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Current Concept Review

Pediatric Musculoskeletal Infection Roundtable: Tips and Tricks for Streamlining Care in Common Scenarios

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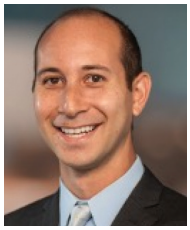
Invited Experts



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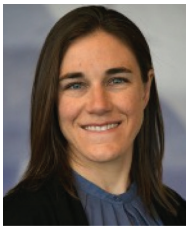

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Abstract

Musculoskeletal infections originate from pathogens introduced into the tissues via direct inoculation, through hematogenous spread, or via contiguous extension from adjacent areas of infection. In pediatric patients, these infections are a common cause of morbidity, with the possibility of long-term functional impairment. Prompt diagnosis and treatment are important to prevent irreversible damage to the bones and joint space, to decrease length of hospital stay, and to minimize treatment morbidity. While pediatric orthopaedic surgeons may definitively manage these cases, multidisciplinary collaboration provides the best outcomes for patients.

Available resources and subsequent management decisions often vary between institutions and physicians; interinstitutional variation in care pathways may be attributed to differences in endemic bacteria. Standardization of treatment algorithms and protocols improves patient outcomes, but they must be modified for regional bacterial prevalence and antibiograms. This manuscript addresses the management of common pediatric musculoskeletal infections through a case-based, roundtable approach with national experts.

Key Concepts

- Management of pediatric musculoskeletal infections requires multidisciplinary collaboration to achieve favorable patient outcomes.
- Treatment algorithms are useful for standardization of care for pediatric musculoskeletal infections due to variety in care pathways among physicians and institutions.
- Some pediatric musculoskeletal infection cases can be managed as scheduled cases in the next workday to decrease overnight add-on cases.

Introduction

Musculoskeletal infections, such as osteomyelitis and septic arthritis, are a common source of morbidity in the pediatric population.[1] In severe cases, they may be associated with prolonged hospital stays, need for extensive and broad-spectrum antibiotic therapy, and multiple anesthetic events and/or procedures.[2] From a biopsychosocial point of view, severe musculoskeletal infections may have a profound impact on family dynamics and economics. The complex, potentially multifocal and multisystem illnesses can also be associated with devastating long-term complications, even when handled appropriately.[2]

As stewards of the immature musculoskeletal system, pediatric orthopaedic surgeons play a critical role in the management of pediatric musculoskeletal infections. Musculoskeletal infections can make up a significant portion of many pediatric orthopaedic surgeon's clinical activities,[3] particularly early in practice.[4,5] Early in their course, musculoskeletal infections may mimic other conditions such as trauma, strains, or normal aches and pains of childhood. As such, the orthopaedic surgeon is often relied upon in the diagnostic workup of an infection. Beyond assisting in the diagnosis, the orthopaedic surgeon also plays an important role in surgically irrigating and debriding any drainable focus or foci of infection as a means of achieving source control.[6] In the long-term, the orthopaedic surgeon is tasked with facilitating rehabilitation/return to activities and managing secondary complications (such as pathologic fracture) or adverse sequelae (such as physeal arrest or avascular necrosis).[7]

The past decades have seen significant changes in the incidence, etiology, evaluation, and treatment of pediatric

musculoskeletal infection. Changes in vaccination, bacterial prevalence, antibiotic resistance, and antibiotic stewardship have influenced the medical management thereof. The incidence of methicillin-resistant *Staphylococcus aureus* (MRSA) and musculoskeletal infections have risen substantially in recent years.[1,8,9] Over that period of time, more virulent strains have emerged that are associated with increased morbidity and associated complications such as thromboembolic disease, pathologic fracture, greater need for intensive care unit (ICU) care, prolonged hospitalization, more rapid spread, and higher chance of mortality.[8-11]

A better understanding of the pathophysiology of the body's inflammatory response to infection and advances in laboratory medicine have influenced evaluation and management of severe infections.[12] Furthermore, changes in the quality and availability of advanced imaging such as MRI have influenced the diagnostic workup of suspected or established infections.

Despite these advances, the fundamental principles behind management of musculoskeletal infection remain largely unchanged—early diagnosis, proper source control, and appropriate antibiotic therapy while optimizing the safety and value of care. Although the management principles of pediatric musculoskeletal infection are well-documented and agreed upon, variation in practice matters exist. A recent review of the **C**hildren's **OR**thopaedic **T**rauma and **I**nfection **C**onsortium for **E**vidence-based **S**tudy (**CORTICES**, www.cortices.org) database found that significant variation occurs in the surgical management of acute hematogenous osteomyelitis, and that this variation appears to be driven largely by institutional practices.[13] This variation may be explained, in part, by regional and temporal differences in bacterial flora, and local susceptibility patterns make the creation of universal diagnostic protocols or treatment recommendations more challenging than care pathways for more elective type conditions.[14,15] Furthermore, controversies regarding the need and timing of advanced imaging, the use of intravenous contrast for said imaging, and the timing of procedural interventions may have a profound impact on a surgeon's day-to-day practice.

The purpose of this roundtable is to discuss the management of common pediatric musculoskeletal infections through a case-based, roundtable approach. This case review includes three very common scenarios encountered by a pediatric orthopaedic surgeon taking call on a regular basis:

1. Management of a presumed septic hip
2. Management of osteomyelitis without an associated abscess
3. Management of osteomyelitis with an associated subperiosteal abscess

Panelists were recruited from CORTICES study group based on their clinical interest in treating infection and systems-based improvement. At the conclusion of this paper, the panelists will share their general pearls for success in managing pediatric musculoskeletal infection.

**This manuscript summarizes key and representative points from each panelist. Areas of disagreement or controversy are highlighted to demonstrate areas that are potential areas for further investigation and/or systems-based improvement.*

Case 1: A 2-year-old with a Presumed Isolated Septic Hip

History: A 2-year-old otherwise healthy female is brought to the emergency department by her parents with concerns regarding worsening left leg pain over the past 3 days without antecedent trauma. Initially, the pain was associated with a limp, but over the past 12 hours, the patient has refused to bear weight on the left lower extremity. The pain has been associated with subjective fevers at home and with decreased oral intake. On presentation to the emergency department, the patient is febrile to 38.2°C and is holding the left lower extremity in a flexed and externally rotated position. Any range of motion of the left hip from this resting position elicits significant discomfort. On examination, there is no other areas of effusion, swelling, skin discoloration,

or masses. Laboratory studies are notable for a white blood cell (WBC) count of 14.3 k/uL (71% Neutrophils, ANC of 10.080 k/uL), a platelet count of 305 k/uL, a Sedimentation Rate of 42 mm/hr, and a C-reactive protein (CRP) 6.89 mg/dL. Blood cultures are drawn but are not back yet. It is now 10:30 pm. The patient last ate solid foods 3 hours ago. A radiograph and an ultrasound are ordered (Figures 1 and 2).

