of histology during reimplantation to assess the presence of persistence infection is less well studied.

The role of histology in the workup of patients with painful total elbow arthroplasty (TEA) is less well known. Our extensive search of the literature revealed only one study that specifically examines the subject of histology in the diagnosis of infected TEA [7]. This study was a retrospective analysis of 208 patients undergoing revision TEA. The sensitivity of histology in the diagnosis of PJI was 51.3%, with a specificity of 93.1%. The positive predictive value of histological examination was 60.6% with a negative predictive value of 90.2%.

Among the cohort, 65 (31%) did not have either histology or cultures taken at the time of revision, which raises the question of selection bias. The sampling sites of the histologic specimens were not standardized and were performed at the discretion of surgeon, averaging less than two samples per patient. Finally, the gold standard to define infection was the presence of a single positive intraoperative culture. Within these limitations, the data suggests that when intraoperative histology demonstrates acute inflammation (according to the criteria of Mirra et al. [8]) the probability of infection is high, but the absence of the acute inflammation does not rule out infection.

Based on the literature (mostly from hip and knee arthroplasty) and our understanding of the challenges that exist in the work-up of patients with painful TEA, we recommend that histological examination of tissues from around the elbow be part of the workup of patients undergoing revision TEA.

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Authors: Michael McKee, Graham King

QUESTION 4: Is there a role for sonication of retrieved implants from an elbow in the diagnosis of a possible periprosthetic joint infection (PJI)?

RECOMMENDATION: At present, there is no evidence to support the routine use of sonication of removed elbow implants to improve the diagnostic accuracy or yield of cultures in the diagnosis of elbow PJI.

LEVEL OF EVIDENCE: Limited

DELEGATE VOTE: Agree: 100%, Disagree: 0%, Abstain: 0% (Unanimous, Strongest Consensus)

RATIONALE

Sonication involves the application of high-frequency ultrasound (approximately 40 kHz) to a retrieved implant in an ultrasound "bath" of appropriate fluid medium. The liquid medium from the bath is then collected and centrifuged, and these aliquots are

cultured with conventional techniques. The concept is that organisms ensconced in a biofilm on the implant are loosened or released by this process, and are more readily cultured.

There was some promising initial evidence from retrospective reviews that the sonication process increased the number of positive cultures, especially in patients who had been receiving antibiotics, or those who had previously negative cultures despite clinical and serological evidence of infection. However, these studies focused on lower extremity arthroplasty. A paper by Holinka et al. noted improved diagnostic accuracy with sonication ($p = 0.008$) compared to conventional cultures, but none of the 60 patients studied had an elbow prosthesis [1]. Similarly, a study by Achermann et al. reported on only one elbow implant in 37 cases, which significantly limits the applicability of this information to the upper extremity [2].

There is only one study in the literature that is specific to the elbow. A review of 27 presumptively uninfected and 9 infected patients with a prosthetic elbow noted that while sonification of removed elbow arthroplasty implants had a sensitivity of 89% and a specificity of 100%, this did not differ significantly from the results of standard microbiological culture techniques at their institution (sensitivity 55%, specificity 93%, $p = 0.18$ and $p = 0.16$, respectively). While this may represent a "beta-error" in which a true improvement in the yield of sonication is obscured by insufficient numbers to prove statistically significance, in the eight years since this paper was published, we were unable to find a more definitive or compelling study [3,4].

A larger study of 53 shoulder arthroplasty patients examining the results of sonication of retrieved upper extremity implants has recently been published by Grosso et al. [5]. They found that the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and accuracy of the cultures were not improved by sonication (US) when compared to standard (S) techniques: Sensitivity 96% (S) versus 96% (US), specificity 75% (S) versus 64% (US), PPV 77% (S) versus 71% (US), NPV 95% (S) versus 95% (US) and accuracy 85% (S) versus 79% (US). None of these differences were statistically significantly different. Additionally, it is well-recognized that the microbiological flora of the shoulder, and the subsequent infections that result from it, are distinctly different than that of the elbow. Therefore, it is not advisable to directly compare (or extrapolate the findings of) one joint to the other.

To conclude, at the present time there is insufficient evidence to either support or refute the utility of routine sonication of prosthetic elbow implants removed at the time of surgery in order to increase the yield or accuracy of cultures. Until a sufficiently-powered, prospective study has been performed demonstrating the efficacy of sonication to diagnose infection for revision elbow arthroplasty, we cannot support the routine use of this technology.

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Authors: Mark Morrey, Shawn O'Driscoll

QUESTION 5: Do molecular markers have a role in the diagnosis of elbow periprosthetic joint infection (PJI)?

