Minimally Invasive Management of Displaced Intra-Articular Calcaneal Fractures: Functional and Radiological Outcomes

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Abstract

Background: Displaced intra-articular calcaneal fractures (DIACFs) represent one of the most complex injuries in foot and ankle trauma, often resulting from high-energy mechanisms and associated with substantial morbidity. Traditional open reduction and internal fixation (ORIF) via extensile lateral approaches has been considered the gold standard for restoring calcaneal anatomy and subtalar congruity. However, this technique is associated with high rates of wound complications, infection, and soft-tissue morbidity. In response to these challenges, minimally invasive and percutaneous techniques have gained increasing attention as alternatives aimed at reducing soft-tissue complications while achieving acceptable reduction and fixation.

Aim: This review aims to critically evaluate the functional and radiological outcomes of minimally invasive and percutaneous management strategies for displaced intra-articular calcaneal fractures. Emphasis is placed on patient-reported outcomes, restoration of calcaneal morphology, complication profiles, and comparative effectiveness relative to traditional open approaches.

Methods and Content Overview: A comprehensive review of the contemporary literature was conducted, focusing on percutaneous and minimally invasive techniques including percutaneous screw fixation, limited sinus tarsi approaches, and minimally invasive plate osteosynthesis. Functional outcomes assessed include validated scoring systems such as the American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score, visual analog scale (VAS) for pain, and return-to-work rates. Radiological outcomes, including restoration of Böhler and Gissane angles, calcaneal height, width, and subtalar joint congruity, are analyzed. The review also examines complication rates, learning curve considerations, indications and contraindications, and factors influencing outcome such as fracture classification and patient selection.

Conclusion: Minimally invasive management of displaced intra-articular calcaneal fractures offers a promising balance between anatomical restoration and reduction of soft-tissue complications. Current evidence suggests that, in appropriately selected patients, percutaneous and limited approaches can achieve functional and radiological outcomes comparable to extensile ORIF, with lower wound-related morbidity. Nonetheless, outcomes are highly dependent on fracture pattern, surgeon expertise, and adherence to sound reduction principles. Further high-quality comparative studies and long-term follow-up are required to define optimal indications and establish standardized treatment algorithms.

Keywords: *Minimally Invasive, Displaced Intra-Articular Calcaneal Fractures*

Introduction

Displaced intra-articular calcaneal fractures (DIACFs) account for approximately 60–75% of all calcaneal fractures and are most commonly the result of high-energy axial loading mechanisms such as falls from height or motor vehicle collisions. These injuries frequently affect young, working-age individuals and are associated with substantial socioeconomic impact due to prolonged disability, delayed return to work, and chronic pain. The complex anatomy of the calcaneus, combined with comminution of the posterior facet and disruption of hindfoot alignment, makes anatomical reduction and durable fixation particularly challenging [1,2].

Historically, open reduction and internal fixation (ORIF) through an extensile lateral approach has been advocated to achieve accurate articular reduction and restoration of calcaneal morphology. While this technique allows excellent visualization of the subtalar joint and lateral wall, it is associated with significant soft-tissue complications, including wound edge necrosis, deep infection, and sural nerve injury, with reported complication rates ranging from 15% to 30%. These concerns are amplified in patients with compromised soft tissues, smoking history, diabetes, or severe swelling at presentation [3,4].

In response to the high morbidity associated with extensile approaches, minimally invasive and percutaneous techniques have evolved over the past two decades. These methods aim to minimize soft-tissue disruption while achieving acceptable reduction of the posterior facet and restoration of calcaneal height, width, and alignment. Techniques such as percutaneous screw fixation, limited sinus tarsi approaches, and minimally invasive plate osteosynthesis have gained popularity, particularly for selected fracture patterns and in high-risk patients [5].

Radiological restoration of key calcaneal parameters, including Böhler and Gissane angles, has been shown to correlate with functional outcomes and subtalar joint mechanics. However, the ability of percutaneous techniques to consistently achieve and maintain anatomical reduction comparable to ORIF remains a subject of ongoing debate. While some studies report equivalent radiological outcomes, others suggest inferior articular reduction in highly comminuted fractures, highlighting the importance of fracture classification and surgeon experience [6,7].

