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Arthritis after Calcaneal Fracture - A Systematic Review and Meta-analysis

Abhijit Bandyopadhyay[1]

Abstract

Background: Post-traumatic arthritis (PTA) is a common complication of displaced intra-articular calcaneal fractures, greatly interfering with patient mobility and quality of life. Regardless of numerous treatment methods, there continues to be debate over the best method to reduce the risk of PTA. This systematic review and meta-analysis seek to evaluate the frequency, risk factors, and outcomes of PTA after calcaneal fractures and compare surgical and non-surgical treatments.

Materials and Methods: The systematic literature search was done in the PubMed, Scopus, Web of Science, and Google Scholar databases. The extracted data involved study design, sample size, fracture type, treatment, duration of follow-up, criteria for diagnosis of arthritis, and the primary outcomes. Meta-analysis was carried out using the Review Manager tool.

Results: Fifteen studies involving 1,097 patients were included. Overall, PTA prevalence was significantly disparate depending on treatment modality and fracture severity. Sanders Type III fractures had a 47% risk for subtalar fusion, and Type II fractures had a decreased rate of 19% ($P < 0.05$). Open reduction and internal fixation had no major long-term functional benefit over minimally invasive methods, which were linked to reduced wound complications and fewer reoperations ($P < 0.05$). Meta-analysis findings showed high heterogeneity among studies evaluating Visual Analog Scale pain scores ($I2 = 99\%$), suggesting variability in pain relief outcomes. Despite surgical intervention improving pain and alignment, complications remained comparable between treatment approaches ($I2 = 22\%$). Nonoperative treatment was linked to higher PTA rates and poorer functional results in comparison with surgery. Comorbid conditions such as smoking and the severity of the fracture, as well as delayed intervention, were variables linked to higher PTA risk.

Conclusion: PTA is a common issue after calcaneal fractures, with surgical treatment usually resulting in improved long-term results compared with non-surgical treatment. Nevertheless, the preference for surgical methods substantially affects complication rates and function restoration. Future research needs to determine specific standards of protocols depending on fracture severity and patient-specific variables to maximize the outcomes of treatment.

Keywords: Post-traumatic arthritis, Calcaneal fractures, Surgical treatment, Fracture severity, Quality of life.

Introduction

The calcaneus, the largest tarsal bone, possesses four articular surfaces [1, 2]. Fractures of the calcaneus occur most commonly among tarsal fractures, making up 1–2% of all fractures [1, 2]. About 75% of such injuries are of the posterior facet type with intra-articular extension [3]. Such serious lower limb fractures are usually caused by high-energy trauma, for example, falls or motor vehicle crashes, that cause axial loading forces. Their influence on patients' lives is significant, with health outcomes similar to those for myocardial infarction and chronic renal disease [3].

IACF's have the main fracture line that splits the posterior facet into medial and lateral fragments. The constant fragment, a superomedial fragment, is fixed to the talus through the deltoid and interosseous talocalcaneal ligaments [4]. There are many classification systems, but the Sanders and Essex-Lopresti

[1]Department of Orthopaedics, Woodland Multispeciality Hospital, Kolkata, West Bengal, India

Address of Correspondence
Dr. Abhijit Bandyopadhyay,
Department of Orthopaedics, Woodland Multispeciality Hospital, Kolkata, West Bengal, India.
E-mail: abhi_34358@rediffmail.com

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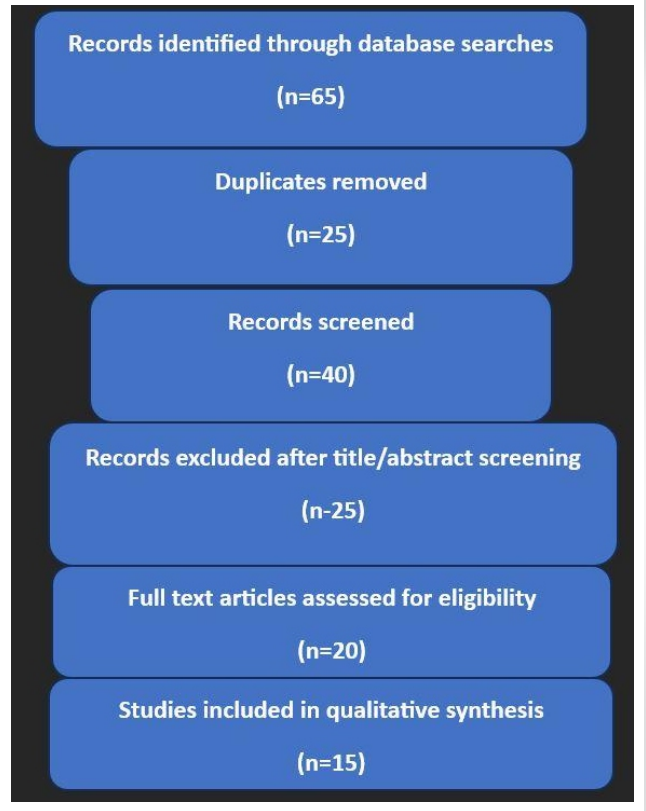

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-Analyses flowchart for study selection.

classifications are the most applied ones [5]. The Sanders system classifies fractures according to the number of fracture lines on semi-coronal computed tomography at the widest point of the talus: type I (nondisplaced), type II (single fracture line, two-part), type III (three-part with central depression), and type IV (comminuted with four or more articular segments) [6, 7]. The Essex-Lopresti system classifies fractures according to the primary and secondary fracture lines, differentiating joint-depression and tongue-type fractures [4, 8]. Joint-depression fractures have a secondary fracture line passing through the calcaneus body, producing a depressed posterior facet fragment and radiographic signs including a diminished Böhler angle, narrowed Gissane angle, and calcaneal shortening [3]. Less frequent, tongue-type fractures have a secondary fracture line passing posteriorly below the facet to the tuberosity, commonly resulting in posterosuperior displacement by Achilles tendon traction [8]. These fractures carry a risk of posterior heel skin necrosis and should have frequent checks for breakdown or blanching since urgent surgery might be necessary [9-11].

