

# Chronic osteomyelitis: a review on current concepts and trends in treatment

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## Abstract

Osteomyelitis is a complex and potentially devastating condition. Appropriate therapy requires a multimodal orthoplastic approach and the cornerstone of treatment is surgical management. The aim is eradication of infection by thorough debridement, leaving only viable tissue and restoring function. Despite the unquestionable need for surgical debridement in chronic osteomyelitis, the need for reliable radiological and tissue diagnosis along with appropriate antimicrobial therapy is paramount for the success of treatment. The route of administration and duration of antimicrobial therapy continues to be debated. The role of biofilm is now clearly established in the chronicity of bone infection, and newer modalities are being developed to address various issues related to biofilm formation. We aim to review the current trends and concepts for treatment of chronic osteomyelitis in this article. This includes the traditional and more novel techniques for obliterating osseous and soft tissue dead space as well as restoring bony stability and function.

**Keywords** biofilm; dead space; debridement; infection; osteomyelitis; reconstruction; sequestrum; treatment

## History of management

The French surgeon Edouard Chassaignac was the first to introduce the term osteomyelitis in 1852, when extensive

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debridement and early amputation were the mainstays of treatment. Lister in 1867 applied Pasteur's discoveries using carbolic acid as a disinfectant in open fracture management. Later on, Esmarch in 1873 advised removal of sequestrum and described the Esmarch rubber tourniquet as a means to avoid massive haemorrhage while performing debridement for chronic osteomyelitis.

During World War I, Carrel and Dakin used continuous irrigation to chemically sterilize open fractures with good results, reportedly due to the chlorine solution used although it was stated that similar results would be obtained with an inert solution and that the value of the treatment laid in the debridement technique itself.

Winnet Orr in 1927 described his technique of extensive surgical debridement followed by Vaseline gauze packing and encasing the limb in plaster cast to allow the infection to 'burn out' inside the cast. As quoted from Orr, 'leave the wound alone. Each time you touch it, you stir up troubles'. Nevertheless, it had the drawbacks of prolonged immobilization producing joint stiffness, disuse atrophy and osteoporosis.

The discovery of penicillin by Fleming in 1929 marked the era of antibiotic treatment and some prophesized the eradication of osteomyelitis. Unfortunately, this has yet to be achieved and with increasing antibiotic resistance trials were eventually commenced using combined antibiotic therapy to overcome multiresistant organisms.

Early concepts of leaving wounds open and discharging changed to favour early closure with obliteration of dead space. Cancellous bone chips to fill the void of debridement were first described by Hassab and Eid<sup>1</sup> then by Papineau et al.<sup>2</sup>

A real contribution to dead space management was the development of bone transport, as described by Ilizarov. Good results were reported by many authors and the technique was later complemented by advances in soft tissue coverage. These advances have led to increased success in the management of chronic osteomyelitis and eradication of persistent infection compared to surgical debridement and antibiotic therapy alone.

## Clinical picture and diagnosis

The diagnosis of chronic osteomyelitis remains a challenge. Recognition of the clinical symptoms, along with imaging and laboratory investigations are mainstays for diagnosis.

The clinical features are heterogeneous and usually non-specific depending on the age of the patient, causative pathogen, area of involvement as well as the presence of co-morbidities. The most commonly reported clinical symptoms include relapsing pain, swelling and bone tenderness with sporadic episodes of low-grade pyrexia, often associated with persistent sinus tracts with purulent discharge. These symptoms are a reflection of the pathogenesis of chronic osteomyelitis, with cyclical pain that increases in severity and subsides when pus breaks out through the sinus. It must be remembered that a Marjolin ulcer, as a result of malignant squamous cell transformation in chronic osteomyelitis, is an easily missed but serious complication with the duration of osteomyelitis being the single most important risk factor.

A number of laboratory investigations can aid with the diagnosis, although all lack specificity for osteomyelitis. Raised inflammatory markers such as C-reactive protein (CRP) and

erythrocyte sedimentation rate (ESR) are an adjunct to diagnosis and are useful for gauging clinical response to treatment. Typically, CRP and ESR are raised although white cell count is usually within normal limits. A normal CRP and ESR does not exclude osteomyelitis.

