Can critically important extruded articular bone fragments, recovered from the injury site despite contamination, be safely re-implanted following appropriate decontamination?

A comprehensive evidence review and consensus recommendation

Background:

Extrusion of a major articular bone fragment represents one of the most challenging scenarios in orthopaedic trauma surgery. These injuries typically occur following high-energy trauma and are frequently associated with Gustilo-Anderson type III open fractures, severe soft-tissue disruption, contamination, and compromised vascularity. Commonly affected structures include the talus, distal tibial plafond, femoral condyle, osteochondral fragments around the knee, and occasionally large osteoarticular segments of long bones.

Historically, contaminated extruded fragments were routinely discarded because of concerns regarding deep infection, osteomyelitis, avascular necrosis (AVN), nonunion, and loss of biological viability. Subsequent reconstruction often required arthrodesis, bone transport, vascularized fibular grafting, structural allografts, or endoprosthetic reconstruction.(2) Although these techniques can achieve limb salvage, they are associated with prolonged treatment, multiple surgical procedures, donor-site morbidity, and imperfect restoration of normal anatomy.

Over the last three decades, increasing clinical evidence has challenged the traditional paradigm of fragment excision. Multiple case reports and retrospective case series have demonstrated successful reimplantation of contaminated extruded fragments following meticulous debridement and appropriate decontamination. The strongest body of evidence concerns complete talar extrusion, where reimplantation has become the preferred treatment strategy in many centres.(7-9,12,13,15,32,34) Similar success has also been reported with extruded distal tibial plafond fragments, femoral condyles, osteochondral segments, and long-bone fragments.(1,4,5,9,16-21,23-28,31,33,35)

Current Evidence

The available literature consists predominantly of case reports, retrospective case series, and narrative reviews. No randomized controlled trials or comparative prospective studies have been published. Consequently, the overall level of evidence remains low; however, the consistency of reported outcomes across multiple centres and countries provides meaningful clinical guidance.

The largest available series is that of Smith et al.,(30) who reported outcomes following reimplantation of complete talar extrusions. Despite significant contamination and soft-tissue injury, delayed amputation was rare, and most patients retained a functional limb. Similar findings were reported by many authors who demonstrated satisfactory functional outcomes following immediate talar reimplantation after irrigation and debridement.(6,7,8)

Several studies suggest that successful outcomes depend less on the specific sterilization method used and more on the quality of debridement, stabilization, antibiotic therapy, and soft-tissue management. Reported decontamination methods include saline lavage, povidone-iodine irrigation, chlorhexidine cleansing, bacitracin irrigation, antibiotic soaking, autoclaving, ethylene oxide sterilization, gamma irradiation, and subcutaneous pouch preservation.

Among these methods, chemical sterilization techniques appear to offer theoretical biological advantages because they preserve osteoconductive architecture and osteoinductive proteins while minimizing thermal damage. The various chemical sterilization includes scrubbing and soaking the fragment in povidone-iodine (1%–10%), chlorhexidine (2%–4%), or antibiotic solutions such as vancomycin, gentamicin, or bacitracin.

Autoclaving remains controversial because of concerns regarding loss of cellular viability and reduction in osteogenic potential, although successful union following autoclaved reimplantation of a contaminated and devitalized bone fragment has been repeatedly reported.(10,14,21,28)

More recently, ethylene oxide sterilization and subcutaneous/subfascial pouch preservation have emerged as alternative strategies when immediate reimplantation is not feasible. Lindvall et al. introduced biological preservation of the extruded bone through subcutaneous implantation and later retrieving and placing it at the fracture with appropriate stabilisation.(3)

Complications

Deep infection remains the principal concern following reimplantation. Reported infection rates vary considerably across studies, ranging from 0% to approximately 22%. The highest risk appears to occur in patients with severe contamination, delayed debridement, extensive soft-tissue compromise, and Gustilo IIIB/IIIC injuries. Deep infection and osteomyelitis remain the most feared complications, historically reaching rates of 38% to 39% in open talar dislocations.(11) Repeated and meticulous debridements and appropriate antibiotics in most cases lead on to successful salvage and function of the limb.

Avascular necrosis is particularly relevant in talar injuries because of the tenuous blood supply of the talus. Nevertheless, several studies have demonstrated that radiographic AVN does not necessarily correlate with poor functional outcome, and many patients maintain satisfactory function despite imaging evidence of osteonecrosis. Multiple reports have even shown that complete revascularization of talus was achieved in followup MRI after reimplantation of the extruded talus.(6,22,29)

Other reported complications include post-traumatic arthritis, secondary arthrodesis, nonunion, delayed union, stiffness, and the need for secondary reconstructive procedures. Despite these complications, modern series consistently report high rates of limb preservation.