The calcaneus plays a critical role in weight-bearing and gait biomechanics, distributing ground reaction forces upon heel strike, the lateral plantar process (LPP) cooperating with the tuberosity to distribute loads [12]. The structure of the LPP is akin to that of the inferior tuberosity regarding bone volume fraction and anisotropy, but its thinly spaced trabeculae facilitate increased surface area for force transfer [13]. Displaced intra-articular calcaneal fractures (DIACF's) can predispose to advanced degenerative changes, needing fusion of the talocalcaneal joints [12]. Studies indicate that those who initially undergo open reduction and internal fixation (ORIF) frequently require fusion within an average of 22.6 months [14]. Functional outcomes are significantly better in patients who first receive ORIF before subtalar fusion compared to those treated nonoperatively [15]. Proper anatomical restoration of hindfoot alignment during initial treatment may enhance long-term outcomes, even if fusion is later required [15].

Post-traumatic arthritis (PTA) is a frequent complication of calcaneal fractures, primarily due to chondrocyte damage and articular surface disruption [16]. Intra-articular fractures significantly reduce chondrocyte viability, with studies reporting an average of 72.8% ± 12.9% in fracture patients compared to 94.8% ± 1.5% in healthy controls [16]. Dysfunctions of the posterior facet of the subtalar joint, particularly with joint gaps larger than 3 mm, significantly influence contact properties and pressure distribution [17]. Moreover, the cell viability of the chondrocytes will decrease as post-injury latency increases [18]. Subtalar joints are especially at risk of developing PTA due to fractures at this joint, with 81% of talar neck injuries covering such cases [19]. Primary cartilage damage at the time of injury may still lead to subtalar arthritis, even with appropriate management [18]. The severity and displacement of the fracture play a key role, as failure to achieve anatomical reduction can result in chronic instability and PTA [18].

Surgical management, especially ORIF, is recommended for patients suffering DIACFs, more commonly in cases concerning the younger more active cohort [19,20]. However, the choice of treatment is determined according to a variety of factors like age, activity level, and general health; conditions such as smoking, diabetes, and peripheral vascular disease put one at higher risk for surgery [20]. Nonoperative management is reserved for less severely displaced and simpler fracture patterns [1]. For improved functional outcomes with better occlusion and less temporomandibular joint pain, ORIF carries with it a higher risk for complications, including temporary facial nerve injury (5%) and condylar resorption (2%). It also confers an increased American Orthopaedic Foot and Ankle Society (AOFAS) rating (89.56), where most are classified as excellent to good [21]. Minimally invasive surgery (MIS) was considered, achieving comparable radiological reductions to ORIF but with a lower incidence of soft tissue complications, with an ensuing AOFAS rating of 82.58 [21]. At the same time, the classical conservative treatment of recurrence in 20% of condylar fractures is far less effective in occlusal correction as

Table 1: Summary of included studies on arthritis after calcaneal fracture

Author's	Study design	Sample size	Fracture type	Treatment type	Follow-up duration	Arthritis diagnosis criteria	Key outcomes
Griffin et al. (2014) [25]	Pragmatic, multicentre, parallel-group, assessor-blinded randomised controlled trial (UK Heel Fracture Trial)	151 patients (73 in operative group, 78 in non-operative group)	DIACFs	ORIF (operative) vs. non-operative treatment	2 years	outcomes assessed using Kerr-Atkins score, AOFAS score, SF-36, EQ-5D, clinical examination, walking speed, and gait symmetry	No significant difference in Kerr-Atkins score between operative (69.8) and non-operative (65.7) groups No significant difference in secondary outcomes (hindfoot pain/function, general health, quality of life) Complications and reoperations were more common in the operative group (OR 7.5, 95% CI 2.0–41.8)
Agren et al. (2013) [26]	Prospective, randomized, controlled multicenter trial	82 patients (42 in operative group, 40 in non-operative group)	DIACFs with ≥2 mm displacement (verified by CT)	Operative vs. non-operative treatment	1 year and 8–12 years	Radiographic evidence of posttraumatic subtalar arthritis	No significant difference in pain, function (VAS), or SF-36 scores at 1-year follow-up At 8–12 years, the operative group showed a trend toward better pain and function scores (P=0.07) and better SF-36 physical component scores (P=0.06) Operative treatment reduced the prevalence of posttraumatic subtalar arthritis (risk reduction: 41%) Higher risk of complications in the operative group
Dickenson et al. (2021) [27]	Pragmatic, multicentre, two-arm, assessor-blinded, randomized controlled trial	151 patients (118 available at 60-month follow-up; 52 ORIF, 66 nonoperative)	Closed DIACFs	ORIF vs. nonoperative treatment	36, 48, and 60 months	Not specified in the study	**Mean Kerr-Atkins scores at 60 months:**ORIF (79.2, SD 21.5), nonoperative (76.4, SD 22.5) No significant difference in function (P=0.975) No between-group differences in difficulty walking (P=0.175) or type of shoes worn (P= 0.432) Higher rate of additional surgical procedures in ORIF group (10 vs. 4, P=0.043) ORIF did not provide better long-term outcomes but increased the risk of additional surgery.
El-Azab et al. (2022) [28]	Prospective randomized controlled study	28 patients (34 feet)	Sanders type II and III DIACFs	Closed reduction and fixation using either cannulated screws or K-wires (without bone grafts)	Not explicitly mentioned	Lower rate of subtalar arthritis observed in the cannulated screw group	**Patient demographics:** Mean age: 34.8 years (cannulated screw group), 36.6 years (K-wire group); Males: 78.6% **Operative time:** Shorter in K-wire group (42 min) vs. cannulated screw group (57 min) **Functional outcomes:** Higher AOFAS score in cannulated screw group (85.9) vs. K-wire group (75.8) **Pain scores (VAS):** Better pain outcomes in the cannulated screw group **Radiographic union time:** Cannulated screw group (8.9 weeks) vs. K-wire group (10.1 weeks) **Subtalar arthritis:**Lower rate in the cannulated screw group **Hospital stay:** Both techniques reduced wound complications and shortened hospital stay **Ease of removal:** K-wires allowed for easy outpatient removal.
Liu et al. (2024) [29]	Randomized controlled trial	40 patients (40 feet)	Sanders type II and III calcaneal fractures	Minimally invasive group: Interlocking intramedullary nail fixation system Control group: Steel plate internal fixation via lateral L-shaped incision	8–12 months (mean 10.2 months for minimally invasive group, 10.4 months for control group)	One case of traumatic arthritis was reported in the control group	**Surgical factors:** ● Shorter incision length, operation time, and hospital stay in the minimally invasive group (P<0.05) ● Reduced intraoperative blood loss in the minimally invasive group (P<0.05) **Complications:** ● No complications in the minimally invasive group ● One case of incisional epidermal necrosis and one case of traumatic arthritis in the control group **Functional outcomes:** ● Higher final AOFAS score in the minimally invasive group compared to the control group (P<0.05) **Radiographic outcomes:** ● Significant improvement in Böhler and Gissane angles, width reduction, and height/length increase at 3 days post-operation and last follow-up (P<0.05) ● No significant differences in healing time between groups (P>0.05) **Overall conclusion:** ● Minimally invasive interlocking intramedullary nail fixation provided advantages of minimal trauma, shorter hospital stay, reliable fracture reduction, and better foot function recovery.