RECOMMENDATION: Despite the presence of data related to the use of molecular markers for the diagnosis of infection in hip and knee arthroplasty, the role of molecular markers in the diagnosis of total elbow arthroplasty (TEA) infection remains unknown.

LEVEL OF EVIDENCE: Limited

DELEGATE VOTE: Agree: 100%, Disagree: 0%, Abstain: 0% (Unanimous, Strongest Consensus)

RATIONALE

An extensive literature search was performed to identify publications related to the use of molecular techniques for the diagnosis of PJI in TEA. Our detailed search revealed numerous articles in total hip and knee arthroplasty. From our search, 180 articles were ultimately reviewed. A complete search of the abstracts, references and selectively full text from systematic reviews specific to TEA revealed there were only three studies with a total of only three elbows examining the use of molecular techniques to diagnose periprosthetic infection in TEA.

The alpha-defensin immunoassay and leukocyte esterase (LE) tests were recently reviewed in a systematic review and meta-analysis by Wyatt et al. [1]. In this review, six studies examined alpha defensin; however, no TEAs were included. Five of the included studies utilized LE for the diagnosis of PJI and only one of these included a single TEA out of 52 prostheses examined [2]. In their study, Colvin at al. found a sensitivity, specificity, positive predictive value and negative predictive value of 100, 97, 95 and 100% respectively [2].

In another systematic review, Suen et al. [3] compared the "quick test" version of alpha-defensin to the laboratory-based test, which further led to a study by Sigmund et al. [4] which included hip, knee, shoulder and elbow revisions done for pain or instability in 49 patients. These authors found a sensitivity and specificity of 69% and 94%, respectively, with a positive and negative likelihood ratio of 12.46 and 0.33, respectively. Again, unfortunately this study only included a single patient with an elbow arthroplasty PJI. The larger systematic review found a pooled

sensitivity and specificity of the laboratory assay to be 95 and 96% respectively, compared to the quick test lateral flow of 77 and 91%, respectively, but again, only a single elbow arthroplasty was included in the pooled group.

Finally, in a pilot study by Wouthuyzen-Bakker et al., synovial calprotectin was examined as a biomarker for PJI [5]. This test is attractive because of the low cost, the possibility to obtain a quantitative value, the use of a lateral flow assay with the possibility to use it as a point of care test and its availability, as it is already used in routine care for other indications in most hospitals. Unfortunately, while this study included TEA, no PJIs were included in the TEA group. The single elbow examined was in a control group without infection. This pilot study revealed that synovial calprotectin had an overall sensitivity, specificity, positive predictive value and negative predictive value of 89%, 90%, 81% and 95%, respectively.

Other biomarkers examined in a pooled meta-analysis by Lee et al. [6] included α-defensin, LE, interleukin (IL)-6 and IL-8. The overall sensitivity of these molecular tests was 85% compared to culture, which was 80%. Alpha-defensin in this study had the highest diagnostic odds ratio. Unfortunately, all studies included hip and knee arthroplasties and not a single study examined TEA.

Of significant note, despite their ability to identify PJIs with a high likelihood in most other joints, all biomarkers utilized in these studies require some element of polymorphonuclear cells to be present in the synovial fluid for detection. These tests do not discriminate between other inflammatory conditions and infection, which would be the most useful to surgeons. Specifically, as inflammatory conditions have historically been the primary indication for surgical intervention about the elbow, a test to discriminate between infection and other inflammatory conditions such as rheumatoid arthritis or gout does not yet exist.

Nevertheless, as these tests have shown promise in PJI in other joints, studies should be undertaken specific to the elbow. However, at this time conclusions are difficult to draw given the lack of clinical data specific to the elbow, which forms the basis of our recommendation.

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QUESTION 6: What are the diagnostic criteria for elbow periprosthetic joint infection (PJI)? (Clinical criteria, radiographic criteria, intraoperative findings, pathology, cultures and serum biomarkers.)

RECOMMENDATION: The following three parameters provide a definitive diagnosis of elbow PJI:

- A sinus tract that is communicating with the prosthesis (Strength: Strong)
- Isolation of identical pathogens from two or more separate cultures (tissue or articular fluid) obtained under sterile conditions (Strength: Strong)
- Presence of intra-articular pus (Strength: Consensus)

The following criteria are concerning for infection and should be considered in aggregate (Strength: Limited):

- Warmth, redness, swelling of the elbow
- Elevated serum inflammatory markers (erythrocyte sedimentation rate (ESR), C-reactive protein (CRP)) – except in cases of inflammatory arthropathies
- Elevated synovial white blood cell (WBC) count
- Elevated synovial polymorphonuclear percentage
- Isolation of organism from one sample (tissue or articular fluid)
- Histologic evidence of acute inflammation
- Early unexpected component loosening
- Endosteal scalloping, rapid progressive loosening on radiographs

LEVEL OF EVIDENCE: Consensus

DELEGATE VOTE: Agree: 92%, Disagree: 8%, Abstain: 0% (Super Majority, Strong Consensus)

RATIONALE

The limited total number of total elbow arthroplasty (TEA) infections reported in the literature makes the assessment of preoperative factors consistent with infection challenging. In addition, limited early recognition of the role of low-grade, indolent infections (*Staph-*

ylococcus epidermidis, Cutibacterium acnes) may make interpretation of earlier studies challenging. Nonetheless, the literature provides valuable insights into the diagnosis of PJI in TEA.

