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Research Article

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Contemporary Surgical Management of Paediatric Chronic Osteomyelitis in Resource-Limited Settings: A Narrative Review

John Enekele Onuminya[1]*, Dorcas Salime Onuminya[2] and Mutaleeb Ayodele Shobode[3]

[1]*Department of Orthopaedics and Traumalogy, Faculty of Clinical Sciences, College of Medicine, Ambrose Alli University, Ekpoma, Edo State, Nigeria*

[2]*Department of Obstetrics & Gynaecology, Faculty of Clinical Sciences, College of Health Sciences, Federal University, Lokoja, Kogi State, Nigeria,*

[3]*Department of Clinical Services, National Orthopedic Hospital, Dala Kano, Nigeria*

***Corresponding Author**
Prof. J.E. Onuminya, Department of Orthopaedics and Traumatology, Faculty of Clinical Sciences, College of Medicine, Ambrose Alli University, Ekpoma, Edo State, Nigeria.

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Abstract

Background: *Paediatric endogenous chronic osteomyelitis is common among children in developing countries of the world with unusual outcome. The treatment of chronic osteomyelitis is difficult, but it involves a combination of antibiotic therapy, bone debridement, bone graft and soft tissue coverage. The need for surgery in the treatment of chronic osteomyelitis is well recognised, but there is no consensus on the optimal method.*

Objective: *This review is an update on the surgical treatment of chronic osteomyelitis.*

Methods: *We carried out a comprehensive review of the literature, using suitable key words such as chronic osteomyelitis, children, developing countries, surgical treatment, bone debridement, bone resection, bone graft, bone lengthening, bone transfer, muscle flap, biological therapy, recurrence, outcome on the search engines of Google scholar and PUBMED in June, 2026.*

Results: *The main problem with the surgical treatment of chronic osteomyelitis is recurrence. Surgical treatment options for chronic osteomyelitis range from simple saucerization, sequestrectomy, and curettage with primary or secondary wound closure (using the Papineau technique or the Lautenbach technique) to radical bone debridement with bone grafting and/or early muscle flap cover in a single stage or double stage, as in the Belfast technique (using antibiotic beads for the first 4 weeks in the first stage, followed by bone grafting and/or muscle flap cover in the second stage). In complicated cases, bone resection and lengthening with Ilizarov technique (using either magnetic lengthening nails or the Linear Ray System or an Ilizarov ring frame) or the Masquelet technique or vascularized free bone transfer or epiphysiolysis or amputation is advocated. In spite of surgical advances, the recurrent challenge remains unresolved.*

Conclusions: *Chronic osteomyelitis requires an interdisciplinary treatment protocol of systemic and/or local antibiotics and surgical procedures. Adjunctive biological therapy may be the panacea for recurrent infections.*

Keywords: Chronic Osteomyelitis, Children, Developing Countries, Surgical Treatment, Dead Space, Recurrence, Biological Therapy

1. Introduction

Paediatric chronic osteomyelitis (COM) remains a significant cause of morbidity in low- and middle-income countries despite advances in antimicrobial therapy, surgical techniques, and healthcare delivery. Unlike high-income settings, where chronic osteomyelitis is relatively uncommon and is predominantly associated with

trauma or orthopaedic implants, children in developing countries frequently present with neglected haematogenous infections characterized by extensive bone destruction, sequestrum formation, involucrum, chronic discharging sinuses, pathological fractures, and limb deformities. Delayed presentation, limited access to specialist care, malnutrition, poverty, and inadequate treatment of acute osteomyelitis contribute substantially to disease chronicity and poor outcomes [1-5].

Successful management of COM requires a multidisciplinary approach combining thorough surgical debridement, culture-directed antimicrobial therapy, dead-space management, skeletal reconstruction, and appropriate soft-tissue coverage. Although numerous surgical techniques have been described—including sequestrectomy, saucerization, the Papineau and Belfast techniques, distraction osteogenesis, the Masquelet induced membrane technique, and vascularized bone grafting—there remains no universally accepted treatment algorithm [4-12]. The choice of procedure depends on disease severity, bone loss, soft-tissue involvement, host factors, and the availability of surgical expertise and resources [4,5,13].

The greatest obstacle to successful treatment remains recurrent infection, which is often related to residual devitalized bone, biofilm formation, compromised vascularity, and inadequate eradication of infection. Advances in local antibiotic delivery systems, reconstructive techniques, and biological therapies have improved limb salvage and functional outcomes; nevertheless, recurrence continues to represent a significant clinical challenge [4,5,7-9].

This review summarizes current concepts in the surgical management of paediatric chronic osteomyelitis, with particular emphasis on practical approaches applicable to developing countries where the disease burden remains greatest.