Author's	Study design	Sample size	Fracture type	Treatment type	Follow-up duration	Arthritis diagnosis criteria	Key outcomes
Kamath et al. (2021) [30]	Prospective comparative study	55 patients with 61 calcaneal fractures	DIACFs	Operative: Surgical fixation (30 patients) Non-operative: Cast immobilization (31 patients)	1 year	Not explicitly mentioned	**Functional outcomes:** ● The operative group had better outcomes when Bohler's angle was restored ● Mean scores at 1-year follow-up: ○ **Operative group:**MRS: 74.783, VAS: 3.348, AOFAS: 78.783 ○ **Non-operative group:**MRS: 57.368, VAS: 4.944, AOFAS: 71.211 **Statistical analysis:** ● Unpaired t-test results: ○ **MRS:**5.807, P<0.001 (significant difference) ○ **VAS:**4.387, P<0.001 (significant difference) ○ **AOFAS:**2.728, P=0.008 (significant difference) **Complications:** Observed in both operative and non-operative groups **Overall Conclusion:** Operative treatment provided better results if Bohler's angle was restored, while non-operative treatment showed fair outcomes.
Zak and Wozasek (2017) [31]	Retrospective case series	8 patients (4 male, 4 female)	Limb-threatening trauma involving the distal tibia or hindfoot, including: ● Open fractures ● Subtotal foot amputations ● Closed fractures with failed osteosynthesis ● Failed ankle joint replacements	TTC arthrodesis using various techniques: ● External ring fixation (1 case) ● External fixation + wires (1 case) ● External fixation + screws (1 case) ● Intramedullary nailing (1 antegrade, 5 retrograde; 1 bilateral, 4 unilateral) Bone defect management: ● Callus distraction or segment transport in 5 cases	Not explicitly mentioned	Presence of posttraumatic osteoarthritis requiring TTC arthrodesis	**Functional outcomes:** ● All patients achieved independent, pain-free mobilization with full weight-bearing ● High patient satisfaction with subjective outcomes **Radiographic outcomes:** ● Complete consolidation at the fusion site in 8 out of 9 cases ● High rate of adjacent joint arthritis ● Lateral radiographic angles showed a tendency toward pes cavus deformity **Surgical considerations:** ● Retrograde intramedullary nailing provided stability, minimal invasiveness, and a low infection rate ● The Ilizarov ring fixator may be required for tibial lengthening in cases of large bone defects **Overall conclusion:** TTC arthrodesis is a viable limb salvage option for severe posttraumatic arthritis and
Evers et al. (2019) [32]	Retrospective study	48 patients (55 fractures)	Calcaneal fractures	Surgical treatment with locking plate osteosynthesis	Not explicitly mentioned	Radiological assessment for posttraumatic arthritis Measurement of 'Böhler's and 'Gissane's angles Clinical evaluation using AOFAS and SF-36 scores	**Complications:** ● 9 patients (18.8%) required surgical revision ● 8 patients underwent subtalar arthrodesis ● 1 patient developed a deep wound infection **Risk factors for poor outcomes:** ● Nicotine abuse and a long interval between trauma and surgery increased wound healing complications **Functional scores:** ● **Average AOFAS score:**68 points ● **SF-36 score:**58.86 points **Factors impacting outcomes:** ● Symptomatic arthritis and the type of health insurance influenced functional results ● Age and fracture complexity were not correlated with worse outcomes **Conclusion:** Nicotine use and delayed surgery were significant risk factors for wound complications. Arthritis development and socioeconomic factors (insurance type) impacted overall results, but patient age did not affect outcomes.
Van der Vliet et al. (2018) [33]	Retrospective study with questionnaire-based follow-up	159 patients identified, 84 completed questionnaires (response rate 59%)	Post-traumatic subtalar arthritis following calcaneal fractures	Subtalar arthrodesis	2001 to 2016 (up to 15 years)	Patients with posttraumatic subtalar arthritis requiring fusion Exclusion of primary arthrodesis for fracture Functional assessment via FAAM, MFS, PROMIS PF, EQ-5D, and EQ-VAS	**Functional Outcomes:** ● **Median FAAM score:**79 (IQR: 48-90) ● **Median MFS score:**74 (IQR: 56-86) ● **Median PROMIS PF score:**45 (IQR: 38–51) **Quality of life:** ● Significantly lower compared to the general population (P=0.001) **Factors associated with poorer outcomes:** ● Smoking ● Complications after subtalar fusion (nonunion, implant failure, infections) ● High-energy trauma ● Ipsilateral injuries **Conclusion:** Subtalar arthrodesis resulted in acceptable functional outcomes, but patients experienced reduced quality of life. Smoking, post-fusion complications, high-energy trauma, and associated injuries were linked to worse outcomes.