Given the subcutaneous nature of the elbow, many infected TEAs do develop draining sinuses. This diagnostic criteria has been consistently used in the literature and was predictive of positive cultures in the vast majority of cases. In the review by Cheung et al. of 29 patients with PJI, 11 (38%) had draining sinuses [1]. Peach et al. showed a 38% rate of draining sinus, as well [2].

Culture growth was the most commonly-cited diagnostic criteria in the literature. Several studies considered a TEA to be infected in the presence of one positive culture [1,3–9]. Several other studies only made the diagnosis of PJI if two cultures were positive for the same pathogen [10–12]. The latter is consistent with the MusculoSkeletal Infection Society (MSIS) criteria [13]. In light of the publication by Wee et al. regarding "unexpected positive cultures," using the criteria of one positive culture for the diagnosis in the absence of other signs would likely over-diagnose PJI [14]. Therefore, one positive culture should be used in the constellation of other signs and symptoms of infection. If two cultures from two separate sources return the same pathogen, the diagnosis of PJI is supported strongly by the literature.

Numerous other criteria were used in the diagnosis of PJI. While these signs and symptoms were frequently seen, they were not seen with enough reproducibility to be diagnostic in isolation. Warmth, redness and swelling were consistently seen [15]. Elevated serum ESR and CRP, as well as aspirate WBC (and differential), and acute inflammation on intraoperative pathology were commonly seen in TEA PJI. However, many of the patients receiving a TEA have inflammatory arthropathy as their underlying diagnosis, leading to a substantial number of false positives. Furthermore, in the setting of low-grade infections, aspiration and serum laboratory studies are not accurate in isolation. These diagnostic criteria should be used in combination with clinical and radiographic assessments to assess likelihood of true PJI.

The radiographic appearance of the TEA and pace of loosening can provide insight into the likelihood of PJI. Early unexpected radiographic failures (< two years) are more likely to be consistent with PJI than late failures [14,16]. In addition, endosteal scalloping and rapidly progressive loosening were associated with PJI in TEA in most series in the literature [4,9,15].

Based on available literature, it is hard to make consensus quantitative assessments of number of criteria required from the "associated criteria" category. Certainly, based on the literature, an increase in the number of positive criteria increases the likelihood of true PJI.

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Treatment

Authors: Mark Cohen, Robert N. Hotchkiss

QUESTION 1: Is there a role for irrigation and debridement with implant retention when treating acute elbow periprosthetic joint infection (PJI)? Should modular implant parts be exchanged?

RECOMMENDATION: Surgical debridement, antibiotic and implant retention (DAIR) is a viable option for management of acute elbow PJI. Modular implant exchange should be considered.

LEVEL OF EVIDENCE: Limited

DELEGATE VOTE: Agree: 100%, Disagree: 0%, Abstain: 0% (Unanimous, Strongest Consensus)

RATIONALE

Total elbow arthroplasty (TEA) has historically been associated with a high risk of PJI. In 1983, Morrey et al. described this association and recommended the use of antibiotic-impregnated cement to reduce the risk of PJI after primary TEA [1]. Although infection rates have improved since then, PJI remains a potentially catastrophic complication of TEA. TEA implant revision is technically challenging, particularly given the relative lack of progress that has been made in TEA implant revision systems over the past 30 years. No comparative study exists to discern the superiority of DAIR versus explantation. Both strategies have been described, with varying degrees of success for both options [1–6].

Of the studies available for review, treatment recommendations varied. Given the variation in patient age and general health, bacteriology, mechanical circumstances, soft-tissue coverage and the retrospective nature of the study designs, it is difficult to make definitive recommendations about the indications for irrigation and debridement with retention of components. Alternative options include removal and reimplantation of new components in a single-stage or two-stage exchange with interval antibiotic cement spacer and resection arthroplasty.

Although no studies exist comparing DAIR with more invasive options, some patients do respond well to isolated irrigation and debridement [5]. There is extensive data to support the role of DAIR in the hip and knee arthroplasty literature. Because TEA systems rely on cement mantle fixation, explantation of well-fixed components leads to significant bone loss and morbidity.