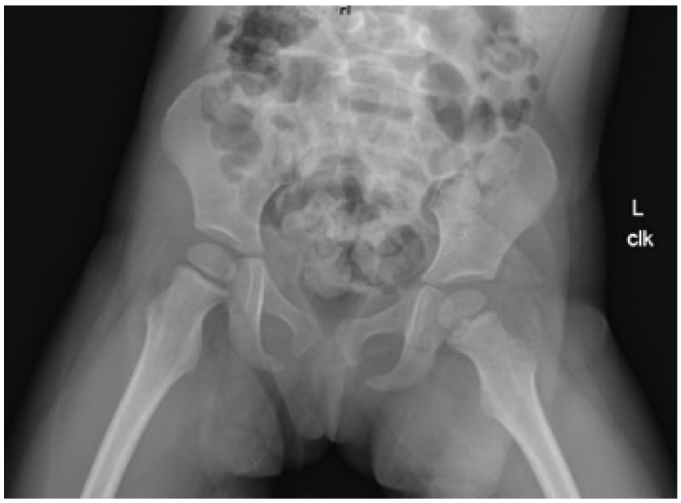

Figure 1. *Plain radiographs of the hip and pelvis reveal no osseous abnormalities. The left hip is in an abducted position and slight joint space widening may be appreciated in retrospect.*

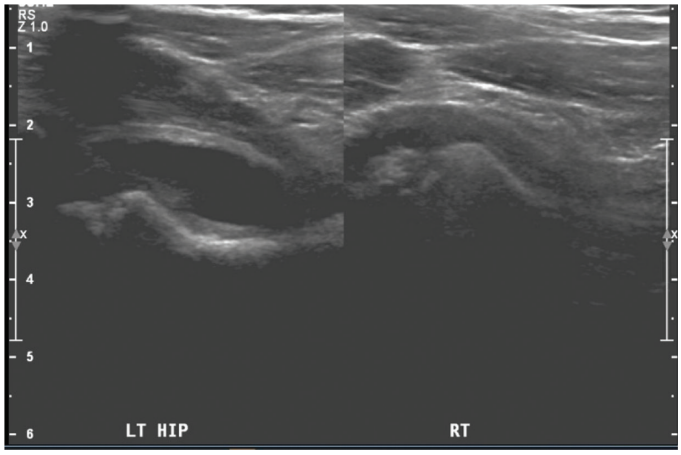

Figure 2. *An ultrasound reveals a left hip effusion.*

At your institution, how is this case typically handled?

1. **Who typically performs the hip arthrocentesis for a case like this at your institution?**

TB: Hip aspirations, when there is a high suspicion for infection, are done intraoperatively by an orthopaedic attending with large C-arm. When there is a lower suspicion for infection or if access to operating room (OR) is limited, aspiration is done by an interventional radiology (IR) attending, who uses ultrasound.

JGS: There would be variability in how this would be managed, but it would be one of either two ways. The patient could either be taken to the operating room the next morning and the aspiration would be done there, or if for some reason the attending on call is not convinced enough that this is a septic hip and warrants a washout, then the resident would aspirate the hip using a portable small fluoroscopy machine.

2. **Do patients with presumed septic hips get MRIs in advance of surgical intervention?**

LC/TB/JSS: Because of the risk of contiguous osteomyelitis or pyomyositis, we almost always recommend an MRI in advance of surgery for a presumed septic hip (provided that it does not cause an undue delay in the time until surgical debridement).

JGS: Generally for both a presumed septic hip or knee, in patients over the age of four we will get a non-sedated fast sequence MRI first as published in *JPOSNA®*.[12] Under the age of four, it depends on how definitive the physical exam is.

3. **Do you typically hold antibiotics prior to performing an arthrocentesis?**

LC/TB/JSS: Yes, our algorithm is to hold antibiotics unless the patient is decompensating clinically.

JGS: We do not hold antibiotics if the CRP is greater than 5mg/dl for an aspiration or washout.

4. **If you have a morning orthopaedic add-on/"trauma block," is a case like this booked into that or is it performed in the middle of the night?**

TB: I would proceed urgently to MRI and then likely OR. A possible septic hip has the unique risk factor of avascular necrosis. I would generally not wait for dedicated morning add-on time in this scenario.

JGS/JSS: This case is urgent and would be added to the operating schedule the following day to go into the "trauma block," typically as the first case.

With respect to surgical intervention:

1. **What type of approach do you perform for a standard hip arthrotomy?**

TB/JGS/JSS: An open modified Smith-Petersen approach through an oblique "bikini line" incision. The joint is irrigated with syringes attached to cystoscopy tubing, a 14-gauge IV catheter, or a red rubber catheter depending on the patient's age/size.

LC: I would use an arthroscopic approach. This is typically through a single anterolateral portal with fluoroscopic assistance. I use 40 to 50 mm Hg pressure and moderate flow through a dual-armed arthroscopy cannula which allows for inflow and outflow. Technical details of this approach as well as a techniques video were reported by Ellis et al.[17]

2. **If a preoperative MRI reveals proximal femoral signal change without an abscess, do you routinely drill the cortex to "decompress" the medullary space?**

TB/JSS: Yes, with a small caliber drill, usually a 2.7 or 3.5 mm or similar.

LC: Yes, I use a 7.3 mm cannulated drill (percutaneously up the femoral neck). I take a culture and I leave a 10 French Hemovac drain limb in the bone.

JGS: No.

With respect to postoperative management:

1. **Do you monitor for avascular necrosis with any imaging studies? If so, at what interval/time point(s)?**

JGS: Only if symptoms warrant.

JSS/TB: X-rays of the pelvis are obtained at 3, 6 and 12 months postoperatively, and if any question of possible avascular necrosis (AVN), an MRI is obtained.

2. **Are there any other pearls you would like to share?**

LC: I do not place as much value in the cell count as I once did. I have found such a wide range of cell counts in cases of confirmed septic arthritis (organism identified by culture or PCR), that I might have otherwise made the mistake of not draining the joint surgically if I had been influenced by a lower number. That would make me uneasy if I later found out the culture was positive.