The gold standard for diagnosis is positive microbial cultures from bone biopsies and is the most sensitive diagnostic tool. Several investigators have emphasized the need for multiple culture samples in order to increase sensitivity and to overcome the problem of contamination. Most agree that samples from five or more sites should be obtained to increase the diagnostic yield. A broth enrichment medium is usually used to enrich growth of suspected pathogens in the culture sample.

Tissue samples should undergo both microbiological and histopathological analysis. Microscopy showing a significant presence of neutrophils and organisms on special stains indicates the presence of infection, even before culture results, and can show fungal spores. False-negative results can result from inadequate sampling or if samples were acquired after the start of empirical antibiotics. Conventional blood cultures are useful only in cases of haematogenous osteomyelitis.

Imaging modalities ranging from conventional radiography up to novel nuclear imaging techniques are invaluable contributors to the diagnosis of osteomyelitis. Plain radiographs are cheap and widely available. Changes include osteopenia, scalloping of the cortex and loss of the trabecular architecture of bone. The appearance of these findings is usually delayed by up to 2 weeks after the onset of infection and not until at least 30% of bone density is lost. Despite poor sensitivity or specificity and delayed diagnosis, it is still helpful in excluding other conditions such as fractures or malignancies. Sinography, which is the opacification of a sinus tract by retrograde injection of contrast material, defines the course and extent of the sinus tract and its communications. Sinography may be performed using plain radiography or combined with CT for better delineation of the sinus tracts.

Computed tomography (CT) provides the most detailed imaging of the cortical bone, and excels over other modalities in its ability to identify sequestrum, periosteal reactions and sinus tracts. It is useful both for diagnosis and surgical planning.<sup>3</sup> However, it is important to mention that in the presence of metalwork, there is substantial loss of image resolution and artifacts limit its reliability in such cases.

Magnetic resonance imaging (MRI) is more accurate in assessing bone marrow and soft tissue changes that usually precede any bony changes, allowing earlier diagnosis. It provides excellent spatial resolution and so can differentiate between intra- and extra-osseous involvement or bone from soft tissue infections. Nevertheless, its value is limited in the presence of implant, fibrous tissue and recent surgery. Intravenous gadolinium contrast MRI better differentiates between necrotic areas and fibrotic areas, such as in cases with previous surgical procedures.

Ultrasonography (US) is mainly used in the early stages for detecting purulent collections under elevated periosteum. Some authors suggest that in some cases it can be diagnostic and particularly helpful in directing guided biopsies, but reliable estimates of its specificity and sensitivity are yet to be determined. It is particularly useful in regions that are complicated by metal instrumentation and therefore might not be well visualized with MRI or CT, or in patients where MRI is contraindicated.

Bone scintigraphy has limited specificity and false-positive results occur particularly in cases of mechanically unstable non unions or crystal arthropathies, although it is less affected by metal artifact. Several agents have been studied, including technetium-99m-labeled methylene diphosphonate (99mTc-MDP), gallium-67 citrate, and indium-111-labelled white blood cells. Technetium-99m three-phase scans show accumulation of isotope in areas of increased blood flow and reactive new bone by adsorption into the hydroxyapatite crystals. On the other hand, gallium attaches to transferrin, which leaks from the blood-stream into areas of inflammation or infection but it does not specifically bind to bone. This indicates that gallium scans are more specific for infection, correlating more closely to it than do technetium scans.<sup>4</sup> It may reveal osteomyelitis even when technetium scans show decreased activity or cold lesions.

Leukocytes tagged with indium-111, similarly to gallium-67, do not show bony detail or distinguish osteomyelitis from soft tissue infections but are more specific for infection. The use of radiolabelled antibiotics is a novel technique offering even better differentiation between infection and sterile inflammatory lesions. The compound most extensively studied is 99mTc-ciprofloxacin.<sup>5</sup> A similar technique uses nuclear monoclonal immunoglobulins to tag leukocytes at areas of infection. The sensitivity for detection of osteomyelitis can reach 100% in lower leg and ankle infections using this modality.<sup>6</sup> Positron emission tomography (PET) using fluorine-18 fluorodeoxyglucose (FDG), however, has the highest sensitivity and specificity and its use is only limited by the high costs.<sup>7</sup> FDG has an affinity towards inflammatory cells, which usually have increased expression of glucose transporters, and so their differential FDG uptake is abnormally increased.