Thus, DAIR may be offered to patients with infection of TEA in the presence of well-fixed components. The following general rules may need to be obeyed in performing DAIR in these patients.

1. If the components are well-fixed, removal of these implants will cause damage to the humerus and ulna, making the revision more challenging. Therefore, all attempts should be made to retain these using repeated irrigation and debridement, oral antibiotic suppression and soft-tissue coverage, even if that includes free tissue transfer.
2. If one component is found to be loose during DAIR, then the well-fixed component may be left in place while exchanging the other component.
3. In the presence of both components being loose, both components (and as much of the cement as possible) should be removed. An antibiotic-impregnated cement may be inserted with intravenous antibiotic treatment. The culture results would then dictate the length, dose and the type of antibiotic therapy needed.

Because resection arthroplasty leads to poor patient-reported outcome scores [6], we recommend that this option be reserved as a final "salvage" option after all other methods have failed or when the patient is not medically stable for two-stage exchange. Given the technical ease and low morbidity, we recommend that any modular components be removed and replaced in every case.

It is important to note that the method by which DAIR is performed influences the outcome of this surgical procedure. It is strongly recommended that clear margins for debridement of infected tissues are obtained, the modular components are taken out, the infected joint is irrigated copiously with antiseptic agents such as dilute betadine and the new modular parts are inserted after new drapes are used.

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QUESTION 2: What are the indications for one-stage and two-stage exchange arthroplasty when treating an acute or chronic elbow periprosthetic joint infection (PJI)?

RECOMMENDATION: Two-stage exchange arthroplasty should be considered for patients with chronic elbow PJI. There are no clear indications for one-stage exchange arthroplasty for infected total elbow arthroplasty (TEA), but two-stage exchange is preferred in patients with sinus tract and/or compromised soft tissues around the elbow or those with systemic sepsis.

LEVEL OF EVIDENCE: Consensus

DELEGATE VOTE: Agree: 100%, Disagree: 0%, Abstain: 0% (Unanimous, Strongest Consensus)

RATIONALE

Treatment strategies for elbow PJI have generally taken four forms: debridement, antibiotic and implant retention (DAIR), one-stage exchange arthroplasty, two-stage exchange arthroplasty, and resection arthroplasty. While DAIR is reported to be successful, this discussion will focus on staged reconstruction [1,2].

The body of evidence to support one-stage exchange arthroplasty is very sparse, with only one retrospective case series reported in the literature. Gille et al. reported on six infected TEAs treated with one-stage exchange arthroplasty. The outcome was successful in five patients, with a follow-up period ranging from 6 months to 16 years. Outcomes indicated patient satisfaction in four of six patients and a mean Mayo Elbow Performance Score of 67 points [3].

The evidence for two-stage exchange arthroplasty is greater than for one-stage, but is also limited to retrospective case series (level IV evidence). In an initial report, Wolfe et al. performed successful two-stage exchange arthroplasty on one elbow in their series of 12 elbow PJIs [4]. Yamaguchi et al. reported successful treatment in four out of five patients with infected TEAs [5]. In a follow-up study of an expanded patient cohort, Cheung et al. found a 28% reinfection rate with two-stage exchange arthroplasty [6]. Finally, Peach et al. studied 26 elbows undergoing two-stage exchange arthroplasty and reported successful eradication in 23 patients (88%) [7]. Pooling of the data on two-stage exchange arthroplasty from the literature results in 59 unique patients with an 18% recurrence rate.

Many of the studies regarding treatment of infected TEAs include a mix of acute and chronic infections with a wide range of surgical treatments and antibiotic regimens. In the setting of acute infection with early diagnosis, some authors recommend DAIR [8,9]. Most of these studies emphasize the importance of sufficiently robust patient health, an adequate soft tissue envelope, a sensitive organism and use of local intra-articular antibiotic placement in addition to intravenous therapy. In particular, debilitated patients may be treated with chronic antibiotic suppression if they are not able to tolerate the proposed surgical course, while intractable infections or inadequate soft tissue sleeves can be managed with resection arthroplasty [2,10].

There are no studies comparing one-stage and two-stage exchange TEA in similar patient populations. Achermann et al. studied 27 elbow PJIs, but most were treated by DAIR. In this series, one patient with a delayed infection was treated with one-stage exchange and two late infections with two-stage exchange arthroplasty. All three patients in this series had successful eradication of infection [9]. Spormann et al. reported on three late (> 24 months) and one acute (< three months) elbow PJIs treated with two-stage reconstruction (all were cleared of infection). Similarly, a one-stage exchange was used in one patient with a delayed (3 to 24-month) TEA infection, which was also successful [8]. Finally, in a review article Somerson et al. found inadequate data to recommend one-stage reconstruction, but reviewed the relative success of two-stage exchange arthroplasty with eradication of infection in 72-88% of patients [10].