Author's	Study design	Sample size	Fracture type	Treatment type	Follow-up duration	Arthritis diagnosis criteria	Key outcomes
Malik et al. (2022) [34]	Retrospective study	15 comminuted calcaneal fractures (14 patients)	Malunited comminuted calcaneal fractures	Percutaneous subtalar screw fixation	Minimum 12 months (mean 17.2±4.4 months)	Presence of subtalar joint arthritis due to malunion Radiographic assessment of Böhler's angle, Gissane's angle, calcaneal inclination, width, length, absolute foot height, and posterior facet height Fracture classification using Sanders classification (Sanders 3AB, 3BC, 3AC, and 4 fractures)	**Restoration of calcaneal anatomy:** ● 80% of patients had restoration of Gissane's angle, absolute foot height, calcaneal length, and inclination ● 54% of patients had Böhler's angle restored within normal range **Functional outcomes:** ● Mean AOFAS score: 74±11 ● Strong correlation between Böhler's angle and AOFAS score (r=0.85, P=0.004) **Complications:** ● 7% (1 patient) had a wound breakdown ● 20% (3 patients) reported heel pain from screws, which improved after removal **Conclusion:** Percutaneous subtalar screw fixation is a reliable method for restoring calcaneal anatomy in comminuted fractures with low complication rates. This technique can serve as a first-stage procedure before definitive subtalar fusion, though further studies on long-term outcomes and arthrodesis rates are needed.
Steelman et al. (2021) [35]	Retrospective study	62 patients (33 in the CRPF group, 29 in the ORIF group)	Intra-articular calcaneal fractures	CRPF ORIF	Minimum 6 months	Clinical subtalar arthritis development requiring arthrodesis Radiographic assessment of Böhler's angle	**Infection requiring reoperation:** ● 3% (1 patient) in the CRPF group ● 24% (7 patients) in the ORIF group **Instrumentation removal:** ● 70% (23 patients) in the CRPF group ● 31% (9 patients) in the ORIF group **Development of subtalar arthritis:** ● 30% (10 patients) in CRPF group ● 24% (7 patients) in ORIF group **Need for arthrodesis:** ● 6% (2 patients) in CRPF group ● 17% (5 patients) in ORIF group **Reduction outcomes:** ● Both techniques resulted in acceptable restoration of Böhler's angle immediately postoperatively and at final follow-up **Conclusion:** Both CRPF and ORIF are viable treatment options for intra-articular calcaneal fractures, with varying indications, risk factors, and complication rates. CRPF had lower infection rates but a higher rate of instrumentation removal, while ORIF had a higher risk of infection and arthrodesis requirement.
Gahlot et al. (2022) [36]	Retrospective cohort study	16 patients (7 males, 9 females)	post-traumatic subtalar arthritis secondary to: ● Calcaneus fracture malunion (50%) ● Talus fracture malunion (25%) ● Ligament injury (12.5%)	PASTA using a modified posterior 2-portal technique	Mean 15.6 months (range: 9–24 months)	Confirmed by local anesthetic injection into the subtalar joint under fluoroscopy guidance, providing immediate pain relief	**Pain reduction:** ● Mean VAS score improved significantly from 7 (range 6–9) preoperatively to 2 (range 0–4) at follow-up (P<0.001) **Functional improvement:** ● Mean AOFAS score increased from 18 (range 10–25) preoperatively to 79 (range 68-89) at follow-up (P<0.001) **No bone grafting required:** ● The modified technique prevented heel height loss and eliminated the need for bone grafting **Technique advantage:** ● Improved ease of cartilage removal and instrument movement within the joint
Fadle et al. (2025) [37]	RCT	157 patients (ELA: 81 patients, 95 fractures; STA: 76 patients, 91 fractures)	DIACFs – Sanders type II and III	ORIF using either: ● ELA ● STA	Not explicitly mentioned	Presence of subtalar osteoarthritis on follow-up radiographs	**Complications:** ● Higher skin complications (infection) in ELA (18.9%) vs. STA (3.3%), P=0.001 ● Higher subtalar osteoarthritis in ELA (32.6%) vs. STA (9.9%), P=0.001 **Surgical timing:** ● STA operated significantly earlier (4.43±7.37 days) vs. ELA (7±6.42 days), P=0.001 **Operative time:** ● STA shorter (55.83 ± 7.35 min) vs. ELA (89.66 ± 7.12 min), P<0.05 **Fracture union time:** ● Faster in STA (6.33±0.8 weeks) vs. ELA (7.13±0.7 weeks), P=0.000 **Radiological outcomes:** ● Significantly better in STA postoperatively and at last follow-up **Functional outcomes:** ● Higher AOFAS score in STA (83.49±7.71) vs. ELA (68.62±7.05), P=0.000 **Intraoperative radiation exposure:** ● No statistical difference between the two approaches

