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Minimally Invasive Tibiotalocalcaneal Arthrodesis with a Retrograde Intramedullary Locking Nail: A Narrative Review

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Abstract

Background: Tibiotalocalcaneal arthrodesis is an important limb-salvage procedure for painful, unstable, or deformed ankles when disease involves both the ankle and subtalar joints. Retrograde intramedullary locking nails provide axial load sharing, compression, and multiplanar fixation while limiting soft-tissue disruption. Objective: This narrative review summarizes the indications, preoperative assessment, implant design, operative principles, role of bone grafting, clinical outcomes, complications, and technical measures associated with retrograde intramedullary nailing for tibiotalocalcaneal arthrodesis. Main body: Appropriate patient selection and accurate correction of deformity are central to successful fusion. The intended position is neutral ankle flexion, slight hindfoot valgus, and slight external rotation. Modern nails have evolved from simple straight constructs with limited distal control to curved or valgus-designed implants with independent calcaneal and talar locking, dynamic compression, and longer tibial segments. Meticulous preparation of the ankle and subtalar joint surfaces, exact guidewire placement, controlled reaming, stable distal and proximal locking, and compression across the fusion sites are essential. Bone graft is not routinely required in uncomplicated primary fusion but is useful when union is threatened by osteonecrosis, bone defects, infection, or previous nonunion. Diabetes, Charcot neuroarthropathy, smoking, severe deformity, compromised soft tissues, and previous infection increase the risk of wound complications, deep infection, delayed union, nonunion, and implant-related failure. Conclusion: Retrograde intramedullary locking nailing is a versatile option for tibiotalocalcaneal arthrodesis, particularly in complex deformity and poor bone quality. Outcomes depend less on the implant alone than on sound indication, accurate alignment, complete joint preparation, stable compression, and careful management of host risk factors.

Keywords: ankle arthrodesis; tibiotalocalcaneal fusion; retrograde intramedullary nail; hindfoot arthrodesis; Charcot neuroarthropathy; bone graft.

Introduction

Ankle arthrodesis remains an established treatment for severe pain, deformity, and instability that do not respond to conservative treatment or joint-preserving surgery. Its goals are to eliminate pain, correct deformity, obtain a stable plantigrade foot, and permit painless weight-bearing. Indications include post-traumatic arthritis, primary osteoarthritis, inflammatory arthritis, sequelae of infection, neuromuscular disorders, instability with advanced degeneration, and failure of total ankle arthroplasty [1,2].

When both the ankle and subtalar joints are painful or structurally compromised, isolated tibiotalar fusion may be insufficient. Tibiotalocalcaneal arthrodesis fuses the tibiotalar and subtalar joints and is commonly used as a salvage procedure in severe post-traumatic deformity, Charcot neuroarthropathy, avascular necrosis of the talus, failed ankle replacement, revision arthrodesis, and major bone loss. This procedure should be distinguished from pantalar arthrodesis, which additionally includes the talonavicular and calcaneocuboid joints [15-18].

Multiple fixation methods have been described, including crossed screws, plates, external fixation, and retrograde intramedullary nails. Conventional constructs may be difficult to apply when bone quality is poor, soft tissues are compromised, or deformity is complex. Retrograde nails address these problems by spanning the calcaneus, talus, and tibia, creating a central load-sharing construct with compression across the intended fusion sites [19-24].

This narrative review examines the clinical rationale for minimally invasive tibiotalocalcaneal arthrodesis with a retrograde intramedullary locking nail, with emphasis on indications, alignment, implant design, operative technique, bone grafting, expected outcomes, and prevention of complications.

Review Approach

This narrative review was developed from the literature assembled in the source thesis chapter on ankle arthrodesis and retrograde nailing. The cited material includes technical reports, clinical series, comparative studies, systematic reviews, and meta-analyses published through 2023. The evidence was organized into clinically relevant themes rather than analyzed quantitatively. No formal meta-analysis or risk-of-bias assessment was performed.

