

Optimising fracture-related infection management: A narrative review of diagnostic precision, surgical timing, and antimicrobial stewardship

Optimización del manejo de infecciones relacionadas con fracturas: una revisión narrativa de la precisión diagnóstica, el momento quirúrgico oportuno y la administración de antimicrobianos

Fabriccio J. Visconti-Lopez^{1*}, Juan David Reyes-Duque², Dustin M. Solorzano-Salazar³

- ¹ Universidad Científica del Sur, Lima, Peru.
- ² Facultad de Ciencias para la Salud, Universidad de Manizales, Caldas, Manizales, Colombia.
- ³ Socios En Salud Sucursal Peru, Lima, Peru.

Article history

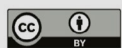
Received: January 13, 2026
Peer reviewed
Accepted: March 23, 2026
Online: March 25, 2026

How to cite this article

Visconti-Lopez FJ, Reyes-Duque JD, Solorzano-Salazar DM. Optimising fracture-related infection management: A narrative review of diagnostic precision, surgical timing, and antimicrobial stewardship. *Med Educ Clin Pract.* 2026;1(1):e011. doi: 10.21142/mecp.2026.1.1.e011.

* Correspondence

Fabriccio J. Visconti-Lopez
E-mail: fvisconti@cientifica.edu.pe



This work is licensed under a Creative Commons Attribution 4.0 International License

ABSTRACT

This narrative review synthesises contemporary fracture-related infection (FRI) management with an emphasis on reducing failure in diagnostic and treatment grey zones. We summarise consensus definitions that separate confirmatory from suggestive criteria and translate them into a practical diagnostic bundle linking clinical assessment, inflammatory markers, selective imaging, and disciplined microbiological and histological sampling. Imaging is framed as a problem-solving tool rather than a stand-alone rule-in test in equivocal cases. We outline a surgical decision matrix based on infection timing, fixation and fracture stability, host factors, and soft-tissue status, and we integrate local and systemic antimicrobial strategies with stewardship principles, including sampling before antibiotics when feasible and early de-escalation. Evidence quality is heterogeneous, and many recommendations derive from consensus and observational data; therefore, areas of uncertainty and priorities for prospective studies are highlighted.

Keywords: Fractures, Bone; Surgical Wound Infection; Osteomyelitis; Consensus; Anti-Bacterial Agents (source: MeSH NLM).

RESUMEN

Esta revisión narrativa sintetiza el manejo contemporáneo de la infección relacionada con fracturas (FRI), con énfasis en reducir el fracaso en las zonas grises diagnósticas y terapéuticas. Resumimos las definiciones de consenso que distinguen criterios confirmatorios de criterios sugestivos y las traducimos en un paquete diagnóstico práctico que integra la evaluación clínica, los marcadores inflamatorios, la imagen selectiva y el muestreo microbiológico e histológico disciplinado. La imagen se plantea como una herramienta para resolver problemas clínicos y no como una prueba aislada para confirmar infección en casos equívocos. Presentamos una matriz de decisión quirúrgica basada en el momento de la infección, la fijación y estabilidad de la fractura, los factores del huésped y el estado de los tejidos blandos, e integramos estrategias antimicrobianas locales y sistémicas con principios de optimización del uso de antimicrobianos, incluyendo la toma de muestras antes de iniciar antibióticos cuando sea factible y la desescalada temprana. La calidad de la evidencia es heterogénea y muchas recomendaciones derivan de consensos y datos observacionales; por ello, se destacan las áreas de incertidumbre y las prioridades para estudios prospectivos.

Palabras clave: Fracturas Óseas; Infecciones en las Heridas Quirúrgicas; Osteomielitis; Consenso; Antibacterianos (fuente: DeCS Bireme).

INTRODUCTION

Fracture-related infection (FRI) represents a formidable complication in orthopaedic trauma, with reported incidence rates of 1–2% following closed fractures and up to 30–50% after open fractures, depending on soft-tissue injury severity^[1,2]. Across published cohorts, FRI is associated with substantially prolonged hospitalization, repeated operations, and markedly increased cost compared with uncomplicated fracture healing, with estimates varying by injury severity, health system, and case mix^[1,3,4].

A critical vulnerability lies in the grey zone of suspected FRI, where patients lack confirmatory criteria (e.g., sinus tract, purulence, or pathognomonic intraoperative findings) and decisions depend on suggestive features such as inflammatory markers and imaging. In some cohorts, a sizeable proportion of cases present without confirmatory signs (reported up to 23%), which is associated with delayed or inconsistent decision-making and potentially avoidable failures^[5,6].