Figure 1: A neglected case of severe chronic osteomyelitis in a one year old boy presenting after nine months of the disease with a telescoping pan-sequestrum of the right humerus. The child was brought to the clinic by his mother from the rural area after failed attempt at the traditional bonesetter's practice. They were lost to follow-up from the clinic after the first visit [5].

2. Methods

2.1. Literature Search Strategy

A narrative review of the literature on the surgical management of paediatric chronic osteomyelitis was conducted in June 2026. Electronic searches were performed using PubMed/MEDLINE and Google Scholar databases. The search strategy combined Medical Subject Headings (MeSH) terms and free-text keywords related to chronic osteomyelitis and its surgical management.

The following search terms and their combinations were used: “chronic osteomyelitis”, “paediatric osteomyelitis”, “children”, “developing countries”, “surgical treatment”, “bone debridement”, “sequestrectomy”, “saucerization”, “bone grafting”, “dead-space management”, “muscle flap”, “Masquelet technique”, “Ilizarov technique”, “bone transport”, “vascularized bone graft”, “bone lengthening”, “biological therapy”, “recurrence”, and “treatment outcomes”.

2.2. Study Selection

Articles published in English between January 1980 and June 2026 were considered for inclusion. Additional relevant studies were identified through manual review of reference lists of selected articles and key review papers. Studies were included if they addressed chronic osteomyelitis in children or adolescents; reported surgical treatment strategies, reconstructive procedures, or treatment outcomes; included data from developing countries or contained findings applicable to resource-limited settings; or were landmark publications describing widely accepted classification systems, surgical techniques, or treatment principles.

Studies were excluded if they focused exclusively on acute osteomyelitis; addressed vertebral osteomyelitis without relevance

to paediatric long-bone disease; were non-English publications without accessible translations; were conference abstracts lacking sufficient methodological detail; or provided duplicate data from previously published studies.

2.3. Data Synthesis

Relevant articles were reviewed and synthesized narratively. Particular emphasis was placed on surgical debridement, dead-space management, local antibiotic delivery systems, soft-tissue reconstruction, management of bone defects, limb reconstruction techniques, recurrence, and emerging adjunctive therapies. Priority was given to contemporary evidence and studies originating from low- and middle-income countries where the burden of paediatric chronic osteomyelitis remains highest.

As this was a narrative review, no formal meta-analysis or quantitative pooling of data was performed.

2.4. Definition

Chronic Osteomyelitis (COM) is a long-standing infection of bone and its soft tissue envelope characterized by chronic sepsis and ischaemia, persistence of microorganisms, presence of sequestrum, involucrum, cloacae, low grade inflammation and discharging sinuses [2,4,5,14-16]. COM in children is rarely seen in developed countries. However, in developing countries, its incidence is much more frequent.

2.5. Epidemiology

Florid haematogenous COM is common among children in developing countries than in developed countries [1-3,14-19]. The incidence of COM in most developing countries are not known, though it has been reported to be a considerable health care burden [1,2].

The annual prevalence of osteomyelitis in general population of kenya is 1:1000 [3]. In Gambia, osteomyelitis accounted for 7.8% of paediatric surgical admission and 15.4% of inpatient's days [20]. In contrast to adult COM where trauma accounts for majority of cases in developed countries, haematogenous chronic osteomyelitis is common among children in developing countries. Albeit, severe manifestations of post-traumatic osteomyelitis are not uncommon among children in developing countries due to the often insufficient medical care, especially in rural areas. Therefore COM with distinct findings can be a result even after minor injuries [1]. The male children are affected more than the females in a ratio of 2:1, tibia is the bone involved in majority of cases, this is followed by femur, and staphylococcus aureus is the infecting organism in 60-70% of cases [1,2]. Even with advances in antimicrobial therapy and surgery for COM, a recurrence rate of 20-30% remains a major complication of surgical treatment.4

3. Classification

Several classification systems have been proposed for osteomyelitis, each emphasizing different aspects of disease pathogenesis, anatomical involvement, or treatment planning. Although no single system is universally applicable, classification remains valuable for standardizing disease severity, guiding surgical decision-making, and facilitating communication among clinicians [13,21].

The Waldvogel classification categorizes osteomyelitis according to aetiology into haematogenous, contiguous, vascular insufficiency-associated, and vertebral disease [22]. Although useful for understanding disease pathogenesis, it has limited value in guiding surgical treatment.

The Cierny–Mader classification remains the most widely accepted staging system for chronic osteomyelitis. It combines the anatomical extent of bone involvement (Stages I–IV) with host physiological status (A, B, and C hosts), thereby providing a practical framework for selecting appropriate surgical intervention and predicting treatment outcomes [4,13]. Despite being developed primarily for adults, it continues to be widely applied in the management of paediatric chronic osteomyelitis.