Indications and Patient Selection

The main indication for tibiotalocalcaneal arthrodesis is painful disease involving both the ankle and subtalar joints when preservation of motion is no longer feasible. Common indications include post-traumatic arthritis involving both joints, combined ankle and subtalar osteoarthritis, neuropathic deformity, rheumatoid arthritis, failed total ankle replacement, revision arthrodesis, severe talar destruction, avascular necrosis of the talus, and selected tumors or infection-related loss of the talus [15-18,21-24].

Patient selection must consider both the local limb and the general host. Smoking, uncontrolled diabetes, severe peripheral vascular disease, active infection, poor soft-tissue coverage, malnutrition, renal disease, neuropathy, and previous nonunion may impair healing. The diabetic neuropathic foot is not an absolute contraindication when the alternative is a persistently unstable deformity with ulceration, infection, or risk of amputation; however, the threshold for vascular assessment, infection control, and prolonged protection should be high [21,22,33-38].

Table 1. Major indications and cautions for tibiotalocalcaneal arthrodesis with a retrograde nail.

Clinical category	Typical indications	Important cautions
Post-traumatic disease	Combined ankle and subtalar arthritis; malunion; fracture-dislocation; distal tibial or talar bone loss	Assess deformity, bone stock, scars, occult infection, and limb length
Neuropathic/Charcot deformity	Unstable ankle-hindfoot deformity, recurrent ulceration, progressive collapse	Higher risks of infection, nonunion, hardware failure, and recurrent deformity
Talar pathology	Avascular necrosis, severely crushed talus, tumor, structural collapse	May require structural graft, talectomy, or tibiocalcaneal fusion
Failed prior surgery	Failed ankle replacement, failed arthrodesis, implant failure	Rule out infection and define nonunion with CT when needed
Inflammatory/degenerative disease	Rheumatoid arthritis or end-stage ankle and subtalar osteoarthritis	Evaluate adjacent joints and overall alignment

Clinical category	Typical indications	Important cautions
Relative contraindications	Severe vascular insufficiency, uncontrolled infection, medically prohibitive risk, inability to comply with protection	Correct modifiable risk factors or consider staged reconstruction

Preoperative Evaluation and Alignment

Careful preoperative evaluation is critical because a solid fusion in poor alignment may remain painful and may transfer abnormal forces to the knee, midfoot, and plantar surface. History should document prior trauma, operations, infection, smoking, diabetes, neuropathy, vascular disease, and functional demands. Examination should assess skin condition, scars, ulceration, perfusion, sensation, deformity, correctability, limb length, and the mechanical axis of the entire lower limb [1,2,4].

Weight-bearing anteroposterior, mortise, and lateral radiographs of the ankle and foot are standard. Full-length alignment imaging may be needed when tibial or knee deformity is present. Computed tomography is useful for defining bone defects, talar viability, subtalar involvement, and previous nonunion. Complete blood count, erythrocyte sedimentation rate, and C-reactive protein are appropriate when infection is suspected, and vascular studies are required when perfusion is uncertain [18,28].

The target position is neutral ankle flexion, approximately 0-5 degrees of hindfoot valgus, and neutral to slight external rotation. Excessive plantar flexion causes metatarsalgia and a recurvatum gait, while excessive dorsiflexion may produce heel overload. Varus should be avoided because it concentrates pressure laterally and may create painful callosity. Slight posterior translation of the talus under the tibia may reduce the lever arm of the foot during gait [2,4,24].

Surgical Approaches and Fixation Options

The surgical approach is selected according to deformity, bone loss, previous incisions, soft-tissue condition, and the intended fixation. Arthroscopic or mini-open in-situ arthrodesis minimizes soft-tissue stripping and is best suited to patients with little deformity. Open realignment arthrodesis is preferred when major varus, valgus, equinus, rotational deformity, talar collapse, or bone deficiency requires direct correction [3,5-12].