Given the paucity of data surrounding one-stage exchange elbow arthroplasty, it is difficult to recommend an indication for this approach in the setting of elbow PJI. Though evidence overall remains limited regarding two-stage exchange, we conclude that this approach is currently favored for the treatment of acute and chronic infected TEA.

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QUESTION 3: Is there a role for preoperative joint aspiration prior to second-stage revision after treatment of elbow periprosthetic joint infection (PJI)?

RECOMMENDATION: Preoperative joint aspiration may play a role in the evaluation of the elbow arthroplasty for PJI before second-stage revision.

LEVEL OF EVIDENCE: Consensus

DELEGATE VOTE: Agree: 96%, Disagree: 0%, Abstain: 4% (Unanimous, Strongest Consensus)

RATIONALE

There are no studies that specifically investigate and prove that there is a role for preoperative aspiration of the elbow prior to second-stage revision arthroplasty. However, in a review of published studies that have addressed total elbow infection, aspiration was found to be the standard of practice in these studies. Furthermore, there is a logical rationale that preoperative aspiration provides useful information for both the diagnosis and treatment of total elbow arthroplasty (TEA) infections. When the risk factors for infection are higher (such as in patients with diabetes, obesity or rheumatoid arthritis), preoperative aspiration prior to second-stage revision has an even stronger recommendation. Currently, no evidence exists regarding what constitutes a positive aspiration. Therefore, the significance of the results should be assessed on a case-by-case basis.

Rudge et al. discussed the management of infected elbow arthroplasty by two-stage revision in 19 patients managed at their center [1]. In their algorithm for management, the authors state, "If the infective organism and sensitivities had been identified before the first stage, further antibiotics were added as necessary. If at the six-week postoperative review there were clinical signs of ongoing infection or inflammatory markers had not normalized, an aspiration was performed. If the aspirate analysis was positive, then patients underwent a repeat first-stage procedure (debridement and washout). If the aspirate analysis was negative, then a second-stage procedure was planned, but with a low threshold for making an intraoperative decision to repeat the first stage rather than re-implanting prosthetic components, if concerned about possible ongoing infection." These authors therefore recommend aspiration prior to second-stage revision as a means of determining when to proceed to the second stage, what procedure to perform and which antibiotics to use.

Using this protocol, the authors were able to treat the majority of TEA infections successfully — "Of the 19 patients undergoing a first-stage procedure, 16 (84%) remained infection free, of whom 11 had proceeded to a second stage and five had not. Of 14 patients undergoing a two-stage revision, 11 (79%) remained infection free. Of patients requiring further surgery due to recurrent infection, 2 (67%) remained infection free after a repeat two-stage revision, with the third patient still awaiting the second-stage procedure."

When aspiration is performed, the joint fluid should be evaluated for white blood cell (WBC) count, with particular attention to the differential (polymorphonuclear percentage). In addition, the fluid should be sent for aerobic and anaerobic cultures. Gram stains lack sensitivity and specificity and are not routinely recommended [2,3]. Cultures remain the most effective method for specific organism identification. The addition of Acid-Fast Bacilli (AFB) and fungal cultures should be performed if there is concern for atypical infecting organisms. Additionally, incubating cultures for a longer period (21 days) may assist in identifying fastidious organisms such as *Cutibacterium acnes*.

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QUESTION 4: What is the role of permanent resection when treating a chronic elbow periprosthetic joint infection (PJI)?

RECOMMENDATION: Permanent resection is a salvage treatment for chronic elbow PJI. Preservation of medial and lateral condyles should be considered to improve functional outcomes.

LEVEL OF EVIDENCE: Limited

DELEGATE VOTE: Agree: 100%, Disagree: 0%, Abstain: 0% (Unanimous, Strongest Consensus)

RATIONALE

Methodology

A comprehensive literature review was performed to identify all studies on permanent resection treatment for elbow PJI. Searches for the terms "elbow," "total elbow arthroplasty," "infection," "periprosthetic," "permanent resection" and "resection arthroplasty" were performed on the PubMed/Medline, Cochrane, Google Scholar and Embase databases through March of 2018. Our systematic review includes English studies (only level IV evidence) regarding permanent resection treatment for the elbow PJI. Non-English studies, technique papers without patient data, studies with inadequate patient follow-up and studies regarding resection treatment for non-elbow PJI were not included. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) statement was followed for this review.