Alternative classification systems have been developed for resource-limited settings. Meier and colleagues proposed a clinically oriented staging system based on disease duration and extent, whereas Solagberu introduced a progression-based classification designed to facilitate treatment planning in developing countries [23,24]. Jones and colleagues subsequently described a radiographic classification of childhood chronic haematogenous osteomyelitis (CURE/Malawi classification), which was later validated by Stevenson et al as a simple, reliable, and reproducible tool with prognostic value using plain radiography [20,25].

From a practical perspective, paediatric chronic osteomyelitis may also be categorized according to its aetiology and clinical presentation into chronic haematogenous osteomyelitis, Brodie's abscess, sickle cell disease-associated osteomyelitis, post-traumatic osteomyelitis, superficial osteomyelitis secondary to chronic ulcers, chronic sclerosing osteomyelitis (Garre osteomyelitis), specific infections such as tuberculous osteomyelitis, and uncommon entities including Pott's puffy tumour [2,4,5,26,27]. This aetiopathological classification is useful for understanding disease mechanisms and teaching purposes but has limited value in guiding surgical management.

Given its correlation with disease extent, host physiological status, treatment strategy, and prognosis, the Cierny–Mader classification remains the preferred framework for discussing the surgical management of paediatric chronic osteomyelitis throughout this review [4,13].

Anatomical Stage	Description	Typical Treatment
Stage I	Medullary	Debridement + antibiotics
Stage II	Superficial	Debridement ± soft-tissue coverage
Stage III	Localized	Radical debridement + reconstruction
Stage IV	Diffuse	Bone resection + complex reconstruction

Physiological Host Classification

Host Type	Description
A	Healthy host
BL	Local compromise
BS	Systemic compromise
BLS	Local + systemic compromise
C	Treatment morbidity exceeds disease burden

Table 1: Cierny–Mader Staging System for Chronic Osteomyelitis and Its Surgical Implications

The anatomical classification describes the extent of bone involvement as medullary (stage I), superficial (stage II), localized (stage III), or diffuse (stage IV). Host physiological status is categorized as A (healthy host), B (local and/or systemic compromise), or C (treatment morbidity exceeds the anticipated benefit). The classification assists in treatment planning, prognostication, and selection of appropriate reconstructive strategies.

4. Aetiopathogenesis

4.1. Microbiology

In general terms, Staphylococcus aureus is the common infecting organism in 60-70% of cases of COM among children in developing countries [1-3,14,17-19]. However, in neonate Streptococcus pyogenes and S. pneumoniae predominate, while in early childhood Haemophilus influenza and kingella kingae are more frequent. Salmonella typhi COM are frequently seen in sickle cell disease. It is worthy of note that even among the sicklers, staphylococcus aureus still remains the most common causative organism of COM [27].

4.2. Predisposing Factors

Septic foci such as boils, infected wounds, tonsillitis, otitis media and pharyngitis are the common predisposing factors to COM among children in the developing countries. Malnutrition, poor environmental sanitation, immune compromise and frequent trauma with wounds which are not treated adequately owing to inadequate health care especially in the rural settings predispose children in developing countries to COM [1,2].

4.3. Site of Election

The metaphyseal ends of tibia and femur around the knees are the most frequent sites of COM as they are most prone to trauma in children. These are also areas of non-anastomosis, vascular stasis, low oxygen tension and poor phagocytic activity hence encouraging bacteria growth and COM.

4.4. Pathology

This varies with age, site, virulence and host response. In early childhood, the bone infection, which is usually a local manifestation of a systemic illness, presents as a progressive inflammatory lesion with suppuration, bone necrosis, sequestrum and reactive new bone formation, involucrum. This may undergo resolution and healing or become intractable with chronic discharging sinuses. Among the infants, epiphyseal involvement may result in septic arthritis. The reason for chronicity may be due to compromised host response, inadequate treatment of acute phase, presence of sequestrum, poor vascular supply and tissue necrosis, bacterial protecting weaponry, glycocalyx biofilm, bacterial adherence to inert surfaces and slow growing intracellular bacteria [1,2,4,5].

4.5. Pathophysiology

The mode of spread of infection from the septic foci to the bone is either via haematogenous or exogenous or contiguous spread. Obliteration or compression of vascular channels results in bone necrosis and formation of sequestrum. Bone damage is facilitated by cytokines, IL-1 and TNF. As the bacteria, Staphylococcus aureus is notorious for forming a protective biofilm on the sequestrum which is a polysaccharide polymer forming a fibrous matrix round the host cells and bacteria [4].

A reactive new bone, involucrum is also formed from intact periosteum and endosteum. A perforation in the involucrum, cloacae allows for egress of pus from the sub-periosteal abscess which tracts through the soft tissue plane to develop fistulae.

The pathogenic bacterial factor therefore involves the formation of fibrous matrix around Staphylococcus aureus with the expression of adhesin, typical phenotypes for intracellular existence with low metabolic rate and protective biofilm glycocalyx.