### Introduction to surgical management

Appropriate therapy requires a multimodal approach and the cornerstone of the treatment is surgical management. When such surgery is planned, a combined orthoplastic strategy is optimal and early input from plastic surgeons should be considered for combined care. The aim is eradication of infection by thorough debridement, leaving only healthy and viable tissue and restoring function. Despite the unquestionable need for surgical debridement in chronic osteomyelitis, it is unrealistic to expect that all infected or necrotic tissue will be removed and surgery should therefore be combined with both local and systemic antibiotic therapy.

### Patient preparation

Optimizing blood sugar levels in diabetics, renal and liver function and smoking cessation before surgery improves success rates. The treatment options should be discussed with the patient with a clear explanation that curative treatment frequently involves multiple procedures over many months. Alternate options of suppressive treatment or amputation should also be considered.

### Debridement

Adequate debridement is of paramount importance in surgical management and aims to remove all infected, necrotic bone and soft tissue identified at the time of surgery. Techniques should be

similar to those for tumour excisions.<sup>8</sup> There is a general consensus that the adequacy of debridement with wide excision margins is the most important clinical predictor of a successful outcome.<sup>9</sup>

Soft tissue debridement should be in an expansile manner rather than an extensile approach. Typically, microbiology sampling will occur at the time of initial debridement and it is crucial that samples are true representatives of the deep infection. Any instrument that contacts the skin should be considered to be contaminated. Retractors should be placed once and ideally without contacting the skin. A bloodless field aids sampling and where possible a tourniquet should be considered. In general, a scalpel should be used instead of cautery. Accessory sinus tracts will usually close with resolution of infection and do not need to be excised but can be useful roadmap to sequestrum and injecting the sinus with dye can be a useful adjunct. Debridement should leave healthy bleeding tissue and should not be compromised in order to achieve primary closure. When closure can be achieved, braided or absorbable sutures should be avoided due to their affinity to harbour microorganisms.

Bone debridement, coupled with removal of any underlying implant, follows soft tissue debridement. Periosteal stripping should be avoided to preserve vascularity. The aim is to excise necrotic tissue though traditionally large sections of bone were removed, which may have led to unnecessary morbidity. Involucrum is viable bone and does not need to be debrided. The limits of debridement have classically been determined by the 'paprika sign', which is punctuate cortical or cancellous bleeding.<sup>10</sup> A selection of sharp osteotomes, chisels, curettes, and gouges are crucial for effective debridement.

Endosteal infection can be debrided with intramedullary reaming and has this been reported to be a successful and reliable technique in several series.<sup>11</sup> This can be used in conjunction with intramedullary antibiotic-coated implants. The Lautenbach technique uses a closed irrigation suction system to wash antibiotics through the medullary cavity. Hashmi et al.<sup>12</sup> reported a series of 17 cases treated by this method with only one recurrence, which resolved after repeat treatment.

To overcome concerns of thermal necrosis the Reamer-irrigator-aspirator (RIA) system (Synthes, Inc. West Chester, Philadelphia) has been used for debridement, as well as bone graft harvest.<sup>13</sup> However, despite the reported encouraging results and low complication rates, its high cost mandates further research to delineate its role in managing long bone infections.

If infection extends into the metaphysis or preoperative radiographs reveal endosteal scalloping, intramedullary reaming may not be adequate. A recent modification of the Lautenbach technique is the 'gutter procedure and muscle flap transposition operation' by Gokalp et al.<sup>14</sup> who reported cures in 29 of 30 patients with chronic osteomyelitis. The created bone gutter allows good exposure while the transposed muscle allowed better vascularization and filling of the dead space. Any debridement poses a risk of iatrogenic fracture although stabilization may not be necessary when 70% of the original cortex remains intact.