JGS: Yes, be absolutely certain that you know what you're washing out. Especially over the age of four, do not have satisfaction of search.

Case 2: Distal Femur Osteomyelitis Without Associated Abscess

History: A 6-year-old otherwise healthy male is brought to the emergency department by his parents with concerns regarding worsening right knee pain for 6 days associated with fevers measured as high as 101°F at home. He was initially seen at an outside emergency department 3 days prior; x-rays were unremarkable and laboratory studies showed a slightly elevated CRP of 1.0 mg/dL. He was discharged home at that point with a plan for close outpatient follow-up. Given the persistent pain despite and new refusal to bear weight on the right leg, he re-presents to the emergency department, afebrile (Temp 37.3°C) and non-toxic appearing. On examination, there is no discrete knee effusion, swelling, or skin discoloration. He has tenderness to palpation

over the lateral distal femur. Active knee range of motion is present from 0-110 degrees of flexion with terminal flexion being limited by pain. Laboratory studies are notable for a WBC count of 12.3 k/uL (73% Neutrophils, ANC of 8.870 k/uL), a platelet count of 360 k/uL, a Sedimentation Rate of 34 mm/hr. and a CRP 5.6 mg/dL. Blood cultures from the emergency department room visit three days prior show no growth to date.

An x-ray of the right knee reveals no abnormalities. An MRI of the knee is obtained without sedation or contrast (Figures 3 and 4).

At your institution, how is this case typically handled?

1. **Do you typically treat osteomyelitis without abscess empirically or insist on a bone biopsy to guide antibiotic therapy?**

TB: For a case like this, we typically treat empirically with antibiotics without performing a bone biopsy in advance. Blood cultures are obtained prior to beginning antibiotics. I tend to recommend biopsy only in cases of chronic infection or to rule out chronic nonbacterial osteomyelitis (CNO) or other unknown etiologies.

LC: If the child is not undergoing sedation for the MRI, we would not put them under anesthesia for a biopsy and culture. Rather, we would initiate empiric antibiotics based on our local microbiome/antibiogram. There is sufficient MRSA in our community that we need to cover it with clindamycin. If obtaining the MRI requires sedation, we like to perform a needle biopsy and culture of the bone while under continued sedation, immediately after the MRI. If the blood culture is positive before we do this, we do not proceed. For many anatomic locations, like the distal femur, we do the aspiration by anatomic landmarks in the Radiology Anesthesia Unit. However, if the anatomy is more challenging (e.g., femoral neck) we do the procedure in the operating room with C-arm, under the continued sedation of the MRI.

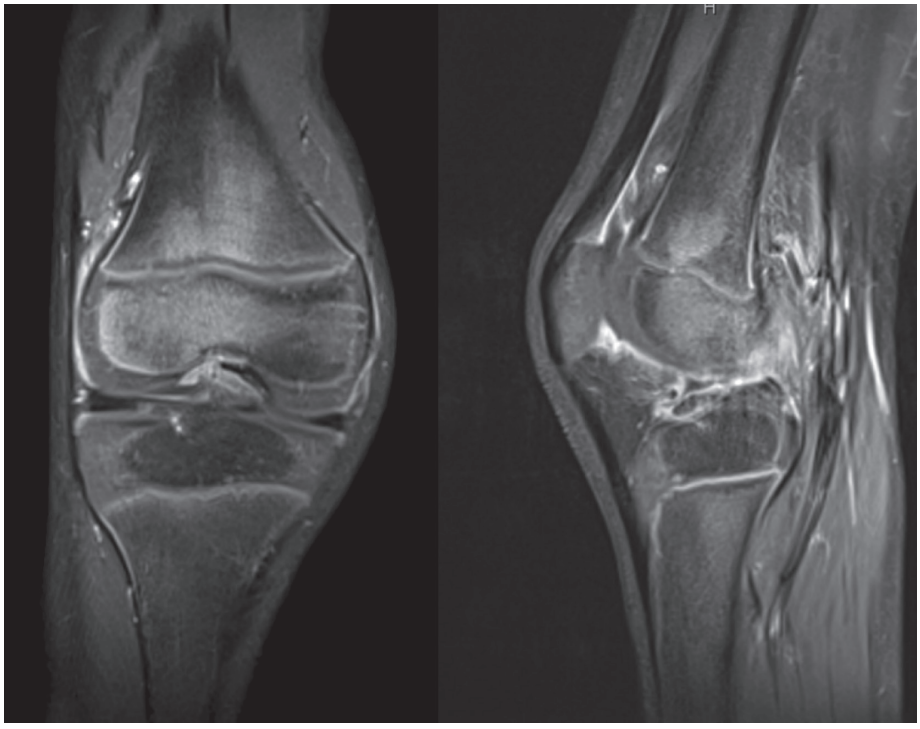

Figure 3. *T2 weighted images of the knee demonstrate hyperintense marrow signal and enhancement in the lateral distal femoral epiphysis. There is no discrete subperiosteal or intraosseous abscess.*

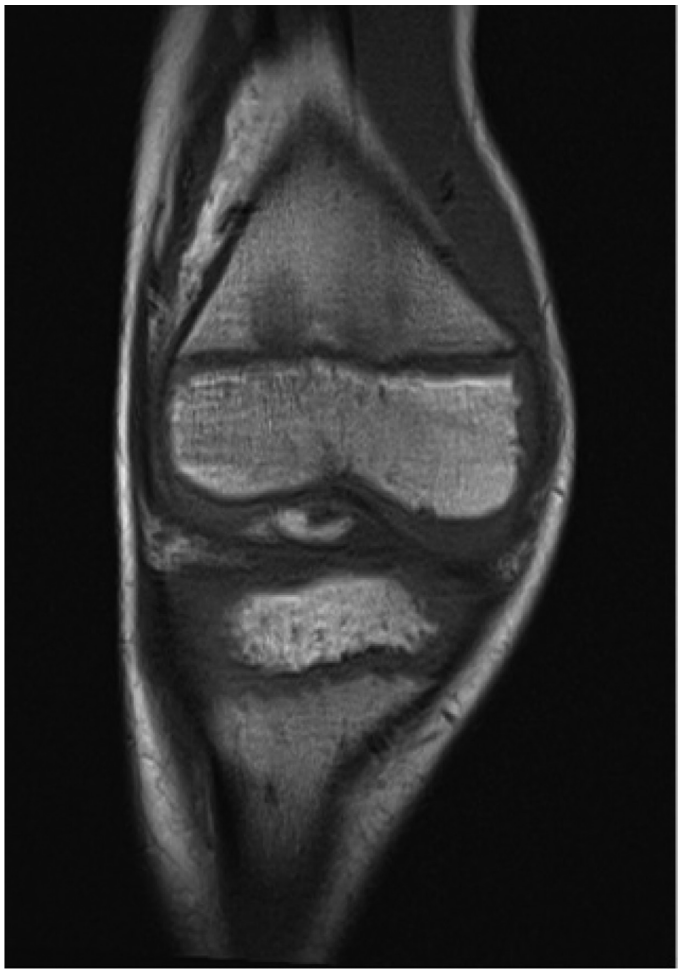

Figure 4. *T1 weighted images of the knee show subtle low intensity of the lateral epiphysis when compared to the marrow in the medial epiphysis.*