External fixation remains useful in the presence of active or recent infection, severe soft-tissue compromise, limb-length discrepancy, or bone loss that precludes internal fixation. Screws and plates can provide effective fixation in selected patients, but may be less suitable when both the ankle and subtalar joints require fusion or when bone quality is poor. Retrograde intramedullary nails are especially attractive in combined ankle-hindfoot disease because they span both joints and centralize load along the tibial axis [13-20].

Table 2. Principal fixation options for ankle and hindfoot arthrodesis.

Fixation method	Advantages	Limitations / preferred setting
Cannulated screws	Low implant prominence; familiar technique; effective in selected primary ankle fusions	Less control in severe deformity or poor bone; limited when both ankle and subtalar joints require fusion
Plates	Direct correction and rigid fixation; useful with open exposure and bone grafting	More soft-tissue dissection; wound risk; may be difficult in compromised skin

Fixation method	Advantages	Limitations / preferred setting
Circular external fixation	Useful with infection, soft-tissue compromise, bone loss, and limb-length correction	Pin-tract problems, patient burden, frame care, and high complication rates in complex cases
Retrograde intramedullary nail	Load sharing, multiplanar locking, compression, minimal dissection, fixation across ankle and subtalar joints	Technically demanding entry point; risk of malalignment, neurovascular injury, nonunion, and tibial stress fracture

Biomechanical and Biological Rationale for Retrograde Nailing

A retrograde hindfoot nail acts as a load-sharing device and creates a stiffer construct than crossed screws in many biomechanical settings. Its central position improves resistance to bending, while distal calcaneal and talar locking limits rotation. Static and dynamic proximal holes allow the surgeon to choose rigid fixation or controlled compression according to the pathology [19,20,23,24,29-31].

The biological advantage is related to reduced soft-tissue stripping and preservation of the periarticular blood supply. Limited incisions may be used for joint preparation and nail insertion when deformity can be corrected without wide exposure. Reaming also provides local autogenous bone debris and promotes contact between cancellous surfaces. Nevertheless, the term minimally invasive should not obscure the need for adequate debridement and correction; severe deformity or bone loss may still require open transfibular or combined exposure [18,20,24].

Evolution of Nail Design

Early straight retrograde nails provided limited control of the calcaneus and subtalar joint. Lateromedial screws alone were vulnerable to rotational motion and did not accommodate subsidence at the fusion sites. Modern designs incorporate a valgus curve or bend, independent calcaneal and talar locking, oblique posteroanterior screws, and static and dynamic proximal options. These features improve hindfoot positioning, rotational control, and compression (Figure 1) [17,19,20].

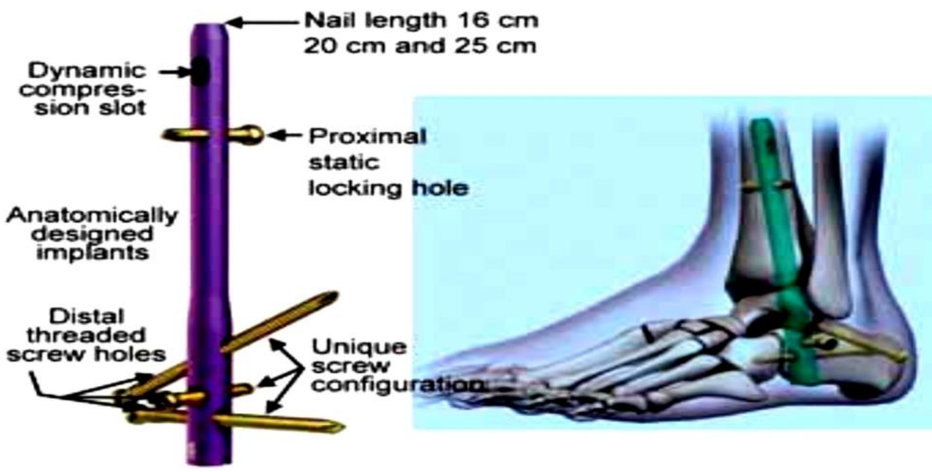

Figure 1. Modern retrograde hindfoot fusion nail showing dynamic compression, proximal locking, and multiplanar distal screw options. The implant is designed to span the calcaneus, talus, and tibia. Illustrative figure reproduced from the source thesis review chapter; permission from the original source should be verified before journal submission.