### Dead space management

Adequate debridement should not be limited by concerns about the resulting osseous or soft-tissue defects or this will increase the risk of recurrence. Generally, the choice of reconstruction for

management of such dead space depends on the characteristics of the lesion following the debridement and the physiological grading of the host.

For osseous defects, shortening of long bones remains a viable option, as most long bones can tolerate some loss of length. Alternatively, small osseous defects that are structurally stable can be filled with a myoplasty, in which muscle is used to fill the defect. When the osseous defect cannot be managed by these simpler methods, the patient has a number of other options.

Bone grafting could be either open bone grafting, as in the classical Papineau technique which has been used to manage small defects successfully.<sup>2</sup> This technique is a staged procedure; after thorough debridement with saucerization the wound is either left open or filled with antibiotic beads for 10–14 days until granulation tissue is formed. Once granulated the defect is filled with cancellous bone chips. Once the graft has revascularized, it can be covered with skin graft or allowed to heal by secondary intention. Larger defects will require serial grafting because cancellous chips thicker than 2 cm can result in graft resorption. The reported success of this technique in the literature is 70–93%. An evolution of the technique is the closed bone grafting Belfast technique proposed by McNally et al.<sup>15</sup> which employs early soft-tissue cover followed by delayed bone grafting. The authors reported a cure rate of 92% with this technique.

Primary grafting is confined to small defects and has a risk of early resorption and unreliable graft incorporation. Koval et al.<sup>16</sup> compared three different methods for management of osteomyelitis and found that flap coverage had a higher success rate (80%) compared to either primary closure with suction irrigation or open cancellous bone grafting, which yielded unacceptable failure rates (44.5% and 60% respectively). High failure and recurrence rates of these techniques attest to the refractory nature of chronic osteomyelitis and the inherent difficulties in its eradication.

Antibiotic-impregnated polymethyl methacrylate (PMMA) beads elute bactericidal levels of antibiotics for 2–4 weeks and after removal there remains a sterile bed for cancellous or vascularized bone graft. Adams et al.<sup>17</sup> found that clindamycin, vancomycin, and tobramycin had the best elution characteristics and highest level in bone and granulation tissue. Cierny<sup>10</sup> cited a 92% overall success rate in staged wound management with beads in 114 patients.

The induced membrane (Masquelet) technique is an extension of the use of antibiotic laden PMMA with encouraging results.<sup>18</sup> This two-stage technique relies upon filling the segmental defect with a solid block of PMMA, which over 6–8 weeks becomes surrounded by a highly cellular bio-membrane. At reoperation the membrane is incised, the cement is removed and replaced with bone graft. It was demonstrated that the membrane produced around the cement has osteoinductive properties due to its ability to produce angiogenic factors as well as bone morphogenetic proteins. In a case report by Malley and Kates<sup>19</sup> the Masquelet technique, with a spinal cage as a scaffold to maintain the graft in the second stage, led to successful eradication of methicillin-resistant *Staphylococcus aureus* (MRSA) infection and reconstitution of a 17 cm diaphyseal defect in the tibia.

Bioactive glass is a novel biocompatible material that combines osteoconductive, angiogenic and antimicrobial properties. Drago et al.<sup>20</sup> demonstrated the efficacy of bioactive glass both

in vitro and in vivo for the treatment of chronic osteomyelitis with particular emphasis on immunocompromised hosts and multiresistant strains. In another study bioactive glass alone compared well to antibiotic loaded cement.<sup>21</sup>

Free vascularized bone transfer aims to provide vascularized structural graft. Typically, the fibula is harvested, although rib, iliac crest, and scapula have been used as well. This is a complex micro-anastomosis procedure and is not suitable in all cases. Furthermore, some studies reported stress fracture rates to be as high as 35% in tibia and 32% in femurs.<sup>22</sup>

Distraction osteogenesis using circular frames to transport corticotomized segments of bone is a well-documented technique. When well executed, this technique allows for replacing like with like and produces diaphyseal bone of the requisite dimensions. Various authors have reported excellent results using this technique. Paley et al.<sup>23</sup> reported 100% union and 76% successful resolution of infection in 13 patients with infected non-union of the tibia. Morandi et al.<sup>24</sup> reported no recurrence of infection in 13 patients followed for 2 years after Ilizarov reconstruction. The procedure has been used in conjunction with bone graft, especially at the docking site, as well as soft tissue transfer for large defects, with similar success rates. However it should be noted that the Ilizarov technique is very labour intensive and requires strict compliance by the patients. Technique-specific complications include pin tract infections and docking site nonunion have been reported to occur in 28–38% of cases.

