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REVIEW ARTICLE

Current concepts in the management of calcaneal fractures

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ABSTRACT

Introduction. Despite advances in non-operative and surgical management, calcaneal fractures remain severe injuries with relatively poor clinical outcomes. These fractures predominantly affect young, active individuals and are often associated with long-term sequelae, permanent disability, a considerable reduction in quality of life, and a substantial economic impact due to work incapacity and rehabilitation needs.

Material and methods. This study is a narrative literature review. A bibliographic search was conducted using PubMed, Hinari, SpringerLink, National Center for Biotechnology Information, and Medline databases. Articles published from 1990 to 2024 were selected based on keyword combinations such as "calcaneal fracture," "comminuted calcaneal fracture," "orthopedic treatment", "surgical treatment," "minimally invasive treatment," "osteosynthesis," "locking plate," and "locked intramedullary nail." After processing information from these databases according to the search criteria, 225 full-text articles were identified. The final bibliography includes 56 relevant sources, which were considered representative of the materials published on the topic of this synthesis article.

Results. Surgical treatment using open reduction and internal fixation for displaced intra-articular calcaneal fractures was superior to non-surgical treatment in restoring Bohler's angle, achieving more stable calcaneal height and width, improving functional recovery, reducing the number of patients requiring orthopedic footwear, and enabling return to pre-injury activities, though it carries a high risk of complications. The minimally invasive approach via the sinus tarsi and the extended lateral L-shaped approach are equally effective for treating Sanders type II and III fractures in terms of restoring anatomical structures, radiological outcomes, and functional recovery. However, the sinus tarsi approach is effective in reducing wound complication rates (3.6–6.3% vs. 13.5–31.2%, respectively; $p < 0.05$), pain syndrome rates, time to surgery ($p < 0.0001$), surgery duration ($p < 0.05$), and hospital stay duration. Therefore, the minimal incision approach is a good alternative to the extended lateral L-shaped approach.

Conclusions. The current concept in managing calcaneal fractures involves developing an individualized treatment plan based on the patient's characteristics and functional requirements, comorbidities, fracture type, and associated injuries, as well as the surgeon's experience with the selected surgical technique.

Keywords: calcaneal fracture, comminuted calcaneal fracture, orthopedic treatment, surgical treatment, minimally invasive treatment, osteosynthesis, locking plate, locked intramedullary nail.

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Key messages

What is not yet known on the issue addressed in the submitted manuscript

The inconsistent clinical outcomes and frequent complications associated with open reduction of calcaneal fractures have made it challenging to standardize the surgical management of these injuries. The optimal approach to managing displaced intra-articular calcaneal fractures, which are highly complex injuries, remains controversial, and there is currently no universal treatment protocol.

The research hypothesis

The analysis and synthesis of contemporary literature will allow for a comprehensive presentation of the current management of calcaneal fractures, determining the indications and contraindications for conservative treatment, surgical treatment, and minimally invasive treatment.

The novelty added by the manuscript to the already published scientific literature

The article provides a synthesis of the latest international publications on the effectiveness of contemporary treatment methods for calcaneal fractures. The study results will contribute to refining the treatment protocol for initial management and optimizing fixation methods for calcaneal fractures by selecting appropriate types of fixators.

Introduction

Although new technologies and osteosynthesis materials have been developed, the treatment of calcaneal fractures (both non-surgical and open reduction with internal fixation) remains a controversial topic in the specialized literature due to the fracture's anatomical complexity, the fragile soft tissue surrounding the bone, and high complication rates. The literature presents contradictory findings regarding outcomes for calcaneal fractures and the potential superiority of one treatment option over another or over conservative treatment. Some reasons for this controversy include issues with different classification systems, varying indications for surgical treatment, and diverse evaluations for clinical and radiological outcomes [1-6].