Author's	Study design	Sample size	Fracture type	Treatment type	Follow-up duration	Arthritis diagnosis criteria	Key outcomes
Rao et al. (2020) [38]	Retrospective review and fracture severity analysis	36 patients with 48 DIACFs	DIACFs, classified using Sanders classification	Percutaneous reduction with small stab incisions, fluoroscopy-guided manipulation (cork screws or Steinmann pins), and fixation using 3.5- and 4.0-mm screws	≥18 months	PTOA assessed using Kellgren-Lawrence scale	• Mean fracture energy: 19.3±3.1 J • Higher in more severe fractures: Type I (16.3 J), Type II (18.0 J), Type III (20.8 J), Type IV (22.0 J) • Fracture energy correlated with Sanders classification (rho=0.53, P=0.0001) **PTOA risk:** • Higher in fractures with increased energy (19.5 J vs. 18.9 J) but not statistically significant • Sanders classification predicted PTOA risk (OR=4.04, 95% CI=1.43–11.39, P=0.0084) **Pain and functional outcomes:** **Fracture energy:** • **Mean fracture energy:**19.3±3.1 J • **Higher in more severe fractures:**Type I (16.3 J), Type II (18.0 J), Type III (20.8 J), Type IV (22.0 J) • Fracture energy correlated with Sanders classification (rho=0.53, P=0.0001) **PTOA risk:** • Higher in fractures with increased energy (19.5 J vs. 18.9 J) but not statistically significant • Sanders classification predicted PTOA risk (OR=4.04, 95% CI=1.43–11.39, P=0.0084) **Pain and functional outcomes:** • No relationship between fracture energy and VAS pain scores • Higher fracture energy correlated with lower SF-36 scores (worse quality of life) **Conclusion:** • Fracture energy correlates with Sanders classification and can
Schindler et al. (2021) [39]	Retrospective monocentric study	140 patients (129 fractures), with 80 available for clinical and radiological follow-up	Intra-articular calcaneal fractures	Surgical treatment	Mean: 91 months (range 12–183 months)	Post-traumatic subtalar arthritis assessed radiologically	**Complication rate:** 29% (37/129 feet), including wound healing issues (11%) and infections (5%) **Non-union:** 4% (only in smokers, P=0.02) **Subtalar arthritis:**77% of cases developed post-traumatic subtalar arthritis **Subsequent subtalar fusion:** 18% required secondary subtalar fusion **Revision rate:** High (60%) after primary fusion **Functional scores:** • **Mean AOFAS Hindfoot Score:**74 • **Sanders I:**99, Sanders II: 74, Sanders III: 77, Sanders IV: 70 **Boehler's angle improvement:** Significant improvement postoperatively (P<0.01) **Correlation Between Boehler's Angle and AOFAS Scores:** • Decreased Boehler angle over time associated with lower AOFAS hindfoot scores (P<0.01) **Conclusion:** • Caution advised in using primary subtalar fusion due to high revision rate • Smoking status should be considered in treatment planning

AOFAS: American Orthopaedic Foot and Ankle Society, **DIACFs:** Displaced intra-articular calcaneal fractures, **PTAOA:** Post-traumatic osteoarthritis, **RCT:** Randomized controlled trial, **ELA:** Extensile lateral approach, **STA:** Sinus tarsi approach, **CT:** Computed tomography, **TTC:** Tibiotalocalcaneal, **VAS:** Visual analog scale, **CRPA:** Closed reduction and percutaneous fixation, **PASTA:** Posterior Arthroscopic Subtalar Joint Arthrodesis, **MRS:** Modified Rankin score, **SF-36:** 36-item short form survey, **PF:** Physical function, **CI:** Confidence interval, **SD:** Standard deviation, **IQR:** Interquartile range, **OR:** Odds ratio, **EQ-5D:** EuroQol 5 dimensions, **FAAM:** Foot and ankle ability measure, **EQ-VAS:** EuroQol visual analog scale, **MFS:** ??? Kindly provide expansion

compared to ORIF [22]. Similarly, diabetes, neuropathy, alcohol use, and psychiatric disorders also increase the risk of needing to perform subtalar arthrodesis after the tibiotalar arthrodesis [23]. In addition, primary immunodeficiency disorders may help in causing septic arthritis of the subtalar joint [24].

A systematic review and meta-analysis are warranted since there is no agreement on the best treatment for minimizing the risk of arthritis after calcaneal fractures. Varied outcomes from studies complicate making a decisive conclusion. Meta-analysis of the evidence will serve to determine incidence, risk factors, and late results of PTA. It offers a balanced consideration to inform decision-making at the clinical level. In this review, we systematically analyze and compare the incidence, risk factors, and prognosis of arthritis after calcaneal fractures and treatment methods to determine the most efficacious method to reduce PTA.

Materials and Methods

This systematic review and meta-analysis were performed according to the preferred reporting items for systematic reviews and meta-analyses to achieve transparency and replicability. PROSPERO registration of the protocol will be achieved, and the study will conduct a synthesis of evidence regarding the incidence, risk factors, and outcomes of PTA after calcaneal fractures, comparing treatments, including both surgical and non-surgical management. Reviewing randomized controlled trials (RCTs), cohort studies, case-control studies, and retrospective observational studies measuring long-term functional and radiographic outcomes will be included (Fig. 1).

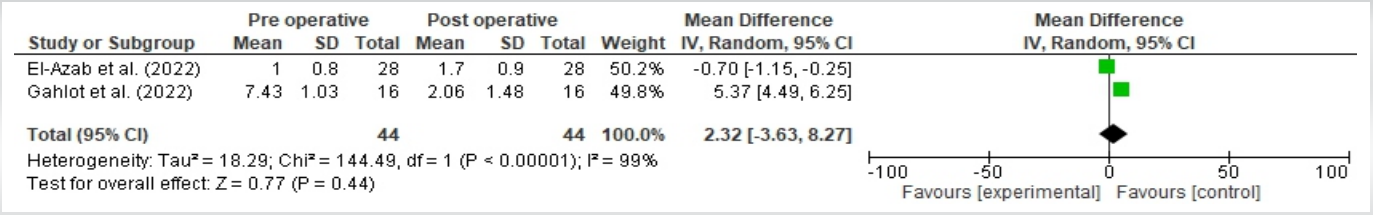

Figure 2: Forest plot depicting the analysis of studies with visual analog scale scores.