Data Extraction Table

Excel sheet attached

Knowledge Gaps

Important gaps remain in the current evidence base. There is no universally accepted protocol for fragment decontamination, no comparative studies evaluating different sterilization methods, and no high-level evidence defining the optimal timing of reimplantation. Furthermore, long-term functional outcomes remain incompletely characterized, particularly for osteochondral and femoral condylar injuries.

The rarity of these injuries make randomized trials unlikely. Consequently, future research should focus on multicentre registries, standardized outcome reporting, comparative evaluation of sterilization protocols, and long-term assessment of joint preservation and functional recovery.

Discussion:

All the available literature recommends retention of the extruded osteoarticular fragments and there is only variability of serialization methods and the rate of complication.

A recurring finding throughout the literature is that successful outcomes appear more dependent on debridement quality than on the sterilization method itself. No study has demonstrated superiority of one sterilization protocol over another.In the larger retrospective case series, outcomes reflect a more realistic clinical picture with higher complication rates, though limb salvage remains viable.

Lindvall et al. utilized a subcutaneous bone pouch for autosterilization of long bone fragments (tibia, femur, humerus) in 8 patients. While all 8 pouches remained free of infection, only 4 achieved successful reimplantation, fracture union and joint preservation. One patient required below knee amputation following reimplantation in view of infection. Three patients did not undergo reimplantation due to persistent infection at the open injury site.(3)

For isolated total talar extrusions, larger series typically employed saline or chemical lavage rather than thermal methods to preserve the articular cartilage. Smith et al. reviewed 27 extruded tali, reporting a relatively low infection rate (2 cases) and acceptable functional scores, despite a high incidence of avascular necrosis and post-traumatic arthritis requiring secondary arthrodesis. Burston et al. reviewed 8 talar extrusions, identifying deep joint infection (2 cases) as the primary driver of poor functional outcomes, while avascular necrosis (5 cases) did not inherently preclude a fair or good clinical joint result. Karampinas et al. observed 9 open talar dislocations, achieving uncomplicated functional recovery in 6 patients (mean AOFAS 82.5), while 2 patients underwent secondary salvage arthrodesis in view of complications like infection and avascular necrois.(10,11,30)

For long bone diaphyseal fractures (femur, tibia, humerus, forearm), Rollo et al. compared patients with bone defects <5cm versus >5cm utilizing the S.A.R.A(Sterilization and Reimplantation Autograft) technique. Immediate reimplantation was done in first group with delayed reimplantation(average 21days) followed in second group. Results revealed complete union in 14 of 15 patients with no deep infections and good functional outcome.(20)

Yu et al., processed comminuted extruded tibial fragments into autologous demineralized bone matrix (ADBM) implanted alongside iliac crest autograft via the masquelet technique, reporting a 100% union rate, zero infections, and satisfactory lower extremity function (mean LEFS score 72.2) across 12 patients.(31)

Risk of Bias: HIGH

Brief Justification:

- **Study Design:** The body of literature consists almost entirely of low-level evidence (Level IV and V), specifically isolated, single-patient case reports and small retrospective case series. There are no randomized controlled trials or large prospective cohort studies.
- **Lack of Comparators and Blinding:** None of the included studies utilize control groups, randomized treatment allocation, or blinding of either the patients or the outcome assessors 1, 2. This introduces a significant risk of performance and detection bias.
- **Publication and Selection Bias:** Because this is a rare, high-energy injury, there is a profound publication bias wherein authors are highly likely to report successful, "miraculous" limb-salvage cases while failing to publish negative outcomes or failures. Furthermore, profound selection bias exists because surgeons selectively choose to attempt reimplantation only in patients with favorable baseline conditions, such as younger age, excellent health, and adequate soft-tissue envelopes 3, 4.
- **Small Sample Sizes and Attrition:** The sample sizes are too small to make meaningful statistical inferences. Even the largest retrospective series included in the data suffer from attrition bias (loss to follow-up); for example, one of the largest series identified 27 extruded talus cases but could only obtain a minimum one-year follow-up for 19 of them.(30)

Conclusion and Recommendation:

Based on currently available evidence, contamination alone should not be considered an absolute contraindication to reimplantation of a critical extruded articular fragment. When meticulous debridement, appropriate decontamination, stable fixation, antibiotic therapy, and early soft-tissue reconstruction can be achieved, reimplantation appears to be a safe and effective limb-salvage strategy. If the contamination is very heavy and immediate reimplantation is not feasible, then it can be stored either in vivo in a subcutaneous plane or in vitro under sterile condition and reimplanted when the host bed is ready and appropriately stabilised

Level/Strength of Evidence: LOW

Justification:

The overall strength of evidence is **LOW**. Based on the **study design**, the available literature consists entirely of Level IV and Level V retrospective studies, predominantly single-patient case reports and a few small case series without control groups or randomization. The **sample size** across all studies is extremely small, ranging from 1 to a maximum of 27 patients, which prohibits broad statistical generalizations. The **risk of bias** is exceedingly high due to severe publication bias (a tendency to only publish successful "miraculous" limb salvages), selection bias (surgeons only attempting

reimplantation in ideal candidates with good soft-tissue envelopes), and a lack of blinding. Finally, the **key outcomes** reported are highly variable; while single case reports universally publish flawless recoveries, the larger series reveal a much more realistic and elevated rate of severe complications, such as osteomyelitis and avascular necrosis.

References:

1. Rathore S, Viswanatha Reddy I, Ashwin Kumar AH. A novel technique for reimplanting extruded bone fragments in open fractures. Trauma Case Rep 2016;4:5-11.
2. Smrke DM, Rožman P, Gubina B, Frangež I, Rejec Smrke B, Arnež ZM. An uncommon treatment of totally extruded and lost talus: a case report. J Med Case Rep 2014;8:322.
3. Lindvall E, Martirosian A, Morshed S. Autosterilization of contaminated and devascularized bone fragments through a subcutaneous bone pouch. J Orthop Trauma 2015;29(12):558-62.
4. Afshar A, Tabrizi A. Reimplantation of a large extruded segment of tibia in an open fracture in a pediatric patient. Surg J (N Y) 2019;5(2):e50-e52.
5. Meininger AK, Figuerres BF, Parameswaran AD, Nam EK, Kapotas JS. Extruded osteoarticular distal tibia: success at 18-month follow-up with reimplantation. J Orthop Trauma 2010;24(11):e102-e107.
6. AlMaeen BN, ElMaghrby IS, AlNour MK, Alrefeidi TA, Abu Adas SM. Complete revascularization of reimplanted talus after isolated total talar extrusion: a case report. Cureus 2020;12(5):e7947.
7. Chang YJ, Hsu CH, Yen YH, Chen JH, Hsu SL. Open fracture dislocation of the talus with nearly total extrusion and with tri-malleolar fracture: a case report and literature review. Medicine (Baltimore) 2025;104(33):e43827.
8. Dumbre Patil SS, Abane SR, Dumbre Patil VS, Nande PN. Open fracture dislocation of the talus with total extrusion: a case report. Foot Ankle Spec 2014;7(5):427-31.
9. Kumar P, Manjhi LB, Rajak RL. Open segmental fracture of both bone forearm and dislocation of ipsilateral elbow with extruded middle segment radius. Indian J Orthop 2013;47(3):307-9.
10. Karampinas PK, Kavroudakis E, Polyzois V, Vlamis J, Pneumaticos S. Open talar dislocations without associated fractures. Foot Ankle Surg 2014;20(2):100-4.
11. Burston JL, Isenegger P, Zellweger R. Open total talus dislocation: clinical and functional outcomes: a case series. J Trauma 2010;68(6):1453-8.
12. Steinmetz S, Rotigliano N, Zermatten P. Isolated open total talar dislocation: a case report and literature review. Arch Trauma Res 2017;6(3):49-52.
13. Burston JL, Brankov B, Zellweger R. Reimplantation of a completely extruded talus 8 days following injury: a case report. J Foot Ankle Surg 2011;50(1):104-7.