Inconsistent clinical outcomes and frequent complications associated with open reduction have made it difficult to standardize the surgical management of these injuries. A universal treatment protocol has yet to be established. Even existing randomized controlled trials comparing operative and non-operative treatments over the past 25 years have failed to provide clarity. While many studies favor surgical treatment, others have found no difference between operative and non-operative management. The irregular bone anatomy, complex joint mechanics among the tarsal bones, and delicate soft tissue coverage make these fractures challenging. Systematic reviews and meta-analyses have not found conclusive evidence for the most effective treatment due to the use of diverse operative strategies and outcome measurements [5-17].

Given this context, the aim of this article is to provide a synthesis of the most recent data on the efficacy of modern treatment methods for patients with intra-articular calcaneal fractures.

Material and methods

To achieve the stated objective, an initial search of specialized scientific publications was conducted using Google Search and databases including PubMed, Hinari (Health Internet Work Access to Research Initiative), SpringerLink, National Center for Biotechnology Information, and Medline. The selection criteria for articles included contemporary data on treatment methods for patients with intra-articular calcaneal fractures, using keywords such as "calcaneal fracture," "comminuted calcaneal fracture," and "intra-articular calcaneal fracture" in various combinations with "orthopedic treatment," "surgical treatment," "minimally invasive treatment," "osteosynthesis," "locking plate," and "locked intramedullary nail" to maximize search yield.

For advanced source selection, the following filters were applied: full-text articles in English, published between 1990 and 2024. After a preliminary title analysis, original research articles, editorials, narrative reviews, systematic reviews, and meta-analyses containing relevant information and contemporary concepts on orthopedic, surgical, and minimally invasive treatment of intra-articular calcaneal fractures were selected. Additionally, reference lists from identified sources were searched to highlight further relevant publications not found during the initial database search.

The information from publications included in the bibliography was collected, classified, evaluated, and synthesized, highlighting key aspects of contemporary views on treatment methods for patients with intra-articular calcaneal fractures.

To minimize the risk of systematic errors (bias) in the study, we conducted thorough searches in databases to identify a maximum number of relevant publications for the study's purpose, assessed only studies meeting validity criteria, and applied reliable exclusion criteria for articles in the study.

Additional information sources were consulted as needed for clarification of certain concepts. Duplicate publications, articles that did not align with the study's purpose, and those not accessible for full viewing were excluded from the list of publications generated by the search engine.

Following the information processing through Google Search and databases such as PubMed, Hinari, SpringerLink, National Center of Biotechnology Information, and Medline, 225 articles addressing treatment methods for patients with intra-articular calcaneal fractures were identified based on the search criteria. After a primary title analysis, 62 articles were initially deemed potentially relevant for this synthesis. Upon further review, 56 publications were ultimately selected as relevant to the stated objective. These 56 articles were included in the final bibliography, representing the materials considered significant for the topic of this synthesis article.

Publications that did not address the topic, even if initially selected by the search program, and articles inaccessible for full viewing, either through the HINARI database or in the scientific medical library of the Nicolae Testemiţanu State University of Medicine and Pharmacy, were subsequently excluded from the list.

Results

The management of displaced intra-articular calcaneal fractures (DIACF) can be divided into four main categories: 1) non-operative management, 2) open reduction and internal fixation (ORIF), 3) minimally invasive reduction and fixation, and 4) primary subtalar arthrodesis (PSA) [18]. Therapeutic options include conservative non-surgical treatment, closed reduction with external fixation using Kirschner wires or an external fixator, closed reduction and internal fixation with screws or nails, closed reduction with calcaneoplasty, ORIF with K-wires, screws, or plates, arthroscopically assisted reduction with internal fixation, arthroscopic reduction with external fixation, and subtalar arthrodesis. Available fixation methods include external fixation, plate fixation, nails, Kirschner wires, and screws [1, 12, 15, 19-24].