Historically, FRI management extrapolated principles from periprosthetic joint infection, but recent FRI-specific consensus definitions and guidelines have catalyzed a paradigm shift toward tailored diagnostics, surgical strategies, and antimicrobial stewardship^[7-9]. In this review, ‘grey zone’ refers to cases without confirmatory criteria but with persistent clinical concern where additional tests are sought to change management rather than to label infection retrospectively.

This narrative review was informed by a targeted, non-systematic search of the FRI literature focused on clinically actionable domains: diagnosis, microbiological and histological sampling, imaging, surgical strategy, local antimicrobial delivery, soft-tissue management, and systemic antimicrobial stewardship. The search was conducted in PubMed, Scopus, and Web of Science. We considered literature till 13 of December 2025, with emphasis on contemporary evidence relevant to current fracture-fixation practice.

We prioritised international consensus definitions, expert-group recommendations, guideline statements, systematic reviews, and higher-quality observational studies because much of the FRI field is guided by consensus-based frameworks and non-randomised clinical evidence rather than large randomized trials. Articles were selected for relevance to adult fracture-related infection, diagnostic or therapeutic applicability, and contribution to decision-making in suspected or confirmed FRI. We excluded studies not directly related to fracture fixation, reports focused primarily on periprosthetic joint infection without clear applicability to FRI, non-clinical basic science studies without direct practice implications, and publications

with limited relevance to the review’s clinical scope. Evidence was synthesised qualitatively; where data were heterogeneous, indirect, or primarily consensus-derived, recommendations were framed accordingly and areas of uncertainty were highlighted. Because this article was designed as a targeted narrative review rather than a systematic review or meta-synthesis, PRISMA and SWiM reporting frameworks were not applied.

DEFINITIONS AND CLASSIFICATION

Current consensus definitions distinguish confirmatory criteria (diagnostic for infection) from suggestive criteria (raise suspicion and prompt further investigation)^[6,9]. Confirmatory criteria include a sinus tract or wound breakdown communicating with the fracture or implant, purulence observed during surgery, phenotypically indistinguishable organisms cultured from at least two separate deep specimens, and histopathological evidence of infection in deep tissue^[9]. Suggestive criteria include new or increasing local pain/swelling, persistent wound leakage, elevated inflammatory markers (C-reactive protein [CRP] and erythrocyte sedimentation rate [ESR]), radiographic progression of osteolysis or loosening, or a single positive deep culture, all of which require contextual interpretation and disciplined sampling^[5,7].

This standardized approach improves comparability across studies and makes diagnostic thresholds more reproducible in multidisciplinary care^[6]. A lack of such standardization has historically hampered the ability to draw meaningful conclusions from studies on FRI, underscoring the urgent need for a unified diagnostic framework^[4,7]. In this review, we use the Fracture-Related Infection Consensus Group framework as the diagnostic backbone, separating confirmatory from suggestive criteria and focusing on how these criteria can be operationalised for fracture fixation. This approach aims to standardise diagnosis and reporting while acknowledging that surgical site infection definitions may be insufficiently specific for the fracture-fixation context^[6].

Suggestive criteria, while valuable, exhibit limited specificity as they may reflect aseptic inflammation, fracture non-union, or healing processes, posing risks of diagnostic uncertainty in up to 23% of cases lacking confirmatory signs^[5]. Undertreatment in these “grey zone” scenarios can lead to persistent infection, biofilm formation, chronic osteomyelitis, recurrent surgeries, and amplified healthcare costs^[4,5].

FRI classification further incorporates host status, adapting the Cierny-Mader system: Host A (normal physiologic/metabolic/vascular status), Host B (compromised locally or systemically, amenable to treatment), and

Host C (severe compromise where treatment risks exceed disease burden, favoring palliation)^[4,7]. Implant/fracture stability is equally pivotal, guiding surgical strategies, retention is viable with stable fixation and early symptoms, versus exchange/removal for unstable constructs to promote union and eradicate infection^[7].

THE “SUSPECTED FRI” DIAGNOSTIC BUNDLE

Confirmatory criteria (e.g., a sinus tract communicating with bone/implant, purulence, phenotypically indistinguishable pathogens from at least two deep specimens, or histopathological evidence) are considered diagnostic within consensus definitions and should trigger definitive FRI management. Suggestive findings (e.g., persistent wound leakage, local erythema, pain, fever, or elevated inflammatory markers) increase suspicion but require targeted confirmation with disciplined sampling and contextual interpretation^[5,6,10].