JGS/JSS: Our algorithm recommends biopsy for source identification and empiric antibiotics until culture results and sensitives are available to tailor antibiotics further. In most cases, the biopsy is done by the orthopaedic surgery team in the operating room with fluoroscopic guidance.

2. **In osteomyelitis cases without an associated abscess, do you typically recommend drilling of the bone?**

TB/JGS/JSS: No.

LC: It depends on the severity of illness of the affected child and the appearance of the bone on imaging. I almost never recommend "drilling the bone," either the bone needs to be addressed by surgical debridement or it doesn't.

Case 3: Distal Tibia Osteomyelitis with Associated Subperiosteal Abscess

History: A 5-year-old otherwise healthy female is brought to the emergency department by her parents with concerns regarding left ankle pain which progressively worsened over the past 5 days. The pain has been associated with intermittent fevers measured as high as 103°F at home. She was seen initially at an outside urgent-care center where radiographs were normal, and she was placed in a controlled ankle motion (CAM) walking boot. Given the persistent pain and fevers, she presents to the emergency department at the recommendation of her pediatrician. On presentation to the emergency department, the patient is febrile to 39.4°C. On examination, there is no appreciable ankle effusion, swelling, or skin discoloration. She has tenderness to palpation in the distal anterior tibia. Ankle motion is present from neutral to 20 degrees of plantarflexion, limited by associated pain in the distal tibia above the ankle. Laboratory studies are notable for a WBC count of 10.8 k/uL (77 % Neutrophils, ANC of 8.280 k/uL), a platelet count of 287 k/uL, a Sedimentation Rate of 74 mm/hr., a Procalcitonin of 0.16 ng/mL, and a CRP 3.7 mg/dL. Blood cultures are drawn but are not back yet. The patient last ate solid food at 2 pm. It is now 6 pm.

Plain radiographs of the ankle are obtained (Figure 5).

At your institution, how is this case typically handled?

1. **In the setting of suspected osteomyelitis, do you typically hold antibiotics prior to advanced imaging/biopsy or give them right away?**

LC: We allow the primary admitting service the latitude to determine if antibiotics are merited based on the evolving illness of the child. As we don't rush these cases to MRI or the operating room, it presumes a lot for us to have them admitted to a pediatric service and tell them to hold antibiotics. We ALWAYS recommend drawing a blood culture before antibiotic administration. We also recommend holding antibiotics in the setting of suspected primary septic arthritis.

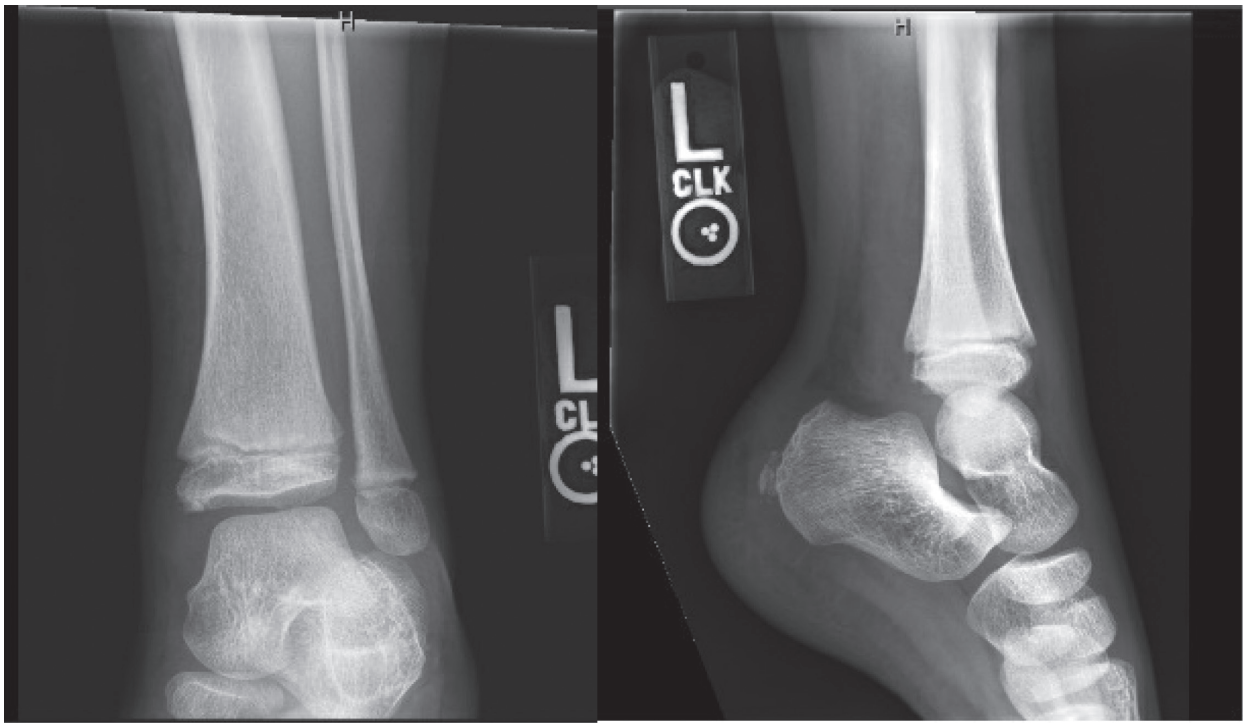

Figure 5. *AP and Lateral radiographs of the left ankle reveal soft tissue swelling but no osseous abnormalities.*

JGS: If the patient's CRP is over 5 mg/dl, we give antibiotics prior to biopsy. If it is under, we hold—unless no intervention is planned.

2. **Do you routinely use any imaging modality other than x-rays/MRI in the setting of suspected osteomyelitis (e.g., CT scan, bone scan etc.)?**

All Panelists: No.