Functional outcomes following minimally invasive management are equally heterogeneous in the literature. Although many reports demonstrate satisfactory American Orthopaedic Foot and Ankle Society (AOFAS) scores, reduced pain levels, and earlier return to work, variability in study design, outcome measures, and follow-up duration limits definitive conclusions. Furthermore, long-term outcomes related to subtalar arthritis and the need for secondary fusion remain incompletely defined [8].

The aim of this review is to critically analyze the available evidence regarding the functional and radiological outcomes of minimally invasive and percutaneous management of displaced intra-articular calcaneal fractures. By synthesizing current data on indications, techniques, outcomes, and complications, this review seeks to identify areas of consensus and controversy, highlight gaps in the literature, and provide a framework to guide evidence-based clinical decision-making in the management of these challenging injuries [1–8].

Fracture Classification and Patient Selection for Minimally Invasive Management

Accurate fracture classification is essential for determining the suitability of minimally invasive management in displaced intra-articular calcaneal fractures. Computed tomography–based classification systems have become the cornerstone of preoperative assessment, with the Sanders classification being the most widely used due to its ability to stratify fractures according to the number and location of

posterior facet fragments. This system has demonstrated prognostic value, as increasing fracture complexity correlates with poorer functional outcomes and higher rates of post-traumatic subtalar arthritis, regardless of treatment modality [9].

Minimally invasive and percutaneous techniques are most commonly indicated for Sanders type II and selected type III fractures, where indirect or limited open reduction of the posterior facet is feasible and stable fixation can be achieved. These fracture patterns typically allow restoration of calcaneal height, length, and alignment without the need for extensive lateral exposure. In contrast, highly comminuted Sanders type IV fractures often present significant challenges for percutaneous reduction and may be associated with inferior radiological and functional outcomes when minimally invasive techniques are used indiscriminately [10].

Patient-related factors play an equally critical role in treatment selection. Displaced intra-articular calcaneal fractures frequently occur in patients with significant soft-tissue compromise, severe swelling, fracture blisters, or comorbidities such as smoking, diabetes mellitus, and peripheral vascular disease. These factors substantially increase the risk of wound complications following extensile lateral approaches, making minimally invasive strategies particularly attractive in high-risk patient populations [11].

Timing of surgery is another important consideration in patient selection. Minimally invasive techniques can often be performed earlier than extensile ORIF, as they place less demand on soft-tissue recovery. Early intervention may facilitate indirect reduction through ligamentotaxis before fracture consolidation occurs, potentially improving radiological restoration while avoiding prolonged delays associated with soft-tissue optimization [12].

Ultimately, successful patient selection for minimally invasive management requires integration of fracture morphology, soft-tissue condition, patient comorbidities, and surgeon experience. When these factors are appropriately balanced, minimally invasive techniques can provide a safe and effective alternative to extensile ORIF, offering satisfactory anatomical restoration with reduced soft-tissue morbidity and favorable functional outcomes [9–12].

Minimally Invasive and Percutaneous Techniques

Minimally invasive management of displaced intra-articular calcaneal fractures encompasses a spectrum of techniques designed to restore calcaneal anatomy while minimizing soft-tissue disruption. Percutaneous reduction methods typically rely on indirect manipulation using ligamentotaxis, Schanz pins, Steinmann pins, or percutaneous elevators to realign the posterior facet and correct hindfoot alignment. Fluoroscopic guidance in multiple planes is essential to confirm reduction quality, particularly given the limited visualization inherent to these techniques [13].

Percutaneous screw fixation remains one of the most widely used minimally invasive strategies, especially for Sanders type II fractures. Cannulated screws are commonly inserted from posterior-to-anterior or lateral-to-medial trajectories to support the reduced posterior facet and restore calcaneal height. This method offers the advantages of reduced operative time, minimal soft-tissue injury, and early postoperative mobilization, although its effectiveness is highly dependent on achieving and maintaining accurate reduction [14].

The sinus tarsi approach represents a hybrid technique that combines limited open exposure with percutaneous fixation. Through a small lateral incision, direct visualization of the posterior facet is achieved, allowing more precise reduction while preserving the lateral soft-tissue envelope. This approach has gained widespread acceptance due to its favorable balance between anatomical reduction and reduced wound complication rates compared with the extensile lateral approach [15].