Serum C-reactive protein and erythrocyte sedimentation rate provide objective inflammatory insights, yet a systematic review and meta-analysis demonstrated their limited standalone diagnostic accuracy for late FRI, with pooled sensitivity and specificity hampered by poor discrimination amid postoperative inflammation or nonunion^[10,11]. Serum CRP and ESR are non-specific after trauma and surgery. Single values should not be used to rule in or rule out FRI; however, a failure to downtrend, a secondary rise, or persistent elevation can support clinical suspicion when interpreted alongside wound status, imaging, and microbiology^[5,10].

In periarticular fractures with suspected FRI, a new or unexplained joint effusion may justify joint aspiration to obtain synovial fluid for cell count, differential, and culture, with crystal analysis where clinically relevant. Although tests such as alpha-defensin or leukocyte esterase are validated in periprosthetic joint infection, their performance in fracture fixation contexts is less certain; therefore, they should be considered adjuncts and interpreted cautiously. When operative management is undertaken, aspiration results should not replace disciplined deep tissue sampling and histology^[6,7,12].

IMAGING: DISTINGUISHING INFECTION FROM INFLAMMATION

Plain radiographs remain the first-line imaging study in suspected FRI because they are accessible and help assess implant position, fracture alignment, and progression toward union, although diagnostic accuracy is limited and findings may overlap with aseptic loosening or mechanical instability^[5,13]. CT is most useful when the main question is bony anatomy, including sequestra, cloacae,

cortical erosions, intraosseous gas, or bone defects^[14,15]. MRI is preferred when the key question concerns marrow involvement, abscess, sinus tracts, or soft-tissue extent, provided metal artifact is manageable; however, postoperative edema, hematoma, aseptic nonunion, and normal healing may reduce specificity^[16,17]. Nuclear imaging, particularly WBC scintigraphy with SPECT/CT and, selectively, 18F-FDG PET/CT, may be reserved for equivocal cases in which the relevant question is infection versus postoperative or healing-related inflammation. These modalities should be interpreted in clinical context and alongside microbiological and histological sampling rather than as stand-alone rule-in tests^[18,19].

MICROBIOLOGICAL AND HISTOLOGICAL SAMPLING DISCIPLINE

Optimal diagnostic precision in fracture-related infection depends on disciplined intraoperative sampling. Multiple separate deep tissue specimens, commonly five, should be obtained from representative sites using clean instruments for each sample, and superficial swabs should be avoided^[20,21]. When clinically safe, antibiotics should be withheld until sampling; if urgent therapy is required, this should be documented and histopathology used as an adjunct, particularly in culture-negative or antibiotic-pretreated cases^[22,23]. Histopathology can provide confirmatory evidence when cultures are negative or affected by prior antibiotics, while sonication of removed implants and selected molecular tests may be considered as adjuncts in specific scenarios, especially chronic infection, hardware removal, or culture-negative cases^[24,25]. These methods should complement, not replace, disciplined deep sampling and conventional culture-based susceptibility testing.

SURGICAL STRATEGY FRAMEWORK: THE DECISION MATRIX

The strategic management of fracture-related infection requires a structured decision matrix for surgical intervention, prioritizing source control through thorough debridement, fracture stability, dead space management, and soft tissue coverage, while considering infection acuity, implant stability, pathogen profile, host factors, and bone defect size^[7]. However, many of these decision principles are informed primarily by expert consensus, cohort data, and observational series rather than high-certainty comparative trials; accordingly, they should be applied as pragmatic guidance within individualized multidisciplinary decision-making rather than as universally validated algorithms. Two primary strategies emerge: debridement, antimicrobials, and implant retention versus implant removal (if healed) or exchange (if unhealed)^[26].

Debridement, antibiotics, and implant retention (DAIR) is generally considered in early presentations, often within the first few weeks of symptom onset, when fixation is stable, reduction is acceptable, soft tissues are viable, and the organism is likely to be susceptible to an effective regimen. Because definitions of 'early' vary and evidence is heterogeneous, the decision should be individualised around stability, host factors, and the ability to achieve adequate debridement and timely soft-tissue coverage^[26]. Situations where implant retention is less likely to succeed include unstable fixation, recurrent infection, prolonged symptom duration with suspected mature biofilm, and difficult-to-treat organisms (e.g., rifampin-resistant staphylococci or fungi)^[26]. Intramedullary devices and compromised hosts may further reduce the probability of success and should prompt a lower threshold for exchange strategies, depending on stability requirements and the feasibility of achieving adequate debridement and timely soft-tissue coverage^[26].