14. Kao JT, Comstock C. Reimplantation of a contaminated and devitalized bone fragment after autoclaving in an open fracture. J Orthop Trauma 1995;9(4):336-40.
15. Mnif H, Zrig M, Koubaa M, Jawahdou R, Hammouda I, Abid A. Reimplantation of a totally extruded talus: a case report. J Foot Ankle Surg 2010;49(2):172-5.
16. Aizah N, Su Y, Shaifulnizam CWM, MRos MA. Reimplantation of an extruded femoral segment after gamma sterilization in a type IIIA supracondylar femur fracture: a case report. Malays Orthop J 2014;8(2):66-8.
17. Farrelly E, Ferrari L, Roland D, DiFelice GS. Reimplantation of an extruded osteoarticular segment of the distal tibia in a 14-year-old girl. Case report and review of the literature. J Orthop Trauma 2012;26(3):e24-e28.
18. Singhi PK, Sivakumar R, Somashekar V, Kusabi V, Vinoth T. Reimplantation of contaminated extruded segment of lateral femoral condyle cleansed with 10% povidine-iodine in complex floating knee injury with excellent outcome: case report with 2 year follow up. J Clin Orthop Trauma 2016;7(Suppl 1):48-51.
19. Sabry AO, Hegazy M, El Barbary H, Hegazy M. Reimplanting a 35-cm extruded femoral bone segment with maintained osteoinductive properties: a case report. JBJS Case Connect 2025;15(1):e24.00594.
20. Rollo G, Luceri F, Pichierri P, Giaracuni M, Bisaccia M, De Gabriele S, et al. Reliability of S.A.R.A. (sterilization and reimplantation autograft) technique in long bone open fractures. J Biol Regul Homeost Agents 2019;33(6 Suppl 3):223-30.
21. Kumar P, Shrestha D, Bajracharya S. Replacement of an extruded segment of radius after autoclaving and sterilising with gentamicin. J Hand Surg Br 2006;31(6):616-8.
22. Kwak JM, Heo SK, Jung GH. Six-year survival of reimplanted talus after isolated total talar extrusion: a case report. J Med Case Rep 2017;11:348.
23. Moosazadeh K. Successful reimplantation of retrieved large segment of open femoral fracture: case report. J Trauma 2002;53(1):133-8.
24. Mazurek MT, Pennington SE, Mills WJ. Successful reimplantation of a large segment of femoral shaft in a type IIIA open femur fracture: a case report. J Orthop Trauma 2003;17(4):295-9.
25. Gannamani S, Kidiyoor B, Kilaru P, Joseph VM, Rachakonda KR, Nugur A. Successful reimplantation of an 18-cm-long extruded femur in an open fracture: a case report. JBJS Case Connect 2019;9(4):e0371.
26. Hu X, Tan Q, Zhu G, Liu K. Successful reimplantation of extruded bone segment in lower limb open fractures: case report and literature review. Front Pediatr 2024;12:1333575.

27. Shanmuganathan R, Chandra mohan AK, Agraharam D, Perumal R, Jayaramaraju D, Kulkarni S. Successful reimplantation of extruded long bone segments in open fractures of lower limb – a report of 3 cases. Injury 2015;46(7):1389-92.
28. Sodhai V, Pradhan C, Sancheti P, Shyam A. Successful sterilization and immediate reimplantation of extruded femoral diaphyseal segment: a case report and review of literature. J Orthop Trauma Rehabil 2020;27(2):220-7.
29. Gerken N, Yalamanchili R, Yalamanchili S, Penagaluru P, Milman E, Cox G. Talar revascularization after a complete talar extrusion. J Orthop Trauma 2011;25(11):e107-e110.
30. Smith CS, Nork SE, Sangeorzan BJ. The extruded talus: results of reimplantation. J Bone Joint Surg Am 2006;88(11):2418-24.
31. Yu L, Liu H, Wang Y, Deng L, Shen Z, Shah NG, et al. The fate of comminuted extruded or devitalized fragments of bone in Gustilo type III open fractures and an innovative form of treating them. Bone Joint J 2026;108-B(4):544-52.
32. Fleming J, Hurley KK. Total talar extrusion: a case report. J Foot Ankle Surg 2009;48(6):690.e19-e23.
33. McGilvery W, Hasson C, Wongworawat MD, Witkos M. Traumatic humeral diaphysis extrusion and replantation with periosteal involvement. J Med Cases 2022;13(8):408-13.
34. Breccia M, Peruzzi M, Cerbarano L, Galli M. Treatment and outcome of open dislocation of the ankle with complete talar extrusion: a case report. Foot (Edinb) 2014;24(2):89-93.
35. Devendra A, Imran A, Velmurugesan PS, Ramkumar S, Dheenadhayalan J, Shanmuganathan R. Successful salvage of an extruded knee joint in an open injury: an integrated team approach: a case report. JBJS Case Connect 2025;15(3):e25.00169.