Minimally invasive plate osteosynthesis has also been introduced as an option for fractures requiring additional stability. Low-profile plates can be inserted through limited incisions and fixed percutaneously to maintain calcaneal alignment and prevent late collapse. While this technique offers enhanced fixation strength, it requires meticulous soft-tissue handling and fluoroscopic control to avoid malposition and neurovascular injury [16].

Selection of the appropriate minimally invasive technique depends on fracture morphology, bone quality, soft-tissue condition, and surgeon expertise. No single method is universally applicable, and intraoperative flexibility is often required to optimize reduction and fixation. When performed with careful technique and appropriate indications, minimally invasive approaches can achieve reliable radiological restoration with lower soft-tissue morbidity than traditional extensile approaches [13–16].

Radiological Outcomes of Minimally Invasive Management

Radiological assessment is a fundamental component in evaluating the effectiveness of minimally invasive management of displaced intra-articular calcaneal fractures. Restoration of calcaneal morphology, particularly Böhler angle, Gissane angle, calcaneal height, length, and width, serves as an objective measure of reduction quality. Numerous studies have demonstrated significant postoperative improvement in these parameters following percutaneous or limited open fixation, with results approaching those achieved through extensile lateral ORIF in appropriately selected fracture patterns [17].

The restoration of Böhler angle has been consistently correlated with improved functional outcomes and reduced incidence of subtalar arthritis. Minimally invasive techniques have shown the ability to correct this angle effectively, especially in Sanders type II fractures, although maintenance of correction over time remains a concern in more comminuted injuries. Loss of reduction has been reported in some series, emphasizing the importance of stable fixation and adherence to postoperative weight-bearing protocols [18].

Articular congruity of the posterior facet is another critical radiological endpoint. While percutaneous techniques rely largely on indirect reduction, the use of limited approaches such as the sinus tarsi incision allows direct visualization and more accurate restoration of the subtalar joint surface. Several comparative studies have reported no significant difference in postoperative CT-assessed articular reduction between sinus tarsi and extensile approaches, supporting the radiological adequacy of minimally invasive strategies [19].

Calcaneal width reduction is particularly relevant in preventing lateral impingement and peroneal tendon irritation. Minimally invasive techniques have demonstrated effective correction of lateral wall bulging through indirect compression and screw fixation, although complete restoration may be more challenging in fractures with severe lateral wall comminution. Residual widening has been associated with persistent lateral hindfoot pain in some patients [20].

Overall, radiological outcomes following minimally invasive management of displaced intra-articular calcaneal fractures are generally favorable when strict selection criteria are applied. Accurate reduction of key anatomical parameters can be achieved and maintained in the majority of cases, reinforcing the role of minimally invasive techniques as a viable alternative to extensile ORIF in selected patients [17–20].

Functional Outcomes and Patient-Reported Measures

Functional outcomes represent a critical endpoint in assessing the success of minimally invasive management of displaced intra-articular calcaneal fractures, given the long-term impact of these injuries on gait, mobility, and quality of life. Most studies evaluating percutaneous and limited open techniques report functional outcomes using validated scoring systems such as the American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score, visual analog scale (VAS) for pain, and patient-reported return-to-work status. Overall, these measures demonstrate good to excellent functional recovery in a substantial proportion of appropriately selected patients [21].

Minimally invasive techniques are frequently associated with earlier mobilization and reduced postoperative pain compared with extensile lateral ORIF. Preservation of the soft-tissue envelope appears to play a central role in facilitating rehabilitation and minimizing postoperative stiffness. Several comparative studies have shown faster return to work and daily activities in patients treated with percutaneous or sinus tarsi approaches, particularly in those without severe comminution or associated injuries [22].

Despite generally favorable results, functional outcomes are influenced by fracture severity, quality of reduction, and patient-related factors. Sanders type III and IV fractures are associated with lower functional scores regardless of treatment modality, reflecting the inherent severity of articular damage. Inadequate reduction of the posterior facet or persistent calcaneal malalignment has been consistently linked to poorer patient-reported outcomes and chronic hindfoot pain [23].

Long-term functional results also depend on the development of post-traumatic subtalar arthritis. While radiographic degenerative changes are common following displaced intra-articular fractures, not all patients develop clinically significant symptoms. Studies suggest that when anatomical reduction is achieved through minimally invasive techniques, the incidence of symptomatic subtalar arthritis is comparable to that observed after extensile ORIF [24].