For unhealed fractures in which fixation cannot be retained, the strategy should balance infection control with restoration of mechanical stability. A planned one-stage exchange (removal of infected hardware, debridement, and immediate re-fixation) may be appropriate in selected patients with favourable host status, limited contamination, and available definitive soft-tissue coverage^[26]. Staged approaches are more commonly used in chronic infection, resistant organisms, compromised soft tissues, or when stability cannot be restored reliably in a single setting^[27]. Patient selection, dialogue, and stability are paramount^[28].

Post-debridement voids necessitate management to prevent recurrence; options for critical-sized defects include Masquelet induced-membrane technique, docking-site interventions with bone transport, or vascularized grafts, with bone transport showing reliable union but prolonged fixation^[29]. Choice depends on defect size, infection status, and surgeon expertise^[30].

LOCAL ANTIBIOTIC DELIVERY

Local antibiotic delivery may help overcome some limitations of systemic therapy, particularly when vascularity is compromised or biofilm is suspected, but it should be considered an adjunct to debridement and targeted systemic therapy rather than a stand-alone solution^[30,31]. Nonabsorbable carriers such as polymethylmethacrylate require later removal and have elution limitations, whereas absorbable carriers may aid dead-space management but can be associated with wound leakage and heterogeneous comparative evidence^[32,33]. In both open fractures and established FRI, reported benefits vary across studies and are strongly influenced by debridement quality, stability, soft-tissue

management, and case selection; therefore, carrier selection should be individualised and interpreted within antimicrobial stewardship principles^[34,35].

SOFT TISSUE MANAGEMENT

Adequate soft tissue coverage is paramount in FRI management, creating a favorable biological environment for healing and reducing the risk of recurrent infection^[36]. A judicious, well-planned bone and soft tissue debridement remains one of the cornerstones of state-of-the-art treatment, necessitating radical excision of all non-viable tissue despite the potential creation of large soft tissue defects requiring reconstructive techniques^[37].

Thorough debridement of non-viable soft tissue is essential to achieve source control, with orthopaedic surgeons advised not to limit excision due to concerns over reconstruction feasibility; prior multidisciplinary planning enables comprehensive removal without hesitation^[38].

Early collaboration between orthopaedic and plastic surgeons is central to achieving stable fixation and timely soft-tissue coverage. In high-energy open injuries, this often takes the form of coordinated 'fix and flap' pathways, aiming for definitive coverage as early as feasible once the wound is adequately debrided. In established FRI, coverage planning should be integrated with the debridement and stability strategy and may be single-stage or staged depending on contamination, host status, and reconstructive options^[38,39].

Negative pressure wound therapy functions as a temporary bridge to definitive flap coverage in scenarios precluding immediate closure but is not a standalone treatment for FRI due to risks of persistent bacterial colonization, pathogen shifts, and infection recurrence; prolonged use should be avoided, favoring prompt reconstruction^[40,41].

SYSTEMIC ANTIMICROBIAL STEWARDSHIP

The judicious selection and administration of systemic antimicrobial agents are critical components of FRI management, complementing surgical interventions and local antibiotic delivery by targeting pathogens throughout the host^[42].

Empiric therapy should be initiated after deep tissue sampling whenever feasible, but should not be delayed in septic or rapidly deteriorating patients. Empiric regimens should reflect local epidemiology and individual risk factors, typically ensuring coverage for staphylococci (including methicillin-resistant *Staphylococcus aureus* where relevant) and, in selected high-risk scenarios,

Gram-negative organisms, then narrowed promptly once cultures and susceptibilities return [7].

Suppressive antimicrobial therapy may be considered when curative source control is not feasible or is deferred (e.g., implant retention required to maintain stability, prohibitive surgical risk, or limited reconstructive options) [7]. The goal is symptom control and containment rather than eradication; therefore, regimens should be individualised with infectious diseases input, explicit monitoring plans, and periodic reassessment of surgical options. Reported outcomes vary substantially by pathogen, host factors, tolerability, and follow-up, and evidence in FRI is largely observational and often extrapolated from related implant infections [43].

CONCLUSION

Fracture-related infection failures often arise in predictable grey zones: equivocal diagnostic signals, poorly standardised sampling, and unstable fixation or compromised soft tissues that prevent durable source control. The main practice-changing message of this review is that avoidable failure is less likely to be reduced by any single test than by disciplined use of confirmatory versus suggestive criteria, problem-focused imaging that answers a specific management question, and multiple deep tissue samples with histology before antibiotics when feasible. On the treatment side, the framework is most clinically useful when it prioritises thorough debridement, preservation or restoration of stability, timely soft-tissue coverage, and prompt culture-guided antimicrobial de-escalation within a multidisciplinary pathway.