### Soft tissue reconstruction

Central to the modern management of chronic osteomyelitis is combined orthopedic and plastic surgical care.

Soft tissue cover has been graded as the 'reconstructive ladder' starting with primary closure or healing by secondary intention up to free vascularized flap coverage. Primary closure describes a wound closed without the use of borrowed tissue and historically has been successful less than 50% of the time. Where a healthy bed of granulation exists, split or full thickness skin grafting allows for quicker epithelization. To encourage this granulation tissue a number of methods have been used.

Negative-pressure wound therapy removes exudates from the wound by means of gentle suction and encourages the formation of granulation tissue. Recent laboratory studies also suggest that this modality may induce the release of cytokines stimulating angiogenesis. It has been shown to provide better outcomes than traditional dressing methods in one randomized study.<sup>25</sup> The WOLLF study (Wounds in Open Lower Limb Fractures) is a large randomized multicentre study being conducted in the UK to assess if negative-pressure dressing application yields better outcomes in wound management.<sup>26</sup>

Bilayer wound matrix synthetic graft is an engineered material designed for soft tissue reconstruction. The bilaminar membrane acts as a scaffold for cellular invasion and capillary growth. After placement, the dermal layer becomes progressively vascularized over 2–3 weeks.

In cases of more significant soft tissue loss a local fasciocutaneous flap may be required and either applied by rotation, advancement, or transposition techniques. For larger, deeper defects with scarce vascularity, or pressure regions such as the plantar aspect of the foot, myofasciocutaneous flaps could be

utilized. Finally, if no local tissues are available then microsurgical free flaps (e.g. latissimus dorsi) can be used for reconstruction.

Local muscle flaps in general are an option for lower extremity reconstruction and infection management. In comparison to fasciocutaneous flaps they are more resistant to ischemia, easily moulded to fill a defect and provide a wound bed, which can immediately accept a skin graft. The downside to using rotational muscle flaps is the expected loss of the donor muscle function and limitation by anatomical reasons below the proximal tibia. There may be a loss of vascularity over time.

Vascularized free flaps are excellent for soft tissue cover and the management of dead-space even in large defects. Free flaps, however, require sophisticated equipment, and a well-trained surgical team and failures can be difficult to manage.

Amputation always remains a treatment option should reconstructive efforts fail. Amputation level is defined by the availability of healthy tissue for closure and the practicality of prosthesis fitting. This is particularly important in the lower limb, where metabolic demands significantly increase with more proximal amputations. In the diabetic population, osteomyelitis with soft tissue infection frequently leads to amputation. In these patient's assessment and treatment of vascular inflow would be the first step as often a simple stenting or vascular bypass can improve healing.

### Antibiotic management of chronic osteomyelitis

Antibiotics alone for the curative management of chronic osteomyelitis are unlikely to be successful. This is due to poor antibiotic penetration into necrotic bone and subsequent failure to sterilize the infected nidus. As discussed elsewhere in this review, debridement, removal of prosthetic material and in some cases, revascularization, of infected tissue are the mainstay of treatment. Antibiotics form part of the combined medical and surgical management.

Antibiotic considerations relate to timing of antibiotics, establishing the causative pathogen(s), choice of agent, route of administration and duration. These topics are dealt with individually below.