In summary, functional outcomes following minimally invasive management of displaced intra-articular calcaneal fractures are generally favorable and comparable to traditional open approaches in selected cases. Preservation of soft tissues, accurate reduction, and stable fixation are key determinants of patient-reported satisfaction and long-term function, underscoring the importance of careful technique and patient selection [21–24].

Complications and Soft-Tissue Outcomes

Soft-tissue complications remain one of the most significant concerns in the surgical management of displaced intra-articular calcaneal fractures. Minimally invasive and percutaneous techniques were developed primarily to address the high rates of wound-related morbidity associated with extensile lateral approaches. Numerous studies have demonstrated a substantial reduction in wound complications, including skin necrosis, deep infection, and delayed wound healing, when minimally invasive techniques are employed, particularly in patients with compromised soft tissues or significant swelling at presentation [25].

The reduced surgical exposure inherent to minimally invasive techniques also lowers the risk of sural nerve injury and peroneal tendon irritation. Preservation of the lateral soft-tissue envelope and avoidance of extensive dissection contribute to improved neurovascular safety profiles. As a result, minimally invasive approaches are often preferred in high-risk patients, including smokers and individuals with diabetes or peripheral vascular disease [26].

Despite these advantages, minimally invasive techniques are not devoid of complications. Malreduction, loss of fixation, and hardware-related irritation have been reported, particularly during the early learning curve. Inadequate reduction of the posterior facet or failure to restore hindfoot alignment can result in persistent pain and functional impairment, sometimes necessitating secondary procedures such as subtalar arthrodesis [27].

Deep infection rates following minimally invasive fixation are consistently lower than those reported for extensile ORIF; however, pin-tract infections and superficial wound issues may occur with percutaneous techniques. These complications are generally manageable with local care and antibiotics but highlight the importance of meticulous surgical technique and postoperative monitoring [28].

Overall, the complication profile of minimally invasive management compares favorably with traditional open approaches, particularly with respect to soft-tissue outcomes. When performed by experienced surgeons and in appropriately selected patients, minimally invasive techniques offer a safer alternative with reduced morbidity while maintaining acceptable radiological and functional results [25–28].

Subtalar Arthritis and Need for Secondary Procedures

Post-traumatic subtalar arthritis remains a common long-term sequela following displaced intra-articular calcaneal fractures, regardless of the surgical technique employed. The development of subtalar degeneration is primarily related to the degree of initial cartilage injury and the accuracy of posterior facet reduction rather than the choice of surgical approach alone. Minimally invasive techniques, when able to restore articular congruity and hindfoot alignment, do not appear to increase the risk of symptomatic subtalar arthritis compared with extensile lateral ORIF [29].

Several studies have reported comparable rates of radiographic subtalar arthritis following minimally invasive and open techniques, with a subset of patients progressing to clinically significant pain and stiffness. Importantly, radiographic degeneration does not always correlate with poor functional outcomes, as many patients remain asymptomatic or experience only mild symptoms. Accurate reduction and maintenance of calcaneal morphology are critical factors in mitigating long-term degenerative changes [30].

The need for secondary procedures, most commonly subtalar arthrodesis, serves as an important indicator of long-term treatment success. Available evidence suggests that rates of secondary fusion following minimally invasive fixation are similar to those reported after extensile ORIF, particularly when minimally invasive techniques are applied to appropriately selected fracture patterns. Sanders type IV fractures remain the most common indication for delayed subtalar fusion irrespective of initial management strategy [31].

An additional advantage of minimally invasive management is the preservation of the lateral soft-tissue envelope, which may simplify future reconstructive procedures when required. Patients undergoing secondary subtalar arthrodesis after percutaneous or sinus tarsi fixation generally experience fewer wound-related complications compared with those who previously underwent extensile lateral approaches, highlighting a potential long-term benefit of minimally invasive strategies [32].

In summary, minimally invasive management of displaced intra-articular calcaneal fractures does not appear to increase the risk of subtalar arthritis or secondary fusion when anatomical reduction is achieved. Careful fracture selection, precise reduction, and stable fixation remain the primary determinants of long-term joint preservation and patient satisfaction [29–32].