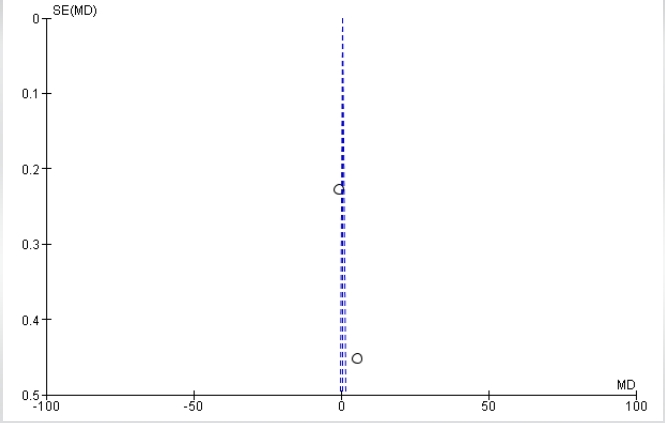

Figure 3: Funnel plot depicting the analysis of studies with visual analog scale scores.

Search strategy

A systematic literature search was performed utilizing PubMed and Google Scholar for peer-reviewed articles. Search terms will be a combination of both Medical Subject Headings and free-text keywords, using Boolean operators. Keywords like "Calcaneal fracture," "Post-traumatic arthritis," "Subtalar arthritis," "Surgical treatment," "Non-surgical treatment," "Open reduction internal fixation," "Minimally invasive surgery," "Conservative management," and "Long-term outcomes" will be employed. The reference lists of included studies and systematic reviews will also be searched manually for additional relevant studies.

Data extraction

Studies were chosen using a two-stage process of screening. Two independent reviewers will first screen titles and abstracts to suggest potentially relevant studies. Full papers will then be screened for eligibility against predefined inclusion and exclusion criteria. Disagreements will be resolved by consultation with a third reviewer.

Inclusion criteria

Studies of PTA after calcaneal fractures, RCTs, cohort studies, case–control studies, and retrospective observational studies, Comparative studies of surgical vs. non-surgical intervention and their influence on the development of arthritis, at least 12-month follow-up to determine long-term outcomes, trials reporting at least one functional, radiographic, or clinical outcome, incidence of PTA and articles published in English were included in the study.

Exclusion criteria

Case reports, conference abstracts, opinions, and editorials, insufficient data studies for outcomes of arthritis, and studies with animal models or cadavers were excluded from the study.

Statistical analysis

A meta-analysis was carried out using Review Manager software. Heterogeneity was evaluated by 'Cochran's Q test and the I2 statistic, and a value of I2 >50% will be considered as significant heterogeneity, which would require the use of a random-effects model. Outcomes were visualized in forest plots and funnel plots.

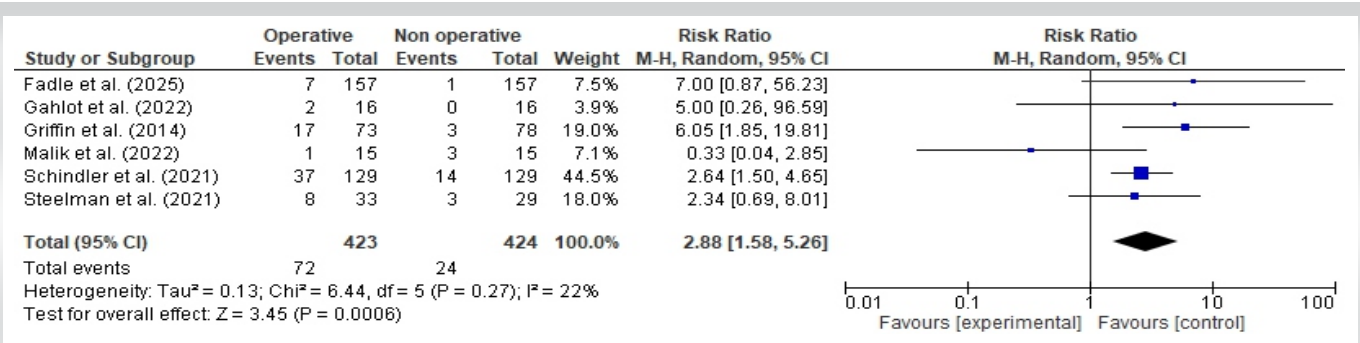

Figure 4: Forest plot depicting the analysis of studies with complications.

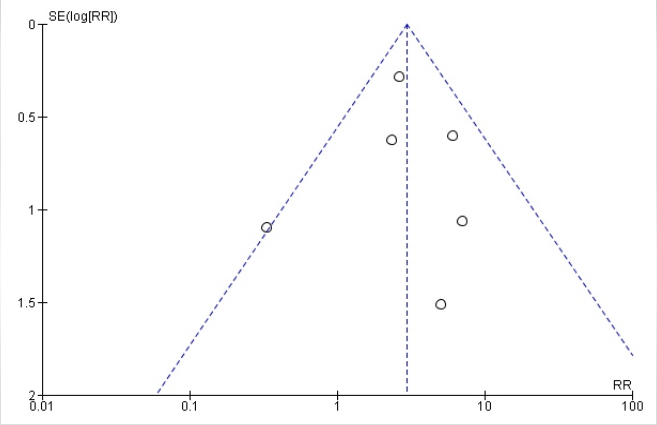

Figure 5: Funnel plot depicting the analysis of studies with complications.