A range of factors and their negative impacts on the healing process should be considered, as they inform strict indications for the optimal treatment strategy. These include patient factors (comorbidities, age, gender, functional needs, smoking, psychological disorders), limb and soft tissue injury characteristics (open fracture, bilateral fracture, severe edema, fracture blisters), and fracture features (Sanders classification, Bohler's angle, type of fracture—whether intra-articular or extra-articular) [18].

The most important imaging data for planning reconstructive surgery are: the number of posterior articular surface fragments (according to the Sanders classification, prognosis worsens with an increasing number of fragments, making surgical reconstruction of the posterior articular surface unfeasible in cases of excessive comminution with poor prognosis), the direction of fracture lines (the more medial, the harder it is to achieve reduction), the direction of displacement of the calcaneal tuberosity fragment (varus or valgus with rotational elements), the width and degree of collapse of the calcaneus (affecting footwear selection and the risk of peroneal tendon or malleolar impingement against a bulging lateral calcaneal wall), and involvement of the calcaneo-cuboid joint [25].

Orthopedic (non-surgical) treatment is indicated for extra-articular fractures without displacement or with displacement <2 mm from the anatomical position, fractures located in the anterior process affecting less than 25% of the calcaneo-cuboid joint, patients with comorbidities (e.g., diabetes, severe neurovascular insufficiency, peripheral vascular disease), severe local soft tissue conditions that preclude extensive approaches, or elderly patients unable to tolerate surgery [7, 16, 18, 26-30].

Conservative treatment for calcaneal fractures involves immobilizing the fracture area in a plaster splint (5–7 days), followed by a plaster cast or orthosis for the heel (60 days), use of nonsteroidal anti-inflammatory drugs, and physiotherapy procedures. For non-displaced calcaneal fractures, the healing time is approximately 10–12 weeks [7, 16, 18, 26-30].

Early joint mobilization is recommended, but without weight-bearing on the affected foot. After 10–12 weeks, the patient can begin full weight-bearing walking on the injured foot, but only after radiographic confirmation of bone consolidation [16]. Potential disadvantages of non-operative management compared to surgical treatment include the inability to achieve anatomic reduction of the posterior facet, insufficient functional recovery, higher rates of subtalar and calcaneo-cuboid arthritis, risk of malunion, and higher rates of subtalar arthrodesis (16% and 3%, respectively; $p < 0.0001$) [5, 7, 11, 18, 29, 31].

Modern surgical management of calcaneal fractures is based on the following steps:

1. **Surgical Approaches:**
   - **Medial approach** (for sustentaculum tali fractures)
   - **Extended lateral L-shaped approach (ELLA)** (for Sanders II, III, and IV intra-articular fractures) – This is the most used approach, suitable for most DIACF cases where access to the posterior facet, posterolateral and anterolateral fragments, and subtalar joint is necessary.
   - **AST** is a limited, customized lateral approach allowing access to the subtalar and calcaneo-cuboid joints.
2. **Combined approach (medial and lateral)** has been described for DIACF with wound complications [20, 23, 28, 31].
3. **Timing of surgery:**

Surgery is performed 10–14 days after the fracture occurs, allowing time for significant reduction or resolution of edema and blisters. Keeping the affected limb elevated and immobilized helps reduce the time needed for edema resolution. Surgery is considered safe when lateral skin folds appear [20]. However, in the case of an open fracture, immediate treatment is required due to the risk of osteitis [20, 30].

4. **Surgical objectives:**

The surgical goals include restoring heel height and width, reconstructing anatomy to approximate Bohler's and Gissane's angles, repairing and realigning the subtalar joint, restoring the functionality of the posterior mechanical axis, reconstructing the medial and lateral walls, and protecting tendons and neurovascular structures. There is a significant correlation between preoperative Bohler's angle and fracture severity, and postoperatively, Bohler's angle significantly correlates with functional recovery [4, 19-21, 32]. Restoration of the posterior facet is essential for achieving a normal gait, an earlier return to professional activities, and reducing the need for subtalar joint arthrodesis [33].