Learning Curve, Indications, and Limitations of Minimally Invasive Techniques

Minimally invasive management of displaced intra-articular calcaneal fractures is technically demanding and associated with a recognized learning curve. Successful application of percutaneous and limited open techniques requires a thorough three-dimensional understanding of calcaneal anatomy, fracture morphology, and subtalar joint mechanics. Surgeons must rely heavily on intraoperative fluoroscopy and indirect reduction maneuvers, which can be challenging in the absence of direct visualization, particularly during early experience with these methods [33].

Clinical outcomes have been shown to improve as surgeon experience increases, with reductions in operative time, malreduction rates, and fixation-related complications reported in higher-volume centers. Standardization of surgical steps, careful preoperative planning using CT imaging, and progressive case selection beginning with less complex fracture patterns are essential strategies to mitigate the risks associated with the learning curve [34].

Indications for minimally invasive management continue to evolve but are generally centered on Sanders type II and selected type III fractures, fractures with limited comminution, and patients at high risk for soft-tissue complications. Minimally invasive techniques are particularly advantageous in cases with severe swelling, fracture blisters, or medical comorbidities where extensile exposure would pose unacceptable risk. Early surgical intervention is often feasible due to reduced soft-tissue insult, potentially improving indirect reduction through ligamentotaxis [35].

Despite their advantages, minimally invasive techniques have inherent limitations. Highly comminuted fractures, significant posterior facet depression, and Sanders type IV patterns often preclude reliable indirect reduction and stable fixation. In such cases, minimally invasive approaches may result in suboptimal articular restoration and inferior functional outcomes, underscoring the importance of recognizing situations where extensile ORIF or primary subtalar arthrodesis may be more appropriate [36].

Furthermore, the lack of universal consensus regarding optimal fixation constructs, postoperative protocols, and outcome measures limits direct comparison across studies. Variability in technique, implant selection, and rehabilitation strategies contributes to heterogeneity in reported results and highlights the need for further high-quality, comparative research [37].

In conclusion, minimally invasive techniques represent a powerful addition to the surgical armamentarium for displaced intra-articular calcaneal fractures but demand careful patient selection, technical expertise, and institutional support. When these prerequisites are met, minimally invasive management can deliver excellent functional and radiological outcomes while minimizing soft-tissue morbidity, reinforcing its role in modern foot and ankle trauma care [33–37].

Conclusion

Minimally invasive management of displaced intra-articular calcaneal fractures has emerged as an effective and increasingly adopted strategy in modern foot and ankle trauma surgery. By prioritizing preservation of the soft-tissue envelope while striving to restore calcaneal anatomy and subtalar joint congruity, these techniques address many of the limitations associated with traditional extensile lateral approaches. When applied to appropriately selected fracture patterns, minimally invasive strategies provide functional and radiological outcomes that are comparable to open reduction and internal fixation, with a substantially lower risk of wound-related complications.

The success of minimally invasive management is highly dependent on accurate fracture classification, meticulous preoperative planning, and precise execution of reduction and fixation techniques. Sanders type II and selected type III fractures represent the most favorable indications, whereas highly comminuted injuries continue to pose significant challenges. Surgeon experience and familiarity with indirect reduction principles play a decisive role in optimizing outcomes and minimizing complications.

Radiological restoration of key calcaneal parameters and preservation of subtalar joint congruity remain critical determinants of long-term function. When these goals are achieved, patients typically experience satisfactory pain relief, improved mobility, and earlier return to daily activities and work. Importantly, minimally invasive approaches do not appear to increase the risk of post-traumatic subtalar arthritis or the need for secondary fusion when anatomical reduction is maintained.

Despite encouraging results, limitations persist, including a notable learning curve and variability in reported techniques and outcomes. Further high-quality comparative studies with long-term follow-up are needed to refine indications, standardize protocols, and clarify the role of minimally invasive strategies relative to traditional open approaches.

In conclusion, minimally invasive management represents a valuable, evidence-based option in the treatment of displaced intra-articular calcaneal fractures. When integrated into a thoughtful, patient-centered treatment algorithm, these techniques offer an optimal balance between anatomical restoration, functional recovery, and soft-tissue preservation, reinforcing their role in contemporary orthopedic trauma practice.

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