Nail length is also important. A short nail may concentrate stress at its proximal tip and predispose to tibial fracture, especially in osteoporotic bone or neuropathic patients. Longer nails that engage the tibial isthmus distribute stress over a wider segment and may reduce this complication [20,32].

Operative Principles and Technical Steps

Joint preparation and correction

Successful fusion requires complete removal of residual cartilage, excision of devitalized bone, exposure of bleeding cancellous surfaces, and preservation of congruity. Multiple drill holes may be used to stimulate vascularity. Varus, valgus, equinus, rotational deformity, and talar translation must be corrected before definitive fixation. Cavitary defects are filled with graft, whereas structural deficiency may require larger grafts or additional bone resection to create stable parallel surfaces [8,9,24,28].

A transfibular approach may provide broad access and allows the distal fibula to be used as a strut graft. In the modified Mann technique, a fibular segment is reflected and later fixed across the fusion to provide additional stability (Figure 2). This open method is valuable for severe deformity, although it requires greater soft-tissue dissection than a limited approach [9].

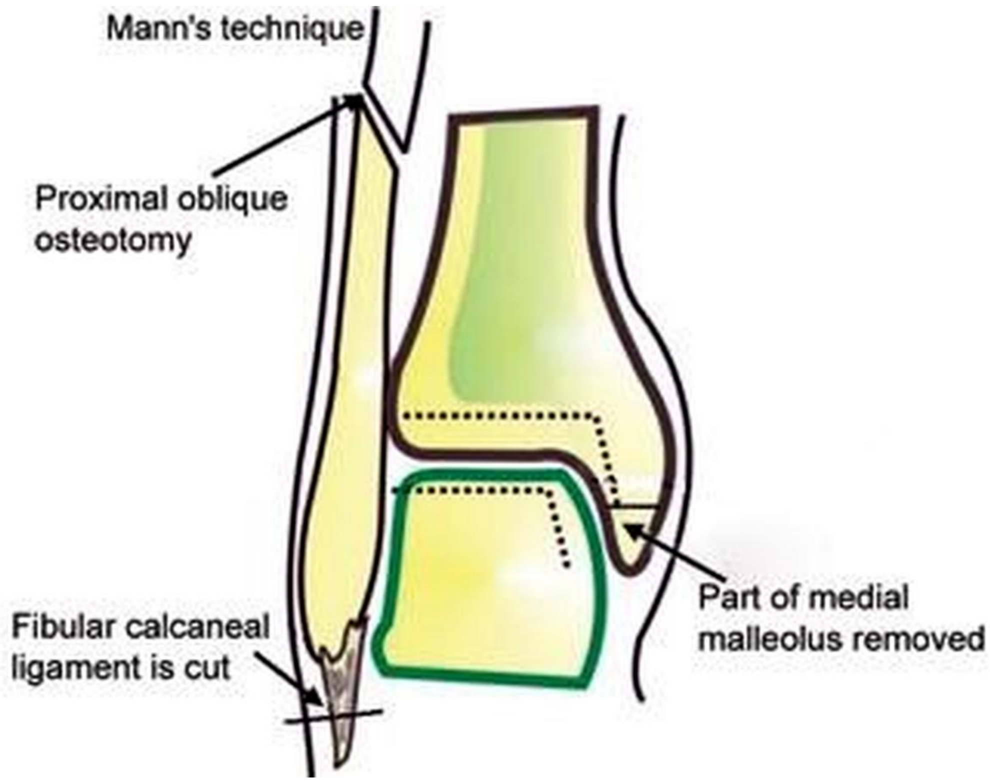

Figure 2. Schematic of the modified Mann transfibular technique, in which the distal fibula is osteotomized and may be used as a strut graft. Illustrative figure reproduced from the source thesis review chapter; permission from the original source should be verified before journal submission.