3. **At what age does your institution typically recommend/require sedation for MRI?**

JGS: We always attempt a non-sedated scan first, regardless of age.

TB/LC/JSS: There is not a strict age rule and it depends heavily on the personality of the patient. Generally, children above age 5 or 6 years can lie still long enough for us to get reasonable images to make a diagnosis and guide treatment. Pain and anxiety are factors in some older children, so it is a case-by-case decision.

4. **If a patient requires sedation for MRI, do you coordinate for an OR room to follow in case imaging reveals that surgical intervention is needed?**

LC: We always try to coordinate a procedure to follow by blocking an OR room and team. We give OR a general impression of the relative likelihood of the need for a procedure based on all that we know about the child on the basis of history, physical findings, laboratory results, and preliminary imaging. For low likelihood cases, they have the next patient brought down to the pre-anesthesia holding area and do not open the room or equipment for our case until we call them to confirm that we need to go. For high likelihood cases, the team is prepped to go, and they do not send for the next patient yet.

JGS: No.

TB/JSS: Yes, if possible, though in practice it varies. It is a complicated logistics challenge and it depends on OR availability and the pre-test suspicion for infection.

5. **In what instances do you typically recommend contrast with MRI?**

TB: At our center, all patients under age 2 receive contrast enhanced MRIs. I also obtain contrast enhanced studies in patients with lower concern for infection, when perhaps clinical and laboratory data are conflicting or do not suggest a high likelihood for infection.

LC: I almost never need contrast to determine the presence of abscesses or their approximate volume, so I do not recommend using it. Whenever possible, I discuss this with the radiologist who is interpreting the MRI, real time, as the scan is being done. If we are both in agreement that contrast would not add additional guidance, then we stop the scan after the non-contrast sequences.[6] With this approach, our utilization of contrast has become increasingly rare as published by Ojeaga et al.[18]

JGS: Only in instances of a chronic infections or confusing clinical scenarios where more information is needed.

JSS: All screening MRIs for infection at our institution receive contrast, unless contraindicated.

Case Continues: An MRI is obtained which reveals findings consistent with distal tibia osteomyelitis (Figure 6).

With respect to surgical intervention:

1. **Do you use a tourniquet if performing an irrigation and debridement for osteomyelitis?**

TB/LC: Occasionally, if it is possible (distal femur, knee joint, proximal or distal tibia, or ankle joint). We don't use an Esmarch for exsanguination. We just elevate and inflate.

JSS / JGS: No.

2. **How do you prefer to obtain specimens for cultures in this setting?**

LC: The easiest way to get bacteria from an infection sample in which bone is the source is to take the pus from within or around the bone when the periosteum is incised. We usually just remove the plunger from a syringe and allow the pus to pour into the back of the empty syringe, then replace the plunger (carefully). If this is not the case, I will place a needle into the cancellous bone and aspirate until I get 1 mL of bloody fluid.

JGS/JSS: We typically aspirate the subperiosteal abscess fluid via a large bore needle prior to opening the periosteum. The local cancellous bone is also gently curetted and sent for culture.

3. **Do you send cultures for anything beyond aerobic and anerobic organisms? (e.g., AFB, fungal etc.)?**

TB: Always. I also always send a sample of tissue labeled "hold for PCR" in event cultures are negative and note for microbiology lab to holds the specimens for at least 1 week.

LC: We send aerobic culture and a specimen of bone for pathology. If the child has a compelling history of penetrating inoculation or immunocompromise, we send for AFB and Fungus. I try to avoid sending anaerobic cultures any longer due to the high rate of contaminants.

JGS: Not unless it is a weird case.

JSS: We send a MRSA/MSSA rapid PCR (which reflexes to Kingella if Staph Aureus PCR is negative, and the patient is under 5). AFB and fungal are requested only if there is a clinical concern for an atypical organism. We also send permanent pathology routinely.

4. **In cases with osteomyelitis and a subperiosteal abscess, do you routinely vent open the bone?**

TB/JGS/JSS: Yes, I vent with a 2.7 or 3.5 mm drill to make a single hole to get a curette in.