Because the evidence base remains dominated by consensus guidance and heterogeneous observational studies, these recommendations should be implemented with awareness of uncertainty and audited locally using measurable pathway endpoints such as time to debridement, sampling quality, and early treatment failure. Future prospective studies should focus specifically on grey-zone cases and prioritise outcomes that are clinically actionable and patient-important, including whether

diagnostic strategies change management, recurrent or persistent infection, fracture union, reoperation burden, treatment-related adverse events, and patient-reported functional recovery. Participation in standardized FRI registries and prospective collaborative studies will be essential to refine these pathways and strengthen the evidence base.

Author contributions

FJVL: Conceptualization, Methodology, Investigation, Data Curation, Writing – Original Draft, Writing – Review & Editing, Project Administration. JDRD: Writing – Original Draft, Writing – Review & Editing. DMSS: Writing – Original Draft, Writing – Review & Editing. All authors assume full responsibility for the content of the manuscript.

Conflicts of interest statement

The authors declare no conflicts of interest

Funding

This study did not receive any funding

Acknowledgments

None

Data availability statement

Not applicable

Artificial Intelligence use statement

ChatGPT 5 was used to assist with English-language editing for clarity and grammar only. No data, results, or references were generated by the tool, and all final content was reviewed and approved by the author.

ORCID

Fabriccio J. Visconti-Lopez: [0000-0002-8056-2112](https://orcid.org/0000-0002-8056-2112)

Juan David Reyes-Duque: [0000-0002-5184-4479](https://orcid.org/0000-0002-5184-4479)

Dustin M. Solorzano-Salazar: [0000-0003-3993-2473](https://orcid.org/0000-0003-3993-2473)

REFERENCES

1. Foster AL, Warren J, Vallmuur K, Jaiprakash A, Crawford R, Tetsworth K, et al. A population-based epidemiological and health economic analysis of fracture-related infection. *Bone Joint J.* 2024;(1):77-85. doi: [10.1302/0301-620x.106b1.bjj-2023-0279.r2](https://doi.org/10.1302/0301-620x.106b1.bjj-2023-0279.r2).
2. Wang B, Xiao X, Zhang J, Han W, Hersi SA, Tang X. Epidemiology and microbiology of fracture-related infection: a multicenter study in Northeast China. *J Orthop Surg Res.* 2021;16(1):490. doi: [10.1186/s13018-021-02629-6](https://doi.org/10.1186/s13018-021-02629-6).
3. Haidari S, Buijs MAS, Plate JDJ, Zomer JJ, IJpma FFA, Hietbrink F, et al. Costs of fracture-related infection: the impact on direct hospital costs and healthcare utilisation. *Eur J Trauma Emerg Surg.* 2024;50(4):1701-7. doi: [10.1007/s00068-024-02497-9](https://doi.org/10.1007/s00068-024-02497-9).