5. **Surgical technique**

The goal of surgical treatment is to restore the morphology of the calcaneus and joint congruence, and it includes:

- **Closed reduction and external (percutaneous) fixation with screws** – recommended for extra-articular fractures when the fractured fragments are large and for minimally displaced "tongue" type fractures.
- **Open reduction and internal fixation (ORIF) with screws or plates (conventional or locking)** – indicated for fractures that cannot be reduced by less invasive methods (displaced complex intra-articular

fractures, displaced "tongue" type fractures, Sanders type II and III fractures, fractures of the anterior process with over 25% involvement of the calcaneo-cuboid joint, displaced sustentaculum fractures, and cases with reduced Bohler's angle).

- **Minimally invasive osteosynthesis with or without arthroscopic reduction** [7, 8, 10, 12, 15, 16, 19, 21, 22, 34, 35].

Over the past two decades, surgical management of calcaneal fractures has increasingly become preferred over conservative management. With advances in surgical techniques and biomechanics, surgical treatment is now usually the first-line choice for calcaneal fractures [5]. The goals of modern surgical treatment in the literature are defined as follows: 1) reduction of the posterior articular facet, 2) restoration of the original height and width of the calcaneus, 3) reconstruction of Bohler's and Gissane's angles, 4) ensuring fibular tendon mobility, 5) re-establishment of the valgus position of the calcaneal tuberosity, 6) reduction of the calcaneo-cuboid joint, 7) early rehabilitation of the foot and ankle, and 8) minimization of soft tissue complications [21, 32, 36].

Thus, modern surgical treatment for fractures is designed to reduce bone fragments while achieving joint congruence and stable fixation, allowing for early mobilization [5, 30].

Surgical treatment is performed for patients with open fractures, displaced intra-articular fractures (Sanders types II, III, and IV), "tongue" type fractures that may compromise soft tissue, extensive fractures of the anterior process, fractures located at the posterior tuberosity, or calcaneal fractures with dislocations. An important rule is that calcaneal surgery should be done only after edema and blisters subside (indicated by the appearance of skin laxity—wrinkles), but the time from the fracture occurrence to surgery should not exceed 2–3 weeks to avoid fracture consolidation and development of fibrotic rigidity in the soft tissues surrounding the calcaneus. Additionally, the condition of the soft tissues is crucial [7, 16, 19, 21, 27, 28, 37].

Factors that may influence wound healing include the Sanders type of fracture, open fractures, smoking, comorbidities (especially diabetes and obesity), overcorrection of calcaneal height, early or delayed surgery, prolonged operating time, and wound closure technique [17, 32, 38]. Therefore, the decision to perform surgery is based on three main criteria: (1) displacement or comminution of the posterior facet; (2) the patient's age and surgical contraindications; (3) soft tissue trauma and associated conditions or polytrauma that can influence the timing of surgery and the choice of surgical technique (open reduction, external fixation, percutaneous technique, approach selection) [28, 30].

Since the 1990s, ORIF with a plate has been considered the "gold standard" for surgical treatment of DIACF, including comminuted fractures [23, 39-41]. For internal fixation, most authors use a single lateral plate of various shapes (locked or simple) that matches the anatomical features of the calcaneus and is secured with at least two screws, often in different planes, providing a more rigid fixation. These plates effectively resist rotation and axial loads to achieve stable fixation and are associated with low rates of loosening and fixation failure [26, 31, 39-41].

Locking plate systems were developed to enhance fracture fixation stability, allowing for early mobilization and rehabilitation. The introduction of locking plate technology in orthopedics has improved the biomechanical durability of bone and fracture fixation, representing a significant advancement in treating complex, periarticular, and osteopenic fractures [29, 30].