Microorganisms in the impervious biofilm are protected from the host's immune defences like antibodies and phagocytosis, as well as administered antibiotics. Additional factors that decrease the susceptibility of bacteria in biofilms include a slow rate of growth,

heterogeneity, quorum sensing and induction of biofilm phenotype [4].

The host factors responsible for chronicity include immune status, obesity, smoking, diabetes mellitus and peripheral vascular disease. These bacterial and host factors need to be addressed if successful surgical treatment is to be achieved.

4.6. Diagnosis

The diagnosis of COM is based on clinical features, imaging for COM and laboratory diagnostic tools. Intraoperative intramedullary specimen for microscopy, culture and sensitivity patterns is the gold standard to identifying causative organism and diagnosis of COM [1,2,28].

4.7. Clinical Features

There is no specific symptoms or signs of COM. Chronic pain, persisting discharging sinuses, recurrent condition, exposed bone and chronic wounds are aids to diagnosis [1,2,4]. There could be associated deformity such as limb length discrepancies, angular deformities and sometimes pathological fractures, septic arthritis and other complications.

5. Imaging

These are vital for diagnosis and assessment of COM.

5.1. Pain Radiographs

This is the first imaging modality which shows extent of bone involvement including sequestrum, involucrum cloacae, abscess cavity and pathological fractures. This is the most frequently available and reliable imaging technique for evaluation of patients with COM in the developing countries [1,2,20,25].

5.2. Ultrasound

This will show soft tissue abscess

5.3. Computerised Tomography Scan

Offers multi planar imaging with clear extent of cortical bone involvement. Useful in detecting sequestra masked by extensive sclerosis and helpful in guiding aspiration and biopsy.

6. Magnetic Resonance Imaging

This is helpful in assessing extent of disease and vascularity of tissue [4].

7. Nuclear Medicine Imaging

Positron Emission Tomography (PET) bone scintigraphy and leukocyte scintigraphy or their combination are helpful in elucidating infections of bone. With the advent of MRI the traditional radioisotope scan are no longer popular.

Sinography alone or in combination with CT may help to outline the sinus track especially around the joint to show any communication as in COM complicated with septic arthritis.

None of these imaging modality is enough to confirm the diagnosis of COM except biopsy.

The CT-Scan, MRI and PET are not ready available diagnostic imaging tools in most centres in developing countries and plain x-ray remains the diagnostic imaging of choice [4].

8. Laboratory Investigations

FBC, ESR, CRP, PCR are nonspecific but use to monitor response to treatment. Renal function and blood glucose assays are necessary to elucidate comorbidity in patient with COM.

Nutritional status using albumin and pre-albumin is necessary among children in developing countries, samples for Gram staining, culture and antibiogram are key to a successful antibiotic regimen.

Intra-operative intramedullary specimen is the gold standard biopsy to identify causative organism be it aerobic, anaerobic fungal or mycobacterial culture. Sinus tracks cultures are not reliable. Absence of growth from needle biopsy does not rule out COM [1,2,28].

9. Grading

Cierny – Mader grading system based on [13]:

a) The extent of bone involvement described anatomic stages 1-4 as medullary, superficial, localized and diffused types. Bone debridement is considered as the surgical treatment except for stage 4 with diffused type where bone resection and reconstruction of defect is considered appropriate.

b) The physiologic class of the patient with systemic and local factors affecting the physiologic class of host put into account: this has been staged as ABC where A is the normal host, who could be offered appropriate surgical treatment, B is the host with local impairment such as cellulitis, lymphoedema, scar of sinuses and previous surgery. Surgical treatment of this group includes addressing healing potential of the local tissue; Bs is the host with systematic factors such as diabetes, immunocompromised, vascular diseases and hypoproteinaemia. Surgical treatment of this group include: consideration for the management of the comorbidity; C host has severe infection with severe systemic and local compromise and outcome of surgical treatment in this group is worse than the disease. Surgery is therefore deferred or amputation may be advocated.

c) The Cierny - Mader staging therefore correlates with treatment and prognosis and is widely used to plan treatment for COM.

10. Treatment

Treatment of COM is difficult. There has been no consensus on the optimal method of treatment due to lack of uniformity in case selection and treatment. A practical treatment algorithm for the evaluation and management of paediatric chronic osteomyelitis in resource-limited settings is presented in **Figure 2**. Multi-disciplinary approach to treatment is key in achieving a successful treatment for COM. The treatment team should include orthopaedic and plastic surgeons, infectious disease experts, nutrition expert and psychologist.