4. Bezstarosti H, Lieshout EMMV, Voskamp L, Kortram K, Obremesky WT, McNally M, et al. Insights into treatment and outcome of fracture-related infection: a systematic literature review. *Arch Orthop Trauma Surg.* 2018;139(1):61-72. doi: [10.1007/s00402-018-3048-0](https://doi.org/10.1007/s00402-018-3048-0).
5. Vanvelk N, Lieshout EMMV, Onsea J, Sliepen J, Govaert GAM, Ijpma FFA, et al. Diagnosis of fracture-related infection in patients without clinical confirmatory criteria: an international retrospective cohort study. *J Bone Jt Infect.* 2023;8(2):133-42. doi: [10.5194/jbji-8-133-2023](https://doi.org/10.5194/jbji-8-133-2023).
6. Govaert GAM, Kuehl R, Atkins BL, Trampuž A, Morgenstern M, Obremesky WT, et al. Diagnosing fracture-related infection: current concepts and recommendations. *J Orthop Trauma.* 2019;34(1):8-17. doi: [10.1097/bot.0000000000001614](https://doi.org/10.1097/bot.0000000000001614).
7. Metsemakers W, Morgenstern M, Senneville É, Borens O, Govaert GAM, Onsea J, et al. General treatment principles for fracture-related infection: recommendations from an international expert group. *Arch Orthop Trauma Surg.* 2019;140(8):1013-27. doi: [10.1007/s00402-019-03287-4](https://doi.org/10.1007/s00402-019-03287-4).
8. Foster AL, Moriarty TF, Trampuž A, Jaiprakash A, Burch MA, Crawford R, et al. Fracture-related infection: current methods for prevention and treatment. *Expert Rev Anti Infect Ther.* 2020;18(4):307-21. doi: [10.1080/14787210.2020.1729740](https://doi.org/10.1080/14787210.2020.1729740).
9. Metsemakers W, Morgenstern M, McNally M, Moriarty TF, McFadyen I, Scarborough M, et al. Fracture-related infection: a consensus on definition from an international expert group. *Injury.* 2017;49(3):505-10. doi: [10.1016/j.injury.2017.08.040](https://doi.org/10.1016/j.injury.2017.08.040).
10. Bosch PG, den J van, Plate JDJ, Ijpma FFA, Houwert RM, Huisman A, et al. Limited predictive value of serum inflammatory markers for diagnosing fracture-related infections: results of a large retrospective multicenter cohort study. *J Bone Jt Infect.* 2018;3(3):130-7. doi: [10.7150/jbji.26492](https://doi.org/10.7150/jbji.26492).
11. Kieboom J van den, Bosch PG, Plate JDJ, Ijpma FFA, Kuehl R, McNally M, et al. Diagnostic accuracy of serum inflammatory markers in late fracture-related infection. *Bone Joint J.* 2018;100-B(12):1542-1550. doi: [10.1302/0301-620x.100b12.jbj-2018-0586.r1](https://doi.org/10.1302/0301-620x.100b12.jbj-2018-0586.r1).
12. Quinlan ND, Jennings JM. Joint aspiration for diagnosis of chronic periprosthetic joint infection: when, how, and what tests? *Arthroplasty.* 2023;5(1):43. doi: [10.1186/s42836-023-00199-y](https://doi.org/10.1186/s42836-023-00199-y).
13. Li C, Renz N, Trampuž A, Ojeda-Thies C. The value of conventional radiographs for diagnosing internal fixation-associated infection. *BMC Musculoskelet Disord.* 2021;22(1):411. doi: [10.1186/s12891-021-04170-3](https://doi.org/10.1186/s12891-021-04170-3).
14. Sambri A, Spinnato P, Tedeschi S, Zamparini E, Fiore M, Zucchini R, et al. Bone and joint infections: the role of imaging in tailoring diagnosis to improve patients' care. *J Pers Med.* 2021;11(12):1317. doi: [10.3390/jpm11121317](https://doi.org/10.3390/jpm11121317).
15. Hofmann UK, Eleftherakis G, Migliorini F, Fink B, Mederake M. Diagnostic and prognostic relevance of plain radiographs for periprosthetic joint infections of the hip: a literature review. *Eur J Med Res.* 2024;29(1):314. doi: [10.1186/s40001-024-01891-8](https://doi.org/10.1186/s40001-024-01891-8).
16. Christersson A, Larsson S, Sörensen J. Presurgical localization of infected avascular bone segments in chronic complicated posttraumatic osteomyelitis in the lower extremity using dual-tracer PET/CT. *EJNMMI Res.* 2018;8(1):65. doi: [10.1186/s13550-018-0426-0](https://doi.org/10.1186/s13550-018-0426-0).
17. Yang M, Tan Q, Li T, Chen J, Hu W, Zhang Y, et al. FRID-PI: a machine learning model for diagnosing fracture-related infections based on 18F-FDG PET/CT and inflammatory markers. *Front Med (Lausanne).* 2025;12:1534988. doi: [10.3389/fmed.2025.1534988](https://doi.org/10.3389/fmed.2025.1534988).