In recent years, the technology of locking plates has been evaluated, with researchers supporting that they provide stronger joint stability and fixation than non-locked plate constructs, particularly in comminuted fractures with a wide coverage area. They enable early weight-bearing on the affected limb without compromising fracture stability [27, 29, 40-42]. Although the advantages of locking plates in calcaneal fractures remain debated, multiple studies have demonstrated the superiority of locking plates over conventional constructs. Locking plates are also advantageous in treating DIACF in patients with osteoporotic bone [27, 29, 30, 40-42].

The locked intramedullary nail, a new minimally invasive technique, was developed to combine the benefits of a minimally invasive approach with stable percutaneous fixation. This system has demonstrated high primary stability, comparable to variable-angle locking plates, in fixing fractures in patients with Sanders type II and III DIACF [43, 44].

Among all methods, ORIF is considered the standard treatment and the best method for achieving anatomical joint reduction, restoring calcaneal morphology with a lower prevalence of post-traumatic arthritis. However, soft tissue complications are proportional to the extent of soft tissue trauma, which is why ORIF is not always feasible for every case and is typically performed when the soft tissue has recovered following fracture trauma [8-10, 12, 15, 45].

ORIF with a plate has shown acceptable radiological and functional outcomes: restoration of subtalar joint movement (67.8% of active movement and 80.7% of passive movement), attributed to rigid anatomical reduction and early postoperative rehabilitation [23, 40, 41]. The calcaneal locking plate provides a secure functional outcome by restoring the anatomical reconstruction of calcaneal height, width, Bohler's angle, and Gissane's angle, which leads to on early mobilization [39]. It has been shown that ORIF has higher complication and reoperation rates, yet yields better outcomes in terms of pain relief, walking restoration, time to return to work, and wearing regular footwear [19, 45]. All major randomized studies comparing non-operative treatment with surgical intervention via the extended lateral L-shaped approach (ELLA) found wound complication rates between 19% and 37% in the surgical group [14].

A meta-analysis published in 2012 examined 10 studies (6 randomized controlled trials and 4 controlled clinical studies) with a total of 891 patients, confirming that surgical

treatment of DIACF was superior to non-surgical treatment in restoring Bohler's angle, achieving more stable calcaneal height and width, better functional recovery, reducing the number of patients needing orthopedic footwear, and resuming pre-injury activities. Surgical management of DIACF was associated with a higher risk of complications (22.8% versus 16.2%, p=0.008), while function continued to deteriorate over long-term follow-up in conservative treatment. The authors concluded that surgery can effectively restore the anatomical structures of the calcaneus with better functional recovery, despite a high risk of complications [5, 46].

In a systematic review published in 2013, Veltman E. and co-authors evaluated 25 studies with a total of 1,730 calcaneal fractures and an average follow-up of 4.6 years. The studies reported functional, subjective, and radiographic outcomes following surgical or conservative treatment. The authors support surgical treatment of DIACF with ORIF as the method of choice [5, 47].

Wei N. and co-authors conducted a systematic literature review and meta-analysis published in 2017 that assessed the efficacy of surgical and non-operative management of DIACF. The analysis included 18 studies (8 randomized controlled trials and 10 controlled clinical studies) involving 1,467 patients. The authors concluded that surgical treatment of DIACF, compared with conservative treatment, may increase complication incidence but provides significantly better anatomic recovery, including restoration of Bohler's angle, calcaneal height, and width, and a higher likelihood of resuming previous professional activities [48]. Another similar and more recent systematic literature review and meta-analysis, published in 2022, included 13 studies, including 10 randomized controlled trials and 3 prospective clinical studies with 1,251 patients. The study found that the best available evidence at that time favored an advantage for operative treatment. Fewer footwear issues and a higher likelihood of returning to the desired activity level were observed in surgically treated patients [13].