Goal of treatment should include: 1) Complete eradication of infections, 2) Preservation of soft tissue envelope, 3) Healing of bone segment, 4) Preservation of limb length and function, 5) Optimization of patients and 6) Treatment plan has to be individualize

Aim of Treatment should include: 1) To stabilize patients, 2) Drain abscess, 3) Bone debridement and stabilization and 4) Antibiotic therapy

11. Antibiotic Therapy

The principles of antibiotic therapy should be based on [4]:

i. Culture and sensitivity pattern
ii. Broad spectrum antibiotic, intravenous or orally depending on bioavailability
iii. Oral antibiotic therapy has to be simple, economical and convenient for patients with less risk.
iv. Outpatient Parenteral Antibiotic Therapy (OPAT) would be preferable
vi. Patient requiring long-term intravenous access should be considered for peripheral inserted central catheters
There is however inadequate evidence to recommend the best agent, route of administration and duration of treatment.
vii. The standard recommendation of 4-6 weeks of antibiotic therapy is based on animal studies on time taken for revascularization of bone, hence not sacrosanct
viii. Short course of antibiotic therapy has been advocated in cases where aggressive surgical debridement and vascularized flaps were used.
ix. Cierny - Mader stage 1 and 2 would require a shorter course of antibiotic therapy for about two weeks
x. Cierny - Mader stage 3 and 4 would require longer antibiotic therapy for 4-6 weeks
xi. The duration of antibiotic therapy however should be individualized based on clinical, haematological and radiological response and patient monitoring.
xii. Oral antibiotic therapy of agents with high bioavailability is as good as parental.
xiii. Improved cure rate with addition of rifampicin as well as with surgical resection and antibiotic therapy.
xiv. Cure rate is also improved with the use of local antibiotic therapy either with Gentamycin-PMMA beads or plastic beads or collagen sponge.
xv. The use of rigid carrier such as Gentamycin-PMMA beads would require a second stage surgery for removal, but the biodegradable carrier such as bovine collagen sponge–Gentamycin obviates the need for second surgery.
xvi. Most widely used substrate for delivering local antibiotic has been PMMA. This would require the use of heat-stable and hydrophilic antibiotics such as Gentamycin, Tobramycin and Vancomycin. Gentamycin is an ideal additive with PMMA as it is broad spectrum, bactericidal and heat stable. However, it is most effective against gram-negative bacteria only. Ikpeme et al8 reported better results following surgical debridement with local antibiotic delivery system. They deployed the use of Gentamycin PMMA beads/blocks and antibiotic irrigation/ drainage. Similarly, in the use of induced membrane or the Masquelet technique9 for the treatment of large-bone defect, PMMA spacer in the defect leads to the formation of a membrane that is very vascular and secretes growth factors. Other substrates being considered as spacers include protein-based materials, bone graft substitutes, synthetic polymer, metal and biodegradable calcium sulphate impregnated with antibiotic. Despite advances in treatment, recurrent infection continues to represent a persistent clinical challenge for both patients and treating surgeons.

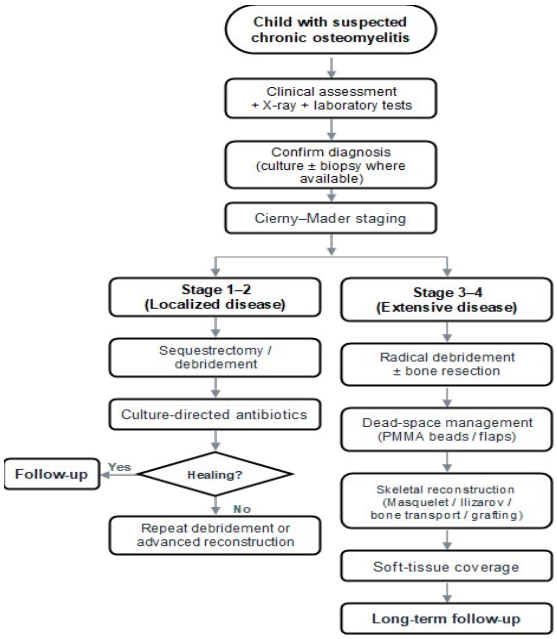

Figure 2: Proposed treatment algorithm for paediatric chronic osteomyelitis in resource-limited settings.

The algorithm summarizes the evaluation and management of paediatric chronic osteomyelitis in resource-limited settings, incorporating disease staging, microbiological diagnosis, surgical debridement, skeletal reconstruction, soft-tissue coverage, and long-term follow-up.

12. Surgical Treatment

There is no consensus on the optimal method of surgical treatment of COM. The recurrence challenge remains a major problem in spite of recent advances.

Surgical options may include: 1) Incision and drainage; 2) Saucerization, Sequestrectomy and Curettage with Papineau technique or Lautenbach's technique; 3) Radical bone debridement with Belfast technique; 4) Bone resection with Ilizarov technique or Masquelet technique or bone transfer and 5) For complicated cases there may be need for Epiphysiolysis, bone lengthening or shortening procedures, corrective osteotomy, arthrodesis or amputation. There may be need for ORIF with antibiotic coated intramedullary nails or Masquelet technique or EFD/Ilizarov techniques for infected nonunion. The indications, advantages, and limitations of the commonly employed surgical techniques are summarized in Table 2.