Discussion

PJI is a serious complication of total elbow arthroplasty (TEA) and is difficult to treat [1,2]. Treatment options include debridement with retention of implants, single or two-stage reimplantation, permanent resection and arthrodesis [1–5]. There are only a few studies with limited evidence comparing the outcomes of these treatment procedures [3–7]. Many authors have emphasized that good functional outcomes are only possible with reimplantation [8,9]. However, the success of the reimplantation treatment depends on remaining bone stock [9,10]. On the other hand, high recurrence rates of infection limits the success of the treatment [8]. Arthrodesis and permanent resection are defined as a salvage procedure in low-demand patients [1,2,5,7]. However, arthrodesis has a very limited role in the treatment of this circumstance, even as a salvage treatment, as it often results in a painful nonunion or infection recurrence [3].

Permanent resection is suggested as a salvage procedure for the treatment of elbow PJI in patients in whom debridement and reimplantation therapy had failed or in medically frail patients [2,7]. Rhee et al. reported that infections in nine patients (90%) could be eradicated with permanent resection for elbow PJI [11]. Despite the high successes of eradication of the infection, it was noted that sufficient stability was essential for the successful functional outcomes. It was emphasized that the condyles which articulate with the olecranon fossa are important for the stability in resection arthroplasty. Moreover, the authors have examined the role of poor bone stock in the condyles (which is common in this patient group) on the success of resection arthroplasty. It has been reported that the best functional results were obtained in patients in whom both condyles could be preserved, whereas the weakest functional results were reported to be obtained in the group of patients in whom only the medial condyle could be preserved. Figgie et al. reported that achieving stability has a key role in the success of resection arthroplasty following failed TEA [12]. Therefore, the authors emphasized that the epicondyles should be preserved.

In a study by Zarkadas et al., resection arthroplasty has been defined as an effective salvage procedure [1]. This study appears to be noteworthy due to fact that it reported the long-term outcomes of 29 patients (30 elbows) after resection arthroplasty for the failed TEA (11 years, range 2.7 to 28 years). In the study, it was noted that the increase in the Mayo Elbow Performance Score was reported to be mostly in the pain component, whereas the stability was directly related to good functional outcomes. However, the authors reported complications such as persistent infection in 24 elbows (47%), intraoperative fracture in 18 elbows (35%) and permanent nerve injury in 9 elbows (18%).

Specifically, the difficulties experienced during removal of the well-fixed humeral component were thought to be responsible for the high complication rates. For this reason, the authors suggested performing an osteotomy in the form of a trapezoidal window, which has a larger distal border in order to facilitate removal of the humeral component and cement. In addition, the authors pointed to the importance of the development of soft tissue scar utilizing a brace or a cast for a minimum of six weeks to surpass instability, which is thought to be responsible for the poor functional outcomes.

PJI following an elbow arthroplasty has a reported rate ranging from 22 to 41%, based on limited literature [1,2]. Diagnosis of chronic elbow PJI has remained a challenge, however, as many presentations are subclinical in nature, leaving cultures still as the recommended diagnostic tool [3]. Treatment of elbow PJI has primarily centered on intravenous antibiotics, debridement and retention as well as staged reimplantation, all of which have been proven to be relatively successful under the right indications [3–5]. There is limited literature regarding the success of this treatment modality. Permanent resection may be considered if previous attempts to resolve elbow PJI fail [3,6,7]. Zarkadas et al. found that 47% of their case series required additional surgery after permanent resection to resolve the infection [6].

There are no level I or II studies available, though one level III and two level IV studies exist examining permanent resection as a treatment modality for chronic TEA PJI. Both level IV studies are case series with sample sizes of 51 and 10 patients, respectively [3,7]. Both level IV studies demonstrated that successful eradication of PJI is heavily dependent on surgical technique and more experienced TEA surgeons are correlated with higher eradication rates for elbow PJI via permanent resection.

One study reported patient outcomes and showed higher functional Disabilities of the American Shoulder and Hand scores with resolution of elbow PJI via permanent resection [6]. Therefore, even with the paucity of literature available, permanent resection should be considered for chronic elbow PJI that fails to respond to other treatment modalities.

In brief, the permanent resection has been suggested for frail patients with low functional demands or for patients who are not interested in additional reconstructive surgeries [1,2,7,11]. The aim of treatment should be the eradication of infection, relief of pain and improved functions [1,4,11]. Contrary to what is known, persistent infection is a frequent complication [8]. Given this finding, all of the infected tissue and foreign materials should be removed [1,7,11,12]. However, aggressive debridement and removal of the well-fixed implants result in loss of bone stock [1,11]. This condition increases the instability risk which is directly correlated with poor functional outcomes [1]. Both condyles should be preserved as much as possible so that a new effective fulcrum might be created, which would make it possible to achieve a stable new elbow joint [8,9,11]. In order to achieve favorable functional outcomes and soft tissue stability, the integrity of the triceps mechanism should be preserved [12] and immobilization should be ensured for a minimum of six weeks postoperatively by casting or bracing [1].