Entry point and guidewire placement

The plantar entry portal is commonly located near the distal heel pad, slightly lateral to the midline, and in line with the center of the tibial canal on anteroposterior and lateral fluoroscopic views. The guidewire should pass through the calcaneus and talar body into the tibial canal. Exact placement is essential because an eccentric entry may create varus, valgus, translation, cortical perforation, or neurovascular injury (Figure 3) [18,23,24].

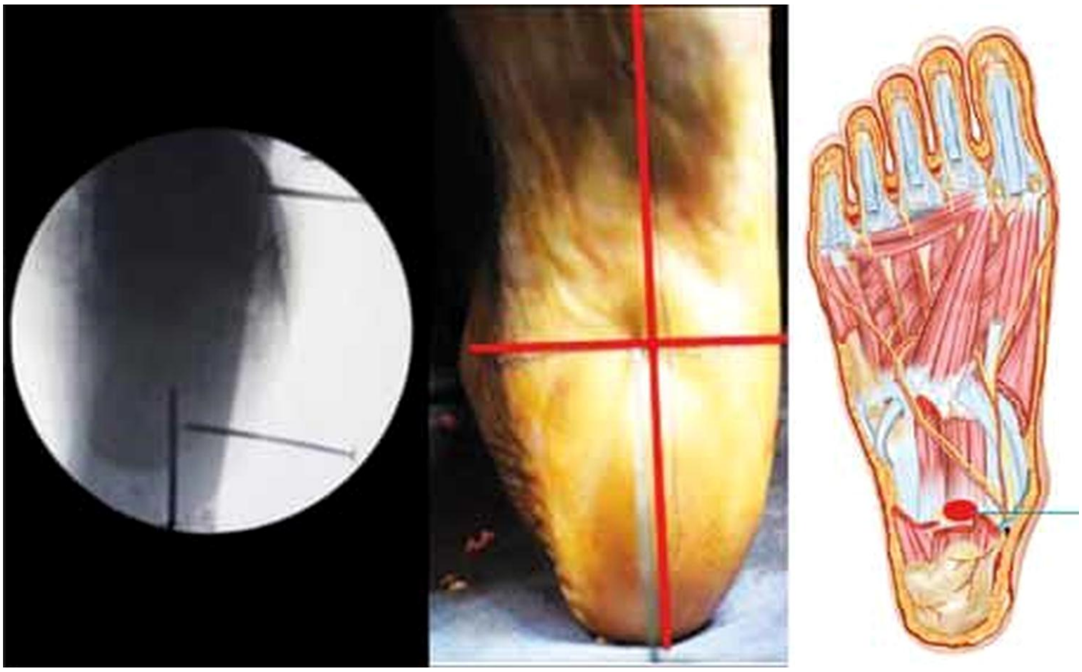

Figure 3. Identification of the plantar entry portal and fluoroscopic guidewire trajectory for retrograde hindfoot nailing. The entry is slightly lateral to the heel-pad midline and aligned with the tibial canal. Illustrative figure reproduced from the source thesis review chapter; permission from the original source should be verified before journal submission.

Reaming, insertion, locking, and compression

After blunt dissection to the calcaneal surface, the guidewire is advanced under fluoroscopy. The canal is sequentially reamed to approximately 1 mm larger than the selected nail diameter to reduce insertional fracture risk. The nail is inserted deeply enough to permit compression without leaving its tip on the weight-bearing heel surface. Foot position is repeatedly checked before distal and proximal locking [18,20,23,24].