### Timing and samples

When possible, antibiotics should be delayed until high-quality surgical samples have been taken to allow a definitive microbiological diagnosis and optimal treatment against the causative pathogen. Antibiotics given prior to sampling risk failure to identify the organism and a drop-off in diagnostic yield of the procedure, as clearly demonstrated in a retrospective study looking at culture positivity, in the context of prosthetic joint infection however, where prior antibiotics decreased culture positivity by an odds ratio of 4.7, versus no prior antibiotics.<sup>27</sup> Again, a study looking at periprosthetic joint infections found an optimal number of deep operative samples to be five or six and isolation of the same organism in three of these was strongly predictive of infection with this organism, although two was also suggestive.<sup>28</sup> The above discussion relates to deep samples from tissues deemed usually sterile, and superficial or potentially contaminated specimens are less useful, and may lead to treatments being directed against organisms not actually causing the

infection. Ultimately a clinical decision as to the significance of the organism(s) is made between the surgeon and infection specialist. This is based on myriad factors including the plausibility of the organism found as a cause for osteomyelitis, the quality of samples, number of positive samples, prior antibiotic therapy and host factors like immune status. Poor local (e.g. diabetic limb) or systemic immunity (HIV, diabetes, immunosuppressants) may allow less pathogenic organisms to set-up opportunistic infections.

### Empirical versus definitive antibiotic therapy

The choice of empirical antibiotics should be based on information relating to the common organisms that cause osteomyelitis, local rates or resistance in these organisms (rates of MRSA etc), appropriateness of this antibiotic to treat osteomyelitis (good bone penetration), as well as patient-specific considerations (allergies, previous microbiology samples from patient, trauma, presence of prostheses, presence of vascular and immunocompromise and severity of illness). Where the severity of systemic illness precludes delaying systemic antibiotics until after surgical debridement, we suggest blood cultures to attempt to isolate the pathogen before giving the first dose. Expediting surgery, or subsequently stopping antibiotics if deemed safe to do so, to increase the diagnostic yield can be considered on a patient-by-patient basis.

Transition from empirical antibiotics to definitive, directed antibiotics against a particular pathogen (or pathogens) is a key step in the optimal management of the patient's infection. Definitive antibiotic therapy allows narrowing of the spectrum of antimicrobial coverage, limiting the potential development of resistance, with the additional benefit of being able to use the best treatment (where one exists) for this infection. Where a pathogen has not been isolated, repeat sampling, different media or prolonged culture methods as well as molecular tests on samples, should be considered.

### Microbiology and definitive antibiotic management

*Staphylococcus aureus* is the commonest cause of osteomyelitis, with other bacterial causes including Gram-negative bacteria, coagulase-negative staphylococci, anaerobes and streptococci and enterococci as well as polymicrobial infections (more than one organism).

There are few data comparing one antibiotic versus another for osteomyelitis. Again, recommendations relate to historical practices, with acquired clinical experience with these agents, knowledge of these agents in other infections and application of pharmacokinetic (in particular bone penetration) and pharmacodynamic considerations. For example, parenteral anti-staphylococcal penicillins (e.g. flucloxacillin in the UK) have been used for the treatment of osteomyelitis caused by methicillin-susceptible *Staph. aureus* (MSSA) for many years, with accumulated clinical experience showing them to be superior to vancomycin in bloodstream infections and exhibition of adequate bone penetration.

Numerous studies have demonstrated improved outcomes using adjunctive rifampicin for staphylococcal infections, because of its ability to penetrate biofilm better than other antibiotics.<sup>29</sup> Rifampicin must be coupled with another antibiotic to prevent mutational resistance occurring.

### Intravenous versus oral antibiotics

Empirical antibiotics are usually given via the intravenous route. The reasons for this are numerous and pragmatic as well as historical, but the patient is likely to remain as an inpatient in this period, and the dosing of some antibiotics, as well as degree of absorption preclude an oral option (antistaphylococcal penicillins such as flucloxacillin for example) or alternatively the oral route is prohibited (e.g. glycopeptides and aminoglycosides).