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QUESTION 5: What is the role of arthrodesis when treating a chronic elbow periprosthetic joint infection (PJI)?

RECOMMENDATION: There is a very limited role for arthrodesis of an infected elbow, as this procedure usually results in painful nonunion and poor functional outcomes.

LEVEL OF EVIDENCE: Limited

DELEGATE VOTE: Agree: 100%, Disagree: 0%, Abstain: 0% (Unanimous, Strongest Consensus)

RATIONALE

The incidence of deep infection after total elbow arthroplasty (TEA) has been reported to be 3–13.3% [1–4]. It has been widely accepted that elbow PJI is difficult to treat and has poor outcomes [1,2,5]. Compared to knee and hip arthroplasties, relatively high infection rates [2] and poor outcomes [6] have led to an assessment of the efficacy of different treatment procedures [2,5]. Treatment modalities include debridement with prosthetic retention, resection with subsequently staged reimplantation, staged reconstruction with composite allograft, permanent resection and arthrodesis [2–9].

Among the aforementioned treatment modalities, arthrodesis must be the last choice and should be regarded as a salvage procedure. Functional limitation after arthrodesis cannot be compensated by adjacent joints [8,10,11]. Small contact areas of the remaining bone stock and high moments generated by the long lever arm preclude obtaining solid bone fusion [8,11,12]. Even if fusion can be achieved, it has been reported that humerus fracture risk increases in longer follow-up [13]. Arthrodesis has been reported to be a successful treatment only if there is adequate bone stock, good soft tissue envelope and sufficient vascular supply [8,14,15]. However, in majority of patients with elbow PJI, there are bone defects due to the destructive effect of infection, removal of bone as part of treatment of infection, vascularity is impaired and soft tissue coverage may be insufficient secondary to recurrent surgical interventions [2,5,12–16].

Wolfe et al. described two patients treated with arthrodesis after elbow PJI [9]. The authors reported a painful fibrous union in one patient and a persistent infection in the other. In the limited literature evaluating the treatment of arthrodesis after elbow PJI, the largest series (by Otto et al.) consists of five patients [11]. The authors reported that no union was achieved in any of the patients, and there was asymptomatic fibrous union in only two patients (40%) at the last follow-up. In that study, high reoperation rates and high complication rates were emphasized, and arthrodesis was not recommended for the elbow PJI.

Severe bone loss in this patient group was seen as an important cause of treatment failure. Thus, Koller et al. described an arthrodesis technique using double fibular strut graft and reported favorable results in a patient at the 12-month follow-up [10]. The arthrodesis of the radius to the humerus described by Presnal et al. aimed to surpass nonunion caused by the massive bone loss in the ulna [8]. Nevertheless, according to widely accepted view, arthrodesis treatments for the elbow PJI have poor outcomes and high reoperation rates, and it is not recommended except in special conditions [4,9,14–18]. It might be considered in the case of a failure of resection arthroplasty due to instability [15,17], especially when control of sepsis due to the mobility of the articulation is not possible [14] and also in young patients who do heavy bodily work [18]. Because of the limited literature and small case series, the role of arthrodesis in the treatment of elbow PJI could be evaluated with a limited level of strength.

Treatment of elbow PJI has centered on antibiotics, surgical debridement and retention or staged reimplantation [1]. In some cases where the joint is extremely damaged or seems unsalvageable, arthrodesis may be a viable treatment choice to avoid amputation [1]. Traditionally arthrodesis of the elbow has only been used when all other motion-preserving interventions are declared not possible and studies have reported elbow arthrodesis results in more impairment than hip, knee or ankle joint arthrodesis [2,3]. Koch and Lipscomb report that arthrodesis should be considered only when there is sufficient tissue damage to prevent reimplantation following TEA PJI, and in these cases they reported a 15% delayed complication rate [13].

Literature examining the success of elbow arthrodesis for chronic PJI is limited. There have been no level I, II or III studies, and only two level IV studies have examined the use of arthrodesis for chronic elbow PJI related to tuberculosis [5,6]. A recent review article suggested that evidence to support the use of arthrodesis is

incomplete as a treatment modality for chronic elbow PJI [11]. One aspect that should be taken into account is the technique used during arthrodesis, as Sala et al. found this influences the functional outcome following elbow PJI [19]. Overall, due to the limited literature, we cannot recommend the use of elbow arthrodesis to treat chronic elbow PJI.

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QUESTION 6: Should all foreign material (including cement) be removed during resection arthroplasty of an infected elbow?