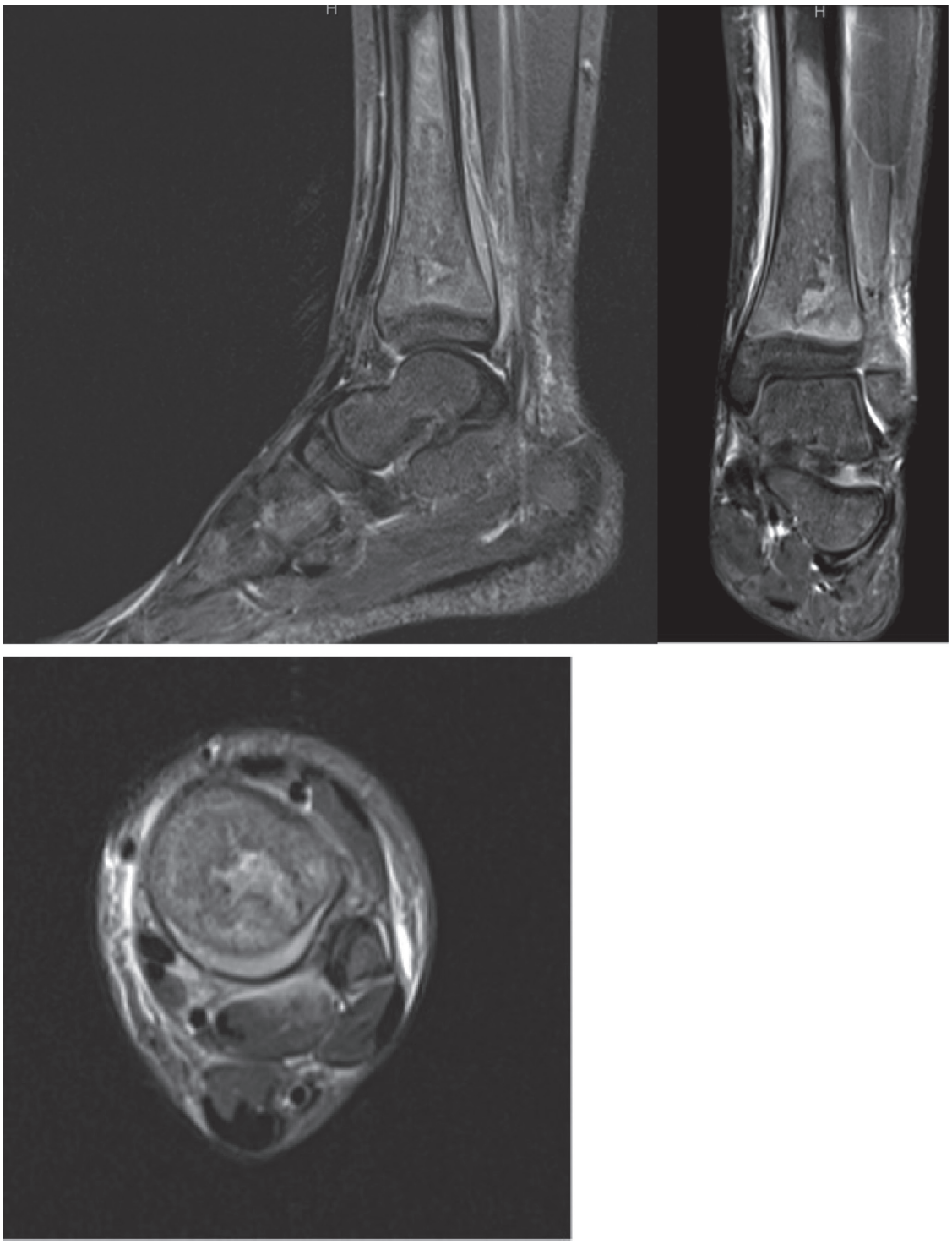

Figure 6. *Sagittal, coronal, and axial T2-weighted images of the left ankle show increased signal throughout the distal tibia consistent with osteomyelitis. There is an associated subperiosteal fluid collection in the posterior distal tibia and a more focal irregular/lobular area of abnormal marrow signal concerning for a developing intraosseous abscess.*

LC: I use a sliding scale approach based on the severity of illness of the child. If the child is in septic shock, on pressors, and in the ICU, they will get a bone window (1 cm by 3 cm) over the metaphyseal cancellous region, and I will remove all of the cancellous bone I can reach by straight and angled curettes (avoiding the physis). I will ensure that I have clear communication with the medullary canal. I do not do this for the proximal femur or calcaneus, as there is risk for pathologic fractures and collapse. I drill decompress the proximal femur and make a slotted channel in the posterior tuberosity of the calcaneus to take away pressure and increase antibiotic penetration.

5. Do you use any topical antibiotics?

TB/JGS/JSS: No.

LC: Not for acute, uncomplicated cases. For chronic or subacute cases which have not responded to primary treatment, I place Calcium Sulfate pellets loaded with vancomycin and tobramycin.

6. Do you use a drain? If so, what type and how long is it left in?

TB: Yes. I typically use a Channel drain and leave it in place for 2-3 days.

LC: I use a 10 French Hemovac drain with one limb placed inside the bone window and one limb in the subperiosteal space. It is left until output is <5 mL in a 24-hour period. I send patients home with this drain if it has not slowed down sufficiently by the time they have clinical and laboratory improvement to allow transition to oral therapy and discharge. I have had the drains last 4-6 weeks.

JGS: I use a Penrose drain in the subperiosteal space filled with wound vac sponge with an incisional type wound vac (Figure 7).

JSS: Very rarely will I leave a drain.

7. Are there any other surgical pearls you would like to share related to this type of case?

TB: Like an I&D in the setting of an open fracture, where the debridement is the most important portion of the procedure, I view infection cases similarly. The most experienced person should be the one doing the debridement. It should be aggressive.

LC: Not every child needs surgery. The occurrence of surgery does not equate with the need for surgery. Small abscesses (1-2 cm, and sometime much larger) will resolve with antibiotics and absorption. I have observed 7 mL volume abscesses resolve completely over time. I look at the illness of the patient to guide what surgery I do, rather than metrics taken from the MRI. I have seen providers not operate on children in the ICU, on pressors or extracorporeal membrane oxygenation (ECMO), because they claimed that the bone did not "look bad" on MRI. All the while, the fever, inflammatory markers, and vital signs were progressing the wrong direction. When all of the foci were subsequently addressed (as described above), the children rapidly improve. Surgical source control is strongly recommended for the sickest children. Otherwise, the ICU and Infectious Disease (ID) teams will be fighting a very frustrating battle with the only tools they have (pressors, antibiotics).

8. Do you immobilize or restrict weight-bearing to the involved extremity for any period of time (e.g., CAM boot, Knee immobilizer, etc.)? How are activities advanced?

TB: Unlikely in this case. I do hold them from sports/athletics until they have completed antibiotic treatment.

LC: Children with bone debridement have weight-bearing restrictions. If they are unsafe with that or there is a vulnerability of pathologic fracture, I sometimes use casts, splints, braces. I prefer no immobilization to allow range of motion and better ability to observe the limb during recovery.

JGS: The need for weight-bearing restrictions depends on whether the bone is dead. If so, then yes.

9. How/when do you monitor for physeal arrest on postoperative follow-up?

TB/JSS: For peri-physeal infections, x-rays are obtained at 3 and 6 months or until certain normal growth can be visualized—longer if any concerns.