Results

Study selection

Fifteen studies were selected in this systematic review and meta-analysis after screening and selection according to predefined eligibility criteria. The studies contained RCTs, prospective comparative studies, retrospective analyses, and long-term follow-up to effectively evaluate PTA following DIACF. The studies included in these trials reported an extremely varied sample-to-sample ratio-neatly, ranging from 15 to 159 patients, the follow-up duration extended from 6 months to more than 15 years, and very widely across treatises, ORIF, minimally invasive techniques, and conservative management. The principal outcome considered was the incidence of post-traumatic subtalar arthritis, besides functional recovery, pain scores, radiological outcomes, and complication rates. The following subdivisions summarize the core findings according to some other variables (Table 1).

Incidence of PTA

Some studies documented the incidence of subtalar arthritis after DIACFs. Agren et al. identified 41% fewer cases of PTA in the operative compared to the non-operative group after 8–12 years of follow-up. Schindler et al. documented that 77% of patients developed subtalar arthritis following surgical intervention, with 18% needing subtalar fusion. Dickenson et al. demonstrated no significant difference between ORIF and non-operative care in long-term functional results but increased secondary surgical rates in patients who underwent ORIF. Evers et al. underlined that a higher rate of symptomatic arthritis was found among patients with delayed surgery.

Research on minimally invasive interventions like percutaneous fixation also identified arthritis outcomes. El-Azab et al. discovered a reduced incidence of subtalar arthritis in the group treated with cannulated screw fixation compared to the K-wire group. Likewise, Liu et al. identified fewer complications, improved functional recovery, and less incidence of arthritis among patients receiving interlocking intramedullary nail fixation compared to those receiving steel plate internal fixation.

Comparison of operative versus non-operative treatment outcomes

The UK Heel Fracture Trial (Griffin et al.) reported that ORIF provided no demonstrable symptomatic or functional advantages over non-operative treatment at 2 years. Their results were corroborated by Kamath et al., who showed that restoration of Böhler's angle was one of the key determinants of functional success following surgery. Van der Vliet et al. confirmed that although the functional results after subtalar fusion were acceptable, patients perceived an impaired quality of life. Conversely, Agren et al. suggested that although ORIF was not associated with immediate benefits within the 1st year, some improvement in pain and function was noted 8–12 years thereafter, together with a lower prevalence of PTA.

Functional outcomes and pain scores

Outcome studies measuring functional recovery employed standardized scoring measures like AOFAS score, Visual Analog Scale (VAS) for pain, and 36-item short-form survey quality of life scores. Kamath et al. noted significantly superior AOFAS scores in the surgical group (78.8) than the non-surgical group (71.2) in a 1-year follow-up. Similarly, El-Azab et al. reported that patients who were treated with cannulated screws reported improved AOFAS scores (85.9) compared to the K-wire group (75.8). Liu et al. demonstrated that patients who were treated with minimally invasive interlocking intramedullary nail fixation had higher AOFAS scores and improved pain relief (VAS) compared to those treated with steel plate internal fixation. Conversely, Zak and Wozasek (2017) discovered that patients who underwent tibiotalocalcaneal arthrodesis experienced pain-free mobilization and complete weight-bearing ability, but adjacent joint arthritis was highly prevalent.

Radiological outcomes and fracture healing

The research evaluated radiographic measurements like Böhler's angle, Gissane's angle, and calcaneal height/width to measure the quality of fracture reduction and the outcomes of healing. Schindler et al. highlighted that time changes in Böhler''s angle were associated with poorer functional results ($P < 0.01$). Equally, Fadle et al. reported improved radiological outcomes in patients who were treated with the sinus tarsi approach (STA), including shorter union time (6.3 weeks compared to 7.1 weeks in the extensile lateral approach group). Rao et al. also associated the severity of fractures with Sanders classification and reported that Type IV (high-energy) fractures had a higher risk of PTA and poorer functional outcomes.

Complications and secondary surgeries

Studies on different techniques of surgery differ in rates of complications. Steelman et al. observed that the infection rate was significantly higher for the ORIF group (24%) than for the CRPF (3%), while the hardware-removal rate was higher in the CRPF (70%) compared to ORIF (31%). Schindler et al. presented a non-union of 4% in smokers only, implicating smoking as a risk factor in any way for poor healing of the bone. Fadle et al. compared injuries to the sinus tarsi and extensile lateral approach (ELA); they found that ELA was associated with many more skin complications (18.9%) and subtalar arthritis (32.6%) compared to STA (3.3% and 9.9%, correspondingly).

VAS pain score

Two studies reported VAS score, and were eligible for meta-analysis (Fig. 2 and 3). They reported signficant difference in mean VAS score between pre-operative and post-operative (2.23 [95% confidence interval [CI] −3.63–8.27)). Heterogeneity among these studies was high (Tau2 = 18.29; Chi2 = 144.49; df = 5 [P < 0.0001]; I2 = 99%).

Complications

Six studies reported complications, and were eligible for meta-analysis (Fig. 4 and 5). They reported no significant difference in complications between operative and non-operative (relative risk [RR]: 2.88 [95% CI 1.58–5.26]). Heterogeneity among these studies was high (Tau2 = 0.13; Chi2 = 6.44; df = 5 [P = 0.27>0.05]; I2 = 22%).