Technique	Indication	Advantages	Limitations
Sequestrectomy and Curettage	Localized disease	Simple, widely available	Higher recurrence if inadequate
Saucerization	Cortical disease	Good drainage	Residual dead space
Papineau Technique	Moderate defects	Effective dead-space management	Prolonged wound care
Belfast Technique	Extensive disease	Good infection control	Two-stage procedure
Muscle Flap Coverage	Soft-tissue defects	Improves vascularity	Requires expertise
Masquelet Technique	Segmental defects	Good biological environment	Two-stage surgery
Ilizarov Bone Transport	Large defects	Simultaneous lengthening	Long treatment duration
Vascularized Fibular Graft	Massive defects	Immediate biological reconstruction	Technically demanding
Amputation	Unsalvageable limb	Definitive treatment	Loss of limb

Table 2: Summary of Commonly Employed Surgical Techniques for Paediatric Chronic Osteomyelitis

Comparison of commonly used surgical techniques, including their indications, advantages, and limitations. Selection of treatment should be individualized according to disease severity, bone loss, soft-tissue condition, patient factors, and available resources.

Indications for surgery may include: drainage of abscess, failure of medical treatment, mature involucrum, infected nonunion and correction of deformities - angular or LLD.

The aims of surgical treatment may include: adequate debridement, management of dead space, soft tissue coverage, skeletal stabilization and treatment of skeletal defects. A practical surgical decision-making algorithm for reconstruction following debridement is shown in Figure 3.

13. Adequate Debridement

Adequate bone and soft tissue debridement is a difficult goal to achieve surgically. There is no reliable indicator of adequate debridement. Reliance on punctate capillary bleeding, the "Paprika Sign" and Methylene blue stain are not adequate, even the advocated radical debridement or bone resection with numerous reconstruction techniques are not adequate panacea to recurrent challenge which remains an enigma to surgeons [1,2,4,5,10,16].

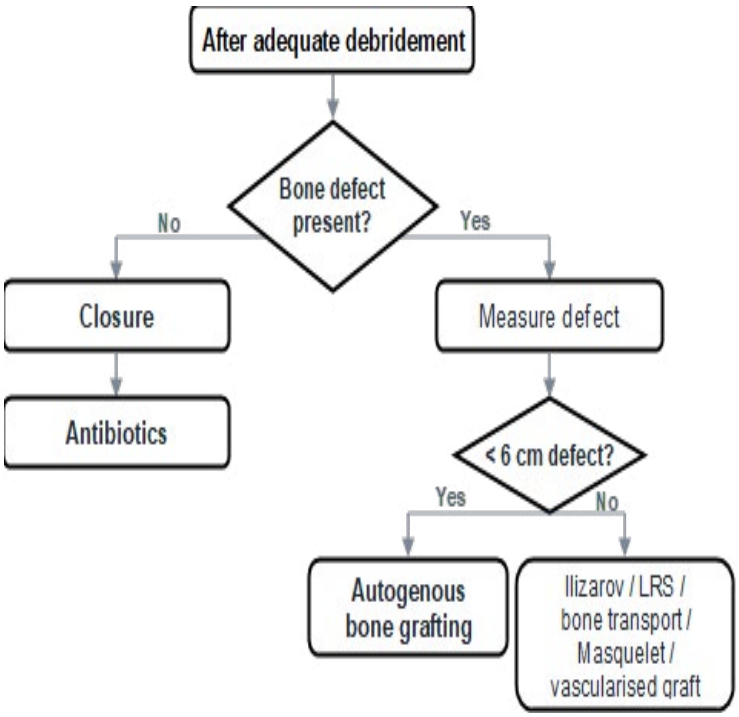

Figure 3: Surgical Decision-Making Algorithm for Reconstruction Following Debridement in Paediatric Chronic Osteomyelitis

The extent of residual bone loss and soft-tissue compromise determines the reconstructive strategy. Small defects may be managed with autogenous bone grafting, whereas larger segmental defects often require advanced reconstruction techniques such as distraction osteogenesis, bone transport, the Masquelet induced membrane technique, or vascularized bone grafting. Soft-tissue coverage and infection control remain fundamental principles throughout treatment.

14. Dead-Space Management

There are several surgical treatment options and choice depends on size of defect [1,2,4,5,8-10,16].

The surgical goal is to obliterate the defect with the use of muscle flaps, bone graft, vacuum assisted closure and use of antibiotic-impregnated PMMA beads or blocks [1,2,4,5-10,16].

Several techniques in one or two stages have been described in the surgical treatment of dead-space. These techniques include the Papineau,29 Belfast,6 Masquelet9and Lautenbach [29].