18. Bosch PG, Glaudemans AWJM, Vries JPM de, Middelberg TR, Govaert GAM, Ijpma FFA. Nuclear imaging for diagnosing fracture-related infection. *Clin Transl Imaging.* 2020;8(4):289-98. doi: [10.1007/s40336-020-00374-0](https://doi.org/10.1007/s40336-020-00374-0).
19. Sacher SE, Koff MF, Tan ET, Burge AJ, Potter HG. The role of advanced metal artifact reduction MRI in the diagnosis of periprosthetic joint infection. *Skeletal Radiol.* 2023;53(10):1969-78. doi: [10.1007/s00256-023-04483-5](https://doi.org/10.1007/s00256-023-04483-5).
20. Díaz-Ledezma C, Espinosa-Mendoza R, Gallo J, Glaudemans AWJM, Gómez-García F, Goodman SB, et al. General Assembly, Diagnosis, Imaging: Proceedings of International Consensus on Orthopedic Infections. *J Arthroplasty.* 2018;34(2S):S215-S223. doi: [10.1016/j.arth.2018.09.073](https://doi.org/10.1016/j.arth.2018.09.073).
21. Glaudemans AWJM, Bosch PG, Slart RHJA, Ijpma FFA, Govaert GAM. Diagnosing fracture-related infections: can we optimize our nuclear imaging techniques? *Eur J Nucl Med Mol Imaging.* 2019;46(8):1583-7. doi: [10.1007/s00259-019-04378-5](https://doi.org/10.1007/s00259-019-04378-5).
22. Govaert GAM, Bosch PG, Ijpma FFA, Glauche J, Jutte PC, Lemans JVC, et al. High diagnostic accuracy of white blood cell scintigraphy for fracture related infections: results of a large retrospective single-center study. *Injury.* 2018;49(6):1085-90. doi: [10.1016/j.injury.2018.03.018](https://doi.org/10.1016/j.injury.2018.03.018).
23. Glaudemans AWJM, Jutte PC, Cataldo MA, Cassar-Pullicino VN, Gheysens O, Borens O, et al. Consensus document for the diagnosis of peripheral bone infection in adults: a joint paper by the EANM, EBJS, and ESR (with ESCMID endorsement). *Eur J Nucl Med Mol Imaging.* 2019;46(4):957-90. doi: [10.1007/s00259-019-4262-x](https://doi.org/10.1007/s00259-019-4262-x).
24. Lemans JVC, Hobbelink MGG, Ijpma FFA, Plate JDJ, Kieboom J van den, Bosch PG, et al. The diagnostic accuracy of 18F-FDG PET/CT in diagnosing fracture-related infections. *Eur J Nucl Med Mol Imaging.* 2018;46(4):999-1008. doi: [10.1007/s00259-018-4218-6](https://doi.org/10.1007/s00259-018-4218-6).
25. Moriarty TF, Muthukrishnan G, Daiss J, Xie C, Nishitani K, Morita Y, et al. Bone infection: a clinical priority for clinicians, scientists and educators. *Eur Cell Mater.* 2021;42:312-33. doi: [10.22203/ecm.v042a21](https://doi.org/10.22203/ecm.v042a21).
26. Hannigan GD, Pulos N, Grice EA, Mehta S. Current concepts and ongoing research in the prevention and treatment of open fracture infections. *Adv Wound Care (New Rochelle).* 2014;4(1):59-74. doi: [10.1089/wound.2014.0531](https://doi.org/10.1089/wound.2014.0531).
27. Hellebrekers P, Rentenaar RJ, McNally MM, Hietbrink F, Houwert M, Leenen LPH, et al. Getting it right first time: the importance of a structured tissue sampling protocol for diagnosing fracture-related infections. *Injury.* 2019;50(10):1649-55. doi: [10.1016/j.injury.2019.05.014](https://doi.org/10.1016/j.injury.2019.05.014).
28. Onsea J, Depypere M, Govaert GAM, Kuehl R, Vandendriessche T, Morgenstern M, et al. Accuracy of tissue and sonication fluid sampling for the diagnosis of fracture-related infection: a systematic review and critical appraisal. *J Bone Jt Infect.* 2018;3(4):173-81. doi: [10.7150/jbji.27840](https://doi.org/10.7150/jbji.27840).
29. Morgenstern M, Athanasou NA, Ferguson J, Metsemakers W, Atkins BL, McNally M. The value of quantitative histology in the diagnosis of fracture-related infection. *Bone Joint J.* 2018;7(7):966-72. doi: [10.1302/0301-620x.100b7.bjj-2018-0052.r1](https://doi.org/10.1302/0301-620x.100b7.bjj-2018-0052.r1).
30. Sigmund IK, McNally M, Luger M, Böhler C, Windhager R, Sulzbacher I. Diagnostic accuracy of neutrophil counts in histopathological tissue analysis in periprosthetic joint infection using the ICM, IDSA, and EBJS criteria. *Bone Joint Res.* 2021;10(8):536-47. doi: [10.1302/2046-3758.108.bjr-2021-0058.r1](https://doi.org/10.1302/2046-3758.108.bjr-2021-0058.r1).
31. Ponraj DS, Falstie-Jensen T, Brüggemann H, Lange J. The value of sonication on orthopaedic implants in an everyday