Even when empirical antibiotics can be targeted to an organism, there is a bias towards IV therapy irrespective of the nature of the antibiotic and its pharmacokinetic profile, although this is changing. A study looking at non-inferiority of oral antibiotics versus parenteral therapy, the OVIVA study, when published should help answer the question systematically about the role of oral antibiotics in the treatment of osteomyelitis, but many favour a complete course of parenteral therapy, or initial parenteral therapy followed by orals with good bioavailability and bone penetration, where these options exist. For example, the fluoroquinolones (ciprofloxacin and levofloxacin) have excellent oral bioavailability and bone penetration with little or no benefits of IV administration over oral. Similarly, linezolid, rifampicin, clindamycin, co-trimoxazole and metronidazole have excellent absorption and do not require the IV route in most instances.

The development of the highly protein bound lipoglycopeptides such as Dalbavancin and Oritavancin, which can be given intermittently and can remain active for weeks may, as experience and evidence accumulates, allow treatments of these infections outside of the hospital setting, assuming some of the benefits of oral therapy.

### Treatment duration

Although no optimal duration of antibiotics has been established, neither has evidence that antibiotic duration beyond 4–6 weeks is beneficial. In the context of spondylodiscitis, an infection of the vertebral bones involving the disc, a study established non-inferiority of 6 weeks antibiotics compared to the standard practice of 12 weeks.<sup>30</sup> As a result, the total duration of antibiotic therapy is suggested as 4–8 weeks by some experts, with the variation accounted for by host and microbiological factors and response to treatment.

### Our unit's strategy

Despite the dizzying array of treatment options in osteomyelitis our unit typically utilizes a similar approach in most cases and our defined aims of treatment are:

- suppression
- reconstruction
- amputation.

**Tissue diagnosis** – We aim to be meticulous in obtaining multiple good-quality tissue samples using separate instruments. This is one of the most difficult and most easily overlooked stages in treatment. It is crucial to ensure that instruments used for sampling do not become contaminated as they are passed from the scrub team to the surgeon, or brush against the patient's skin on entering or exiting the wound as this could result in an inaccurate culture result.

**Debridement of necrotic tissue** – Debridement typically occurs through open procedures with excision of necrotic soft tissue and bone. Necrotic bone can be extremely difficult to distinguish from healthy bone. We look for punctate bleeding and for the consistency of bone when cut with an osteotome. Necrotic bone may appear to be like ‘ivory’ in cortical bone or have an abnormally soft consistency in cancellous regions. For patients who are not suitable for free flaps we sometimes utilize a minimally invasive debridement with mechanical burrs.

**Stable osseous fixation** – The type of fixation is highly dependent on which bone is fractured and the fracture configuration. In general, intra-medullary nails are preferred over plates and circular frames are reserved for cases requiring bone transport or with complex deformities.

**Local antibiotic delivery** – Our practice has been greatly informed by the work of Martin McNally’s group at the Nuffield Orthopedic Hospital in Oxford. They have investigated a variety of local antibiotic delivery systems and we currently use a proprietary calcium sulphate and hydroxyapatite synthetic bone graft, which is pre-loaded with gentamycin (Cerement-G). This serves to deliver high-dose local antibiotics above the MIC for up to 4 weeks as well as being osteoconductive.

**Management of dead-space** – Bony defects are typically filled with the gentamycin loaded synthetic bone graft or through free tissue transfer.

**Soft tissue cover** – This is determined by the size and location of the defect. Clearly if primary closure can be achieved this is optimal, frequently however rotational flaps or free tissue transfers are required.

**Systemic antibiotics** – We have a weekly orthopedic and microbiology multidisciplinary team meeting where all osteomyelitis cases are discussed. Typically, patients receive empiric antibiotic therapy once microbiological samples have been taken. Following this, definitive antibiotics are chosen based on culture results, the route and duration being decided based on consideration of numerous factors discussed in more detail in the antibiotic management section.

**Rehabilitation** – It is our aim to rehabilitate patients to full weight-bearing as soon as the soft tissues allow.

## Conclusion

Osteomyelitis is a complex and potentially devastating condition. Good outcomes can be achieved through a combined orthoplastic approach and relies on good microbiology tissue diagnosis, thorough debridement, robust soft tissue cover and mechanical stability. These complex patients will predominantly be treated in tertiary referral centers but all surgeons should have a basic understanding of the concepts of management to prevent inappropriate and unnecessary treatments. ◆

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