Distal locking should stabilize the calcaneus and talus while resisting rotation and dorsiflexion-plantar flexion. Proximal locking may be static or dynamic. Compression across both fusion sites is mandatory and may be applied through the implant or by controlled impaction. The final construct must maintain neutral flexion, slight valgus, and slight external rotation [17,20,24].

Role of Bone Grafting

Bone graft is not routinely required in uncomplicated primary ankle arthrodesis when broad cancellous contact has been achieved. It becomes important when the potential for union is compromised by infection, osteonecrosis of the talus, cavitary or structural bone defects, previous nonunion, or revision surgery [26-28].

Autogenous graft may be obtained from the distal fibula, medial malleolus, proximal tibia, or iliac crest. Local graft avoids a second operative site, whereas iliac crest provides abundant cancellous and cortical bone at the cost of donor-site morbidity. A fibular strut graft may add both biology and mechanical support. Demineralized bone matrix and allograft are alternatives in selected high-risk reconstructions, although graft choice should reflect defect size, host biology, and the need for structural support [26-28].

Special Clinical Scenarios

Diabetes and Charcot neuroarthropathy

Diabetes and neuropathic deformity increase the risks of infection, nonunion, hardware failure, ulceration, and recurrent collapse. Nevertheless, one-stage ankle and subtalar fusion may offer limb salvage when instability is otherwise likely to progress to ulceration or amputation. The key requirements are eradication of infection, adequate perfusion, correction of deformity, stable compression, prolonged protection, and close postoperative surveillance [16,19,21,22,33-38].

Avascular necrosis, talar destruction, and bone loss

When the talus remains structurally intact, it may sometimes be retained despite osteonecrosis. Collapsed or infected bone must be excised, and the resulting defect may require structural graft or conversion to tibiocalcaneal fusion. The retrograde nail can bridge compromised bone and centralize load, but union depends on viable host surfaces and stable defect reconstruction [15,18,24-28].

Revision arthrodesis and failed prior fixation

Revision cases require identification of the cause of failure, including occult infection, inadequate joint preparation, malalignment, poor fixation, smoking, or host disease. CT is useful to define nonunion and bone loss. The nail can provide a new load-sharing axis and compression, but revision success also depends on removal of nonviable tissue, correction of deformity, biological augmentation when needed, and modification of systemic risk factors [18,28].

Clinical Outcomes and Fusion Assessment

Clinical series and systematic reviews generally report improvement in pain, function, alignment, and the ability to bear weight after tibiotalocalcaneal arthrodesis with a retrograde nail. Results are influenced by indication: patients with post-traumatic arthritis or aseptic deformity tend to have fewer complications than those with Charcot neuroarthropathy, uncontrolled diabetes, previous infection, or major bone loss [29-40].

Union is assessed clinically by a stable, painless hindfoot and radiographically by progressive trabecular bridging without loss of alignment or implant failure. CT is useful when plain radiographs are inconclusive. Serial imaging may demonstrate correction of deformity, stable fixation, and maturation of ankle and subtalar fusion (Figure 4) [23,24,29-31].

Figure 4. Radiographic sequence illustrating severe post-traumatic ankle and subtalar degeneration, retrograde nail fixation, and later fusion with maintained alignment. Illustrative figure reproduced from the source thesis review chapter; permission from the original source should be verified before journal submission.

Although pain and walking ability commonly improve, fusion abolishes ankle and subtalar motion and does not restore normal gait. Patients should be counseled regarding permanent restriction of sagittal and hindfoot motion, altered stair negotiation, possible limb-length discrepancy, and increased loading of the midfoot and more proximal joints [1,29].