The commonly used muscle flaps include the mobilization of local muscle, rotational muscle flap and free-muscle flap. For small defects with soft tissue loss, fascio-cutaneous free flap is used to reduce morbidity from donor site. For large defects, free-muscle flap are preferable. For major bone loss, free vascularized bone graft or composite grafts including bone, muscles and/or skin are advisable [4].

Vacuum-assisted closure is applicable to stages 2, 3, and 4 lesions.1 Antibiotic-impregnated PMMA beads and blocks when used requires re-operation for removal. The use of blocks augments local skeletal stability while maintaining length and space for later reconstruction procedures. Papineau technique is advised following radical debridement for stage 3 COM. Here bone grafting is done in stages with delayed soft-tissue closure. Wound is allowed to granulate naturally or with skin grafting. Belfast technique is a two staged procedure following radical debridement, the cavity is filled up with early muscle flap or Gentamycin-impregnated PMMA bead and delayed bone grafting. In the Lautenbach technique using a close irrigation system, antibiotics are delivered locally and possible to obtain frequent samples for culture [1,2,4-11,16,29].

15. Soft-Tissue Coverage

Micro-vascular free-muscle transfer is the gold standard but rotational flaps in a single stage procedure are good options.

16. Skeletal Stabilization and Management of Skeletal Defects

Small bone defect less than 6 cm are managed with autogenous bone graft. Large bone defects are bridged by distraction osteogenesis using Linear Ray System (LRS) or Ilizarov ring fixator or lengthening nails, Masquelet technique or vascularized fibular graft or bone transfer such as fibular-pro-tibia construct or rib transfer for humeral defects.

Radical debridement for stage 4 and some stage 3 lesions may result in significant bone defects. External fixation device is preferred for infection control than internal fixation. Antibiotic bone cement-impregnated IM nails may be used to achieve stability and local delivery of antibiotics [1,4].

The Masquelet technique otherwise known as the induced membrane technique is a two staged procedure following radical debridement, antibiotic-impregnated PMMA block is used to fill the defect for 4-6 weeks in the first stage to provide stability and achieve infection control and allow a vascularized membrane to develop. In the second stage the membrane is incised and the block is removed followed by bone grafting. Generally, defect less than 6 cm will do well with autogenous bone graft usually cortico-cancellous from the iliac crest. Larger defects are bridged by distraction osteogenesis using magnetic lengthening nails or LRS or Ilizarov ring fixator1, 12 or vascularized bone graft preferably a fibula graft. In hopeless cases, amputation remains a good surgical treatment option for COM. The magnetic lengthening nails, LRS and Ilizarov ring fixator are considered as gold standard in the surgical treatment of major bone defects; aside providing stability they are more effective in correcting severe limb length discrepancy and other deformities, but are associated with high cost of treatment (Table 3).

Bone defect	Preferred reconstruction
<2 cm	Primary closure ± graft
2–6 cm	Autogenous cancellous graft
>6 cm	Masquelet
>6 cm + shortening	Bone transport
Massive defects	Vascularized fibula
Unsalvageable limb	Amputation

Table 3: Advantages and Limitations of Reconstructive Techniques According to Bone Defect Size

Comparison of reconstructive techniques for bone defects following debridement in paediatric chronic osteomyelitis, highlighting indications based on defect size, key advantages, limitations, and practical considerations. Treatment should be tailored to disease severity, soft-tissue status, patient factors, and available resources.

17. Adjunctive Therapies

In view of persistent or recurrent cases of chronic osteomyelitis, there is a need to explore innovative approaches to management. Novel surgical strategies remain limited despite recent advances. Therefore, the use of adjunctive therapies may suffice for the future. Biological therapy aimed at the biofilm production and the biology of bacterial phenotypes to break the chain of bacterial weaponry against host immune system and antibiotics including interfering with the mechanism of developing drug resistance strains may be the way forward in the war against COM. The mechanisms of action and current level of clinical evidence supporting adjunctive therapies are summarized in Table 4.

The use of hyperbaric oxygen therapy which provides oxygen in high concentration and pressure helps to increased bactericidal effects of neutrophil, induces anaerobic organisms enhances antibiotic activity and promotes oxygen-dependent osteoclastic resorption of necrotic bone. Furthermore, growth factors such as BMP are known to accelerate osteogenesis and bone healing. Pulsed electromagnetic fields, ultrasound and platelet-rich plasma are known to promote bone and soft tissue healing.

Understanding genetic and molecular biology of bacterial biofilm may allow us to prevent biofilm formation by inhibiting cell-to-cell signalling. Quorum-sensing inhibitors, use of bacteriophages, interspecies interaction, biofilm disruptors (Sonification) and specific antibiofilm molecules or bacterial vaccine may be the future weapons in cobbling the menace of COM when we are done with surgery [4].