- clinical setting, an exploratory study. *BMC Musculoskelet Disord.* 2023;24(1):691. doi: [10.1186/s12891-023-06796-x](https://doi.org/10.1186/s12891-023-06796-x).
32. Rimoldi SG, Brioschi D, Curreli D, Salari F, Pagani C, Tamoni A, et al. Traditional cultures versus next generation sequencing for suspected orthopedic infection: experience gained from a reference centre. *Antibiotics (Basel).* 2023;12(11):1588. doi: [10.3390/antibiotics12111588](https://doi.org/10.3390/antibiotics12111588).
 33. Baertl S, Rupp M, Alt V. The DAIR-procedure in fracture-related infection, when and how. *Injury.* 2024;55:111977. doi: [10.1016/j.injury.2024.111977](https://doi.org/10.1016/j.injury.2024.111977).
 34. Rimke C, Enz A, Bail HJ, Heppt P, Kladny B, Lewinski G von, et al. Evaluation of the standard procedure for the treatment of periprosthetic joint infections (PJI) in Germany, results of a survey within the EndoCert initiative. *BMC Musculoskelet Disord.* 2020;21(1):791. doi: [10.1186/s12891-020-03670-y](https://doi.org/10.1186/s12891-020-03670-y).
 35. Abouljoud MM, Backstein D, Battenberg AK, Dietz MJ, Erice A, Freiberg AA, et al. Hip and Knee Section, Treatment, Surgical Technique: Proceedings of International Consensus on Orthopedic Infections. *J Arthroplasty.* 2018;34(2S):S445-S451. doi: [10.1016/j.arth.2018.09.029](https://doi.org/10.1016/j.arth.2018.09.029).
 36. Moore A, Wylde V, Whitehouse MR, Beswick AD, Walsh N, Jameson C, et al. Development of evidence-based guidelines for the treatment and management of periprosthetic hip infection. *Bone Jt Open.* 2023;4(4):226-33. doi: [10.1302/2633-1462.44.bjo-2022-0155.r1](https://doi.org/10.1302/2633-1462.44.bjo-2022-0155.r1).
 37. Liodakis E, Giannoudis VP, Harwood P, Giannoudis PV. Docking site interventions following bone transport using external fixation: a systematic review of the literature. *Int Orthop.* 2023;48(2):365-88. doi: [10.1007/s00264-023-06062-8](https://doi.org/10.1007/s00264-023-06062-8).
 38. Bezstarosti H, Metsemakers W, Lieshout E van, Kortram K, Voskamp L, McNally M, et al. Management of critical-sized bone defects in the treatment of fracture-related infection: a systematic review and pooled analysis. *Arch Orthop Trauma Surg.* 2020;141(7):1215-30. doi: [10.1007/s00402-020-03525-0](https://doi.org/10.1007/s00402-020-03525-0).
 39. Depypere M, Kuehl R, Metsemakers W, Senneville É, McNally M, Obremskey WT, et al. Recommendations for systemic antimicrobial therapy in fracture-related infection: a consensus from an international expert group. *J Orthop Trauma.* 2019;34(1):30-41. doi: [10.1097/bot.0000000000001626](https://doi.org/10.1097/bot.0000000000001626).
 40. Maale GE, Eager JJ, Mohammadi DK, Calderon FA. Elution profiles of synthetic CaSO₄ hemihydrate beads loaded with vancomycin and tobramycin. *Eur J Drug Metab Pharmacokinet.* 2020;45(4):547-55. doi: [10.1007/s13318-020-00622-8](https://doi.org/10.1007/s13318-020-00622-8).
 41. Vugt TAG van, Arts JJ, Geurts J. Antibiotic-loaded polymethylmethacrylate beads and spacers in treatment of orthopedic infections and the role of biofilm formation. *Front Microbiol.* 2019;10:1626. doi: [10.3389/fmicb.2019.01626](https://doi.org/10.3389/fmicb.2019.01626).
 42. Gorvetzian J, Kunkel R, Demas C. A single center retrospective evaluation of a surgical strategy to combat persistent soft tissue wounds utilizing absorbable antibiotic beads. *Adv Wound Care (New Rochelle).* 2018;8(2):49-57. doi: [10.1089/wound.2018.0795](https://doi.org/10.1089/wound.2018.0795).
 43. Masters EA, Trombetta RP, Bentley KL de M, Boyce BF, Gill AL, Gill SR, et al. Evolving concepts in bone infection: redefining “biofilm”, “acute vs. chronic osteomyelitis”, “the immune proteome” and “local antibiotic therapy”. *Bone Res.* 2019;7(1):20. doi: [10.1038/s41413-019-0061-z](https://doi.org/10.1038/s41413-019-0061-z).