Complications and Their Prevention

Reported complications include superficial or deep infection, wound dehiscence, hematoma, delayed union, aseptic or infected nonunion, malunion, neurovascular injury, painful plantar callosity, osteomyelitis, implant prominence, screw loosening, nail breakage, and tibial stress fracture. Major failure may require debridement, revision fixation, hardware removal, prolonged antibiotics, or amputation [19,21-24,29-40].

Risk is increased by diabetes, Charcot neuroarthropathy, smoking, severe deformity, poor vascularity, previous infection, compromised soft tissues, and inadequate postoperative protection. Preventable technical causes include incomplete joint preparation, residual varus, inaccurate entry point, failure to compress the fusion sites, and use of a nail that is too short [20,24,32].

Figure 5. Tibial stress fracture at the proximal tip of a short retrograde nail. Longer nails that engage the tibial isthmus may reduce this stress-riser effect. Illustrative figure reproduced from the source thesis review chapter; permission from the original source should be verified before journal submission.

Table 3. Common complications, contributing factors, and practical preventive measures.

Complication	Contributing factors	Preventive measures
Wound complication / infection	Diabetes, smoking, previous scars, poor perfusion, extensive exposure, occult infection	Optimize host factors; assess vascularity; rule out infection; use limited exposure when appropriate; meticulous soft-tissue handling
Delayed union / nonunion	Incomplete cartilage removal, avascular bone, inadequate compression, infection, neuropathy	Expose bleeding cancellous bone; graft defects; stable fixation; compression; prolonged protection

Complication	Contributing factors	Preventive measures
Malalignment	Eccentric entry point, uncorrected varus/valgus/equinus, loss of position during locking	Define target alignment before reaming; repeated clinical and fluoroscopic checks; lock while maintaining rotation
Neurovascular injury	Medial or eccentric plantar entry, aggressive dissection	Slightly lateral entry; blunt dissection; accurate fluoroscopic localization
Tibial stress fracture	Short nail, osteoporotic bone, abrupt stiffness transition	Use a longer nail engaging the tibial isthmus; avoid cortical damage; gradual loading
Implant failure / screw loosening	Poor bone, persistent gap, premature loading, inadequate distal control	Multiplanar locking; dynamic compression where appropriate; protect weight-bearing until union

Limitations of the Current Evidence

The available literature is dominated by retrospective series, technical reports, and small heterogeneous cohorts. Indications vary from post-traumatic arthritis to Charcot neuroarthropathy, tumor resection, avascular necrosis, and revision nonunion. Nail designs, surgical approaches, graft use, definitions of union, weight-bearing protocols, and follow-up duration are not uniform. These differences limit direct comparison and make it difficult to isolate the effect of the implant from the effects of patient selection and surgical technique [19,29-40].

Future studies should use prospective multicenter designs, standardized definitions of union and complications, validated patient-reported outcomes, CT assessment when appropriate, and stratification by diabetes, neuropathy, infection, and bone loss. Comparative research should determine which patients benefit most from minimally invasive preparation and which require open realignment or structural grafting.

Conclusion

Minimally invasive tibiotalocalcaneal arthrodesis with a retrograde intramedullary locking nail is a valuable salvage option for complex ankle and hindfoot disease. The nail offers a central load-sharing construct, multiplanar fixation, and the capacity for compression while limiting soft-tissue dissection. Its principal indications include combined ankle and subtalar arthritis, severe post-traumatic deformity, Charcot neuroarthropathy, avascular necrosis or destruction of the talus, failed ankle replacement, and revision arthrodesis.

Successful treatment depends on rigorous patient selection, correction of modifiable risk factors, precise alignment, complete preparation of the fusion surfaces, an accurate plantar entry point, stable distal and proximal locking, and adequate compression. Bone graft should be used selectively when biology or bone stock is compromised. Complications remain substantial in high-risk patients, particularly those with diabetes, neuropathy, smoking, previous infection, or severe deformity. Larger comparative studies with standardized outcomes are needed to refine indications and postoperative protocols.

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