RECOMMENDATION: When treating elbow periprosthetic joint infection (PJI), attempts should be made to remove all foreign material. However, the benefit of removing all foreign material should be weighed against the effort to preserve bone stock.

LEVEL OF EVIDENCE: Limited

DELEGATE VOTE: Agree: 100%, Disagree: 0%, Abstain: 0% (Unanimous, Strongest Consensus)

RATIONALE

Surgical management of an infected total elbow arthroplasty (TEA) is dependent on the chronicity of the infection and the infecting organism, as well as host factors. The majority of TEA components are placed in a cemented fashion. In cases where the humeral and ulnar components are removed, the cement mantle may or may not be easily extractable at the time of surgery. This discussion will focus on the literature which reports on patient outcomes following TEA component resection with retained foreign material.

A systematic review was performed using the search terms, "retained cement AND total elbow arthroplasty NOT shoulder." This search yielded zero results. Therefore, a broader search criterion was utilized. The second search evaluated "total elbow arthroplasty AND infection AND removal NOT shoulder." All 32 articles were reviewed. Of these, only one paper documented retained cement in the setting of removal of the humeral and ulnar components. Stoodley et al. [1] reported a single case series of a TEA performed for a distal humerus fracture nonunion. The patient underwent multiple staged operations including before and after the index TEA. Cultures remained negative until the seventh operation, when the authors noted a positive culture and documented that retained cement was removed at that time. However, the authors were unable to state if the retained cement was the cause of persistent infection, as the patient had not previously received targeted antibiotics that effectively addressed the infectious antimicrobial profile.

Given the lack of evidence available within the total elbow arthroplasty literature, information regarding the effect of retained cement must be taken from other orthopaedic literature. Early reports in the lower extremity arthroplasty literature raised concern about the correlation of retained cement and incomplete eradication of infection [2]. However, not all series have correlated retained cement with persistence of infection [3,4]. Petty et al. reported on 54 total hips treated for PJI. At the time of revision surgery, the presence of retained cement was not associated with positive intraoperative cultures.

Given the lack of data available in the elbow arthroplasty literature, we are unable to make a recommendation regarding the necessity to remove all cement or other foreign material in the treatment of periprosthetic TEA infections.

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QUESTION 7: Is there a role for chronic antibiotic suppression in the management of elbow periprosthetic joint infection (PJI)?

RECOMMENDATION: Long-term suppressive antibiotics may be used in the treatment of PJI of the elbow. Consultation with an infectious disease specialist should be considered in the decision to use long-term suppressive antibiotics.

LEVEL OF EVIDENCE: Consensus

DELEGATE VOTE: Agree: 100%, Disagree: 0%, Abstain: 0% (Unanimous, Strongest Consensus)

RATIONALE

Treatment strategies for elbow PJI have generally taken four forms; irrigation and debridement with component retention, one-stage exchange arthroplasty, two-stage exchange arthroplasty and resection arthroplasty. Each of these treatment options may be followed by the use of suppressive antibiotics [1].

A systematic review was performed using the terms "elbow arthroplasty AND chronic suppressive antibiotics." This revealed zero results. A second search using the terms "infected elbow replacement AND suppressive antibiotics" produced no results. A third search using the terms "infected elbow AND chronic suppressive antibiotics" produced zero results.

A fourth search using the terms "chronic suppressive antibiotics AND elbow infection" produced a single result: "Gram-Negative Prosthetic Joint Infection: Outcome of a Debridement, Antibiotics and Implant Retention Approach. A Large Multicentre Study" [1]. In this multi-center study from Spain, there were two elbow PJIs out of 242 PJIs managed with debridement and chronic suppressive antibiotics (the other 240 patients included 150 hip, 85 knee and 5 shoulder). They reported 79% successful outcomes. Ciprofloxin exhibited a protective effect and chronic renal impairment predicted failure.

A final search with the terms "chronic suppressive antibiotics AND total joint infection" produced 12 results. Only one study (the previously-cited Rodriguez-Pardo article) included elbow replacement patients. Given the lack of evidence specific to PJI of the elbow, the only evidence available is contained in articles related to PJI of other joints. Aboltins et al. published a review citing a 77% success rate using rifampin-based therapy [2]. These two articles provide the most recent evidence in the use of antibiotic suppression in the treatment of PJI of the elbow. There are several other articles, primarily on hip and knee, and two are referenced that provide further evidence in support of suppressive antibiotic therapy [3,4].

In the absence of concrete data and given the complexity of removing well-fixed cemented components of total elbow arthroplasty, we believe suppressive antibiotic therapy may have more of an expanded role in these patients than in PJI affecting other joints.

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