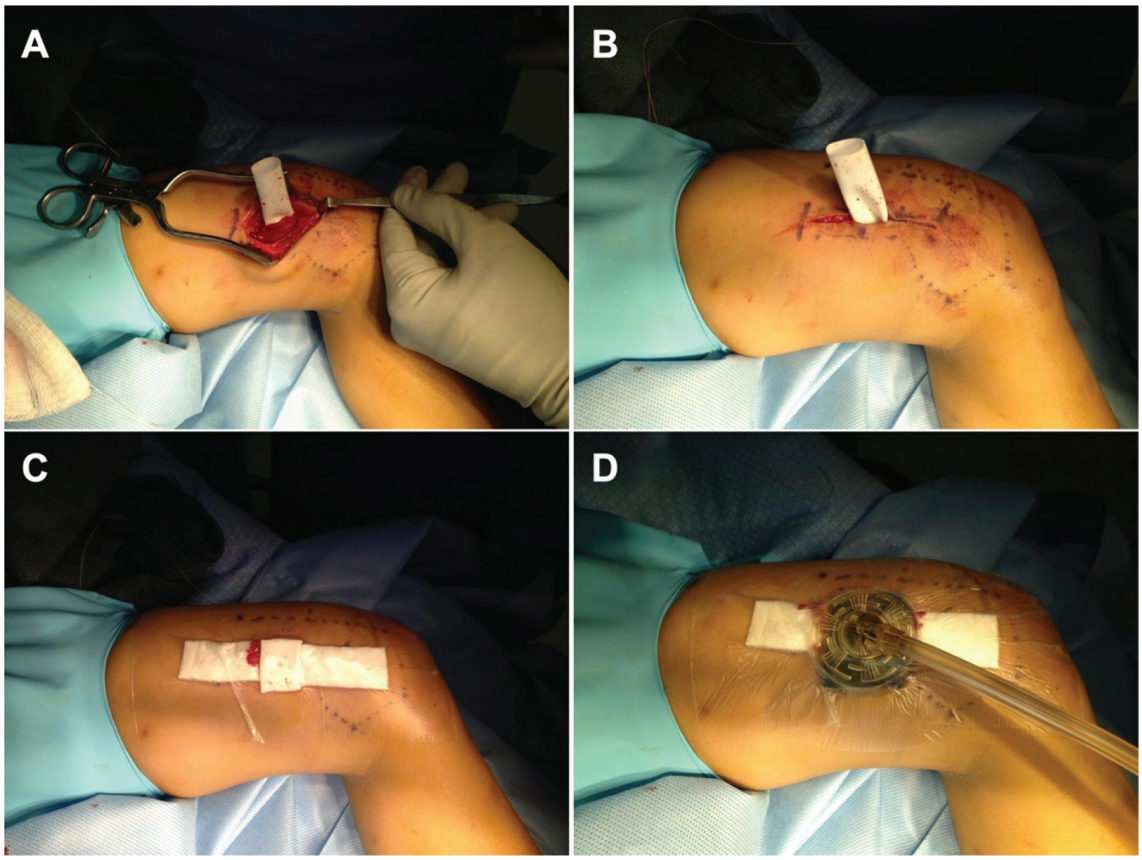

Figure 7. *(A) Penrose drain placed in subperiosteal space following irrigation and debridement of distal femoral osteomyelitis with associated subperiosteal abscess in a 4-year-old patient. (B) Wound is closed around the Penrose drain. (C) Wound VAC applied over the Penrose drain. (D) Completed construct with wound VAC tubing applied. Images courtesy of Dr. Jonathan G. Schoenecker, Vanderbilt University Medical Center.*

LC: It depends on their relative likelihood to have a physeal arrest of clinical significance. This depends on their age and severity of illness. Higher risk with high severity of illness patients (Severity score 7-10).[7,19] Those children have long inpatient courses with multiple surgeries. I usually follow them most closely for 3-6 months and the problem becomes clear. The child in this case would not be anticipated to have an issue.

General Pearls for Success from a Systems Standpoint When Managing Pediatric Musculoskeletal Infection

1. **Tell me about the structure/organization of pediatric musculoskeletal infection at your institution.**

TB: We closely collaborate with infectious disease on all patients admitted with suspected musculoskeletal infection. Unless there are significant medical comorbidities or patient is < 12 months of age, the orthopaedics service admits patients and infectious disease consults. We have surgeon that covers trauma and infection cases, with continuity for the week before transitioning to another attending surgeon. We have a musculoskeletal infection pathway that was designed in collaboration with the emergency department.
The logistical challenges of how and when to obtain advanced imaging is one of the more difficult things about managing these patients. Like many institutions, we are limited by MRI, sedation, and OR access. While not for all circumstances, we have utilized a very rapid sequence fast protocol MRI for patients ages 2-10 with high suspicion for infection based on labs and clinical history. This allows us to confirm (or rule out) potential

musculoskeletal infection. While not perfect, it is another tool available to us, and the imaging takes under 10 minutes, obviating the need for sedation. Patients are followed regularly after leaving the hospital by both ID and orthopaedics.

LC: In 2005, we established a Core Committee for Pediatric Musculoskeletal Infection which has representatives from each of the stakeholder services (Orthopaedics, emergency department, Pediatric Hospitalist Medicine, Intensive Care, Infectious Disease, Radiology, Anesthesiology, Laboratory/Pathology, Nursing, Pharmacy, Social Work and Quality (hospital administration). The team developed institutional guidelines/algorithms and did a level of evidence literature review to ensure the guidelines were supported by existing evidence. We put the guidelines into practice in 2009 and then improved them to apply for a Joint Commission Disease Specific Care Certification in Pediatric Musculoskeletal Infection. We have organized and championed a team approach to communication, patient workflows, image acquisition, surgery, and discharge planning. To encourage participation and knowledge sharing, we have an ABMS Maintenance of Certification program that allows providers of a variety of primary care and subspecialties get board certification credit for attending annual stakeholder updates and participate in the care of our patients. We have all musculoskeletal infection patients followed in a single outpatient clinic by a single provider who ensures appropriate antibiotic administration for compliance and duration. This facilitates long-term outcome studies and monitoring for complications.

Prior to the COVID-19 pandemic, we did daily team rounding with the family in our conference room on the inpatient ward. This included the parents, pediatric hospitalist, orthopaedic attending, residents, APPs, charge nurse, floor nurse of the patient, care coordinator, and physical therapy. After the onset of the pandemic, we have trialed several virtual rounding platforms and have settled on a Zoom App that allows family members who are not in the hospital to follow along during team rounding. It also enables other services who need to weigh in for decisions (ID, Rheumatology, Hematology, Cardiology) be able to call in briefly on their Smart Phone, wherever they may be at the time of the meeting.

Our MRI process has led to substantial improvements in patient workflows pertaining to image acquisition and coordinated procedures.[18] We have a morning huddle in radiology with the anesthesiologist and radiologist working the magnet that day. We schedule the coordinated cases in the afternoon when the safety capacity of OR teams and rooms is more flexible. We communicate diligently in the morning and immediately prior to scanning so that everyone has the same understanding of the relative probability of the case going upstairs. Doing all of this has cut scan duration to about 10-15 minutes and reduced the number of sedated scans.

JGS: All pediatric musculoskeletal infections are admitted to the pediatric hospitalist service with orthopaedics as a consulting service. The hospitalist team organizes and handles communication between different care teams. Our workup principles have been recently published in *JPOSNA®*.[12] At Vanderbilt, we have clinically care pathways designed to streamline and standardize care for patients with musculoskeletal infection through all aspects of their care (including diagnosis, initial management, and ongoing/outpatient management (Additional Links #3). We believe that these pathways help facilitate care in an institution with many trainees and serve to decrease variability.