Discussion

The incident of PTA secondary to calcaneal fractures is one of the graver complications that can impact an individual in the long run. Many factors, some of which are patient-specific, are responsible for the determinative input into the severity of a fracture, hence contributing towards its incidence. Studies have demonstrated many more cases of PTA seen in displaced intra-articular fractures, especially Sanders type III and IV. The extent of joint surface disruption and poor correction of hindfoot alignment largely contribute to the development of PTA in these specific fracture types. Comparative studies done between surgical and conservative interventions reveal that although ORIF greatly restored initial alignment of the fractured surface, it does not always guarantee a long-lasting functional recovery, just as studies by Griffin et al. and Dickenson et al. have reported. Meta-analysis findings also support this, with a significant difference in mean VAS scores between preoperative and postoperative assessments (2.23; 95% CI −3.63–8.27), indicating notable pain relief following surgical intervention. However, heterogeneity among the studies was high (I2 = 99%), suggesting variability in patient responses. Non-operative treatment would likely be safer with a lower risk of complications, but most cases still have residuals like deformity and functionality. Furthermore, minimally invasive techniques, such as percutaneous fixation and interlocking intramedullary nailing, have already shown promise in cutting down PTA risk while also reducing surgical morbidity (Liu et al.; El-Azab et al.). In spite of all the advances in management, many patients still develop subtalar arthritis, occasionally necessitating subsequent surgeries such as subtalar arthrodesis, which ultimately underscores the idea of tailored treatment strategies in relation to fracture features and the uniqueness of each 'patient's profile.

Calcaneal fractures are among the most common tarsal bone fractures and are constituted by 71.0% of intra-articular fractures [40, 41]. Intra-articular calcaneal fractures usually present a high probability of complications, usually caused by displacement, where 95.0% of intra-articular subtalar calcaneal fractures present displacement [40, 41]. The non-operative management results in higher complication rates as compared to those treated surgically [40]. Other than articular collapse and chondrocyte damage, some factors have contributed toward the development of PTA in patients having sustained fractures, with post-fracture cases showing about 72.8% ± 12.9% viability in chondrocytes, which is highly significant when compared to about 94.8% ± 1.5% for controls (P = 0.005) [16]. PTA risk increased with the high-energy-type injuries that correlated with reduced chondrocyte viability (P = 0.13) [16]. In addition, longer injury-to-surgery time lowered the chondrocyte viability further (P = 0.07) [16]. Older age was also associated with lower chondrocyte viability (P = 0.07) [16]. Intra-articular fractures, particularly the displaced type, have an increased chance for complications and can cause subtalar joint PTA by disruption of the joint surface [42].

The comparison between ORIF and minimally invasive reduction with percutaneous fixation (MIRPF) revealed no significant differences in radiological outcomes, although MIRPF demonstrated better functional results and fewer wound complications [43, 44]. ORIF was associated with a 30% incidence of wound-healing issues, a longer hospital stay, and extended wound recovery time compared to minimally invasive approaches [43]. Complications of wound healing were associated with nicotine exposure and operative delays [32]. Of those patients treated operatively, 18.8% (9 of 48) needed revision surgery, of which eight received subtalar arthrodesis and one a deep infection in the wound [32]. While hardware problems were not clearly described, evidence of subtalar arthrodesis in more than one instance implies possible malfunction of fixation or poor fracture healing [32, 45]. PTA continues to be the most frequent late complication after intra-

articular calcaneal fractures [45]. Meta-analysis findings indicate that the overall complication rates between operative and non-operative treatments showed no significant difference (RR: 2.88, 95% CI 1.58–5.26). This suggests that while surgery may provide better fracture alignment and pain relief, the risk of complications remains comparable to non-operative management. Heterogeneity among the studies was low (I2 = 22%), indicating consistent findings across different reports. In conservatively treated fractures, 18% (42 of 233) had severe complications requiring surgical treatment [46]. The best treatment of intra-articular calcaneal fractures is controversial, and conservative measures like elevation, application of ice, early mobilization, and cyclic compression of the plantar arch are used frequently [47].

The Sanders classification system has been widely linked with long-term risk of PTA after DIACFs. Sanders et al. described that Type III fractures had a 47% chance of needing subtalar fusion for arthritis, whereas Type II fractures had a lesser rate of 19%. In addition, Type III fractures were almost four times more likely to require fusion than Type II fractures (RR: 3.94, 95% CI: 1.64–9.48) [48]. Likewise, Rao et al. identified that the Sanders classification was an important predictor of risk for PTA, with odds ratio 4.04 (95% CI: 1.43–11.39, P = 0.0084). Besides, fracture energy correlated well with Sanders classification (rho = 0.53, P = 0.0001), suggesting more severe fractures correspond to greater energy impacts and increased risk of arthritis [38]. Combined articular disruption and fracture energy measurement accurately predicted severity of post-traumatic osteoarthritis in 88% of cases [49]. Even small articular step-offs of 1 mm can change pressure distribution and lead to cartilage degeneration, emphasizing the need for accurate fracture reduction to avoid arthritis risk [50].

We recommend long-term prospective modeling inherent in those studies that seek to understand the complex nature of PTA, following calcaneal fractures, and to identify those factors that may predict long-term outcomes. These very promising modalities include cartilage-sparing techniques and biologic interventions, which could encompass stem cell therapy and regenerative medicine, wherever feasible, toward the aim of joint preservation and procrastination of the onset of arthritis. Otherwise, generalized treatment protocols may be constructed on the basis of fracture patterns, demographics, and disease patterns regarding further optimization of treatment pathways and conditions. Filling in the voids discussed will enable a future for research to inform better clinical decision-making and functional outcomes amid people prone to PTA.

Conclusion

This systematic review emphasizes the significant risk of PTA after calcaneal fractures, especially displaced intra-articular fractures. Surgical methods, such as ORIF and MIS, affect long-term results, with MIS decreasing wound complications. Sanders classification and fracture energy analysis predict the risk of arthritis. Delayed surgery and severity of fracture affect PTA development. Even with progress, there is still a lack of standardized treatment protocols. Future studies will need to investigate long-term analyses, cartilage-sparing strategies, and individually tailored treatment methodologies to reduce risk of PTA, optimize function recovery, and maximize quality of life for patients with calcaneal fractures.

Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given his consent for his images and other clinical information to be reported in the Journal. The patient understands that his name and initials will not be published, and due efforts will be made to conceal his identity, but anonymity cannot be guaranteed.

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