Therapy	**Proposed Mechanism**	**Current Clinical Evidence**
Hyperbaric oxygen	Improved tissue oxygenation	Moderate
BMPs	Enhanced osteogenesis	Limited
Platelet-rich plasma	Growth factor delivery	Limited
Ultrasound stimulation	Bone healing promotion	Emerging
Bacteriophage therapy	Targeted bacterial destruction	Experimental
Anti-biofilm agents	Biofilm disruption	Experimental
Quorum-sensing inhibitors	Prevention of bacterial communication	Experimental

Table 4: Emerging Adjunctive Therapies for Chronic Osteomyelitis

Summary of the proposed mechanisms of action and current evidence supporting adjunctive interventions, including hyperbaric oxygen therapy, growth factors, platelet-rich plasma, ultrasound stimulation, bacteriophage therapy, quorum-sensing inhibitors, and anti-biofilm agents. Although promising, many of these therapies remain investigational and require further clinical validation before widespread adoption in paediatric practice.

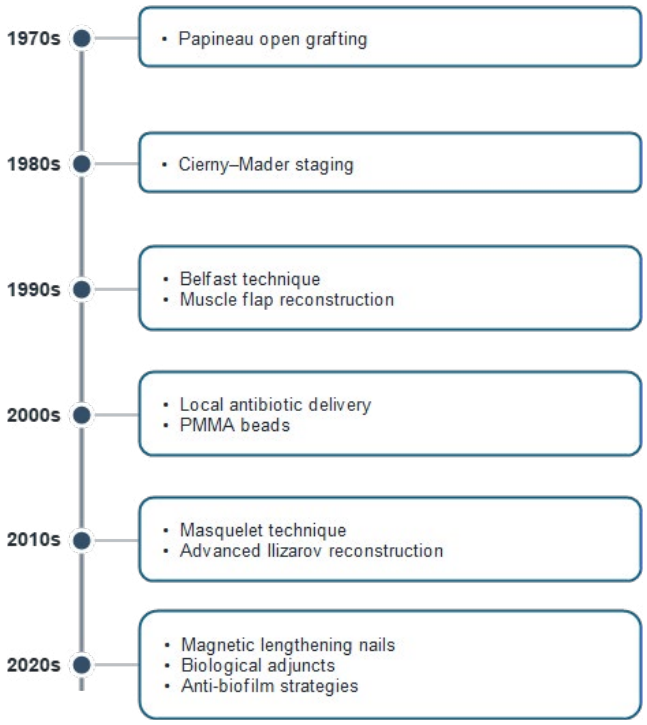

Figure 4: Evolution of surgical management strategies for chronic osteomyelitis (1970–2026).

The timeline illustrates key developments from traditional debridement and Papineau grafting techniques to contemporary approaches including local antibiotic delivery systems, muscle flap reconstruction, the Masquelet induced membrane technique, distraction osteogenesis, magnetic lengthening technology, and emerging anti-biofilm and biological therapies.

18. Conclusion

The surgical treatment of COM is challenging and prolonged, due to the nature of surgical procedures and antibiotic therapy need. While a number of options for surgical reconstruction and delivery of appropriate antibiotics are available, proper staging and identification of causative organism remain vital to success of treatment. Newer treatment modalities to address the role of biofilm in COM when developed will be a useful adjunct in the surgical treatment of COM. Management of COM in developing countries is far from being adequate owing to limited resources. COM like trauma remains a neglected disease. Governments in developing countries should take the lead in taking deliberate decisions to enforce preventive measures by putting in place adequate medical care in the rural areas and provide infrastructure to improve on the issues of environmental sanitation and childhood malnutrition. Prevention of pediatric chronic osteomyelitis is substantially more cost-effective than treating established disease. Despite advances in reconstructive techniques and local antibiotic delivery systems, recurrence remains a significant challenge, and no universally accepted surgical strategy has emerged. The evolution of major surgical strategies over the past five decades is illustrated in Figure 4, highlighting the transition from conventional debridement techniques to modern reconstructive and biological approaches [5,30,31].

There is therefore a great need for high quality innovative studies to develop novel surgical techniques for optimal treatment of chronic osteomyelitis. Based on the available evidence and the authors' experience, practical recommendations for the surgical management of paediatric chronic osteomyelitis are presented in Table 5.

Clinical Scenario	Recommended Management
Small sequestrum	Sequestrectomy + antibiotics
Dead space	PMMA beads ± muscle flap
Bone defect <6 cm	Autogenous bone graft
Bone defect >6 cm	Ilizarov or Masquelet
Soft-tissue loss	Muscle flap/free flap
Infected nonunion	Debridement + stabilization
Extensive destruction	Limb reconstruction or amputation

Table 5: Practical Recommendations for Surgical Management of Paediatric Chronic Osteomyelitis

Practical recommendations for selecting surgical treatment according to disease severity, bone defect size, soft-tissue status, and reconstructive needs in paediatric chronic osteomyelitis. Recommendations are based on current evidence and expert consensus and should be individualized according to patient characteristics and available resources.

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