JSS: We have a robust multidisciplinary musculoskeletal infection service with a detailed protocol in place (Additional Links #4). All suspected MSKIs get labs, blood cultures, and x-rays in the ED, followed by admission to the pediatrics team, with orthopaedics and ID teams consulting. We had a dedicated daily first start sedated MRI slot as well as a dedicated daily orthopaedic urgent room, so patients are usually able to obtain an MRI and then go straight to the OR under the same sedation if necessary. There are daily MSK infection rounds (ID, Peds, Ortho, +/- Radiology) which are

attended by one of two ortho attendings who specialize in MSK infection. IV antibiotics begin with cefazolin and are then tailored based on source identification. Patients are transitioned to oral antibiotics as soon as sensitivities are available, the patient is improving clinically, and the CRP is down. Patients are generally discharged as soon as they are tolerating oral antibiotics. After discharge, patients follow up with Ortho and ID at a coordinated clinic visit for as long as indicated.

2. In your mind, what is the most common mistake that you or other orthopaedic surgeons have made in the management of pediatric musculoskeletal infections?

TB: There is an old orthopaedic adage, "Culture every tumor and biopsy every infection," and I think those remain wise words. I send tissue for biopsy and culture—every time. As a result, I've diagnosed Langerhans Cell Histiocytosis (LCH) and Chronic Non-Bacterial Osteomyelitis (CNO) on more than one occasion by sending adequate tissue for pathological examination in cases that appeared to be "obvious" infection.

LC: Over treatment and under treatment. Too many surgeries have been done in cases when one might have sufficed. I have also seen too minimal of an approach in cases of really sick children when the appropriate approach should have been an aggressive "full court press." I will operate after hours and on weekends when I am not on call if a child is just coming off ECMO so that I can ensure the most aggressive surgery is done after imaging of all suspected foci. That avoids repeat trips to the operating room.

JGS: I think that the biggest misconception by orthopaedic surgeons is the notion that isolated infections are the predominate clinical entity we treat, essentially a form of anatomic ascertainment bias. By not understanding the infection acute phase response,[20] one does not properly understand how to interpret severity of disease.

JSS: The most common mistake I see is failure to be aggressive enough with an infection. I have seen many patients with infections that may have been recognized but were allowed to progress, either due to incomplete surgical decompression/debridement or inadequate/inappropriate antibiotic treatment. If a patient is not improving either on clinical exam or by imaging or laboratory assessment, then they are failing treatment, and something needs to change.

3. What do you see as the "next big thing" on the horizon in the management of pediatric musculoskeletal infection?

TB: The "next big thing" in my mind isn't a new lab test or antibiotic but rather taking time to reduce variability in how your group approaches and manages infections. Hospitals are complex systems and anything that can enable access to limited resources of advanced imaging and operating room time and minimize variation with standardized treatment pathways/protocols at your institution is a worthwhile investment.

LC: I think the biggest advance on the horizon relates to **c**oncepts of decision hygiene to reduce Noise and Ignorance in the treatment of infection. The concepts are introduced very nicely in the book *Noise* by Daniel Kahneman.[21] Judgment under uncertainty is critical for evaluation of children who do not have infection but appear as if they might. The old thinking of clinical prediction algorithms (while better than human judgment alone) will be outpaced by a systematic approach with all system 2 data collection and thinking preceding system 1 intuition. We need both to have the highest accuracy to guide initial decisions and triage these children appropriately.

JGS: In the future, I look forward to much more rapid diagnostics that can be done serially. This will include fast assessment of the acute phase response along with very fast MRI acquisition.

JSS: One big breakthrough on the horizon will be the ability to rapidly identify virulence and behavior through efficient and widely available testing. The ability to rapidly identify infections through a finger prick while anticipating sensitivities based on genetic markers in

bacteria will improve and expedite the care we provide. The benchwork being done now will have a huge impact on our clinical practices within the next 10 years.

Summary

Management of pediatric musculoskeletal infections requires multidisciplinary collaboration, and pediatric orthopaedic surgeons are essential to ensure optimal patient outcomes. Protocols that standardize decision-making have been shown to reduce treatment variability, decrease length of hospital stay and increase medical team efficiency.[22] Treatment algorithms may differ in the management of septic arthritis and osteomyelitis, within and between institutions and geographic regions. The disagreement on care pathways leads to variable patient outcomes.

Among our expert panel, most agree that these cases are urgent and can be scheduled during dedicated OR time as opposed to emergently as an add-on in the middle of the night. There is extensive data to prove that physician fatigue increases medical errors; thus, operating while well-rested would decrease rates of preventable complications.[23,24] There is agreement within our panel on the utility of pretreatment MRIs to identify underlying conditions which would impact treatment regimen or cause a return to the OR in patients with presumed septic arthritis of the hip. However, there is disagreement on the use of sedation and contrast with imaging. Nephrotoxicity associated with contrast use may add to the potential complications facing patients at this stage of treatment.[6]

Most of our experts approach a hip arthrotomy for septic arthritis via an open Smith-Petersen while others opt for an arthroscopic approach. Open incisions have been the mainstay of treatment, but recent evidence has shown more orthopaedic surgeons opting for an arthroscopic approach, which may decrease length of hospital stay.[25,26] There is disagreement among our group as to whether a bone biopsy should be routinely performed when treating osteomyelitis without an abscess. When performing a bone biopsy, some experts will only culture routinely for aerobic and/or anaerobic bacteria while others may include culture for fungi or acid-fast bacillus.

There is general agreement among our experts on a 3-6-month timeline for follow-up after treating osteomyelitis, except in cases of unusually high disease severity.

General pearls for success when treating pediatric musculoskeletal infections include employing a multidisciplinary approach, using care pathways to ensure predictable outcomes, and securing dedicated OR and MRI blocks to address these cases.

Additional Links

- Moore-Lotridge, S. N., Gibson, B. H., Duvernay, M. T., Martus, J. E., Thomsen, I. P., & Schoenecker, J. G. (2020). Pediatric Musculoskeletal Infection: An Update Through the Four Pillars of Clinical Care and Immunothrombotic Similarities with COVID-19 - *JPOSNA®* 2020 Aug; Vol. 2 No. 2.
- Ellis HB, Copley L, Pennock A, Nepple JJ, Willimon C, Mayer SW, Yen YM. Tractionless Hip Arthroscopy for Septic Arthritis in Children - *Arthroscopy Techniques* 2021 Mar; v. 10(3).
- Vanderbilt's Pediatric Musculoskeletal Infection Diagnostic Algorithm
- Children's Hospital Colorado: Musculoskeletal (MSK) Infection

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