The clinical significance of these findings is that surgical treatment should be recommended for DIACF, as it can better restore calcaneal anatomy, improve functional recovery, and increase the likelihood of returning to previous activity levels compared to conservative treatment [48]. A prospective, case-control, and prognostic study revealed that if severe post-traumatic subtalar arthritis does not develop, long-term functional outcomes (10–20 years) with mild pain, minimal changes in daily or professional activities, and normal footwear use are favorable results of ORIF via ELLA [49].

Therefore, ORIF can be performed through various approaches (lateral, medial, plantar, posterior, or combined), including minimally invasive options. ELLA has been the most popular technique, considered since the 1990s as the "gold standard" in treating DIACF. It offers wide and precise exposure of fracture fragments and the subtalar and calcaneo-cuboid joints, easier decompression of the lateral wall, and sufficient lateral space for plates of various shapes. With delicate soft tissue management in mind, particular attention is given to creating full-thickness flaps and using the "no-touch" technique. However, this method is associated with soft tissue complications (wound edge dehiscence or necrosis, superficial or deep infection, hematoma, sural nerve injury, peroneal tendon injuries or displacement, and subtalar arthritis), with complication rates ranging from 5.8% to 43%. Despite this, the ability of ORIF to directly visualize the posterior facet, the advantages of achieving better restoration, and the re-establishment of anatomical parameters (length, width, height, and calcaneal alignment) outweigh the increased complication risk.

Minimally invasive surgical treatment

Although ORIF for DIACF is favored by many authors, the increased risk of soft tissue complications makes this treatment method challenging, especially for patients who smoke or have diabetes. This may explain the growing use of minimally invasive techniques in managing intra-articular calcaneal fractures [3, 18, 24, 32].

Several minimally invasive surgical techniques have been developed for patients with calcaneal fractures to achieve good reductions, favorable clinical and radiographic outcomes, and lower complication rates, particularly for soft tissue complications. These techniques include percutaneous reduction and external fixation, arthroscopically assisted percutaneous reduction and fixation, surgery guided by a three-dimensional model or 3D printing of the fracture, calcaneoplasty, and open fixation via mini incisions. Minimally invasive techniques are more reliable when performed within the first 2 weeks after the fracture, as the fracture fragments are easier to manipulate during this period [8-11, 15, 22, 26, 31, 34, 37]. Some percutaneous techniques are used to realign the calcaneus with minimal tissue dissection and can be performed immediately after injury in cases of extensive soft tissue edema [34, 50].

The primary indications for using minimally invasive approaches in the surgical treatment of calcaneal fractures include fewer complex fractures, minimally fragmented posterior facet fractures, displaced Essex-Lopresti fractures, Sanders type II and III fractures in patients with multiple comorbidities, and those at high risk for significant postoperative wound complications [14, 24, 30, 50]. Recent prospective and retrospective studies, systematic reviews, and meta-analyses have shown promising results with minimally invasive techniques in terms of reducing preoperative time, surgery duration, hospital stay, and complication rates [8-11, 22, 26, 27, 34, 37, 45].

The sinus tarsi approach (STA) is used in minimally invasive reduction and percutaneous fixation of DIACF fragments. This technique, suitable for simple calcaneal fractures, allows a direct visualization of the subtalar joint surface and the exposure of the calcaneal joint by extending the incision if necessary. Additionally, locking plates can be introduced through STA to achieve firm fixation while minimizing soft tissue damage. Patients with diabetes, smokers, and those with comorbidities, who are at risk of wound healing complications, may benefit from minimally invasive techniques, especially STA. Furthermore, STA is the most

cost-effective treatment option for Sanders type II-III DIACF [1, 21, 22, 34, 36, 42, 45].

A comparison of two internal fixation techniques—cannulated screw fixation and plate with screws using STA showed no statistically significant difference in restoring, correcting, and maintaining Bohler and Gissane angles over time, radiographic parameters, or postoperative complication rates. Thus, both fixation methods are equally effective in restoring and maintaining Bohler and Gissane angles with a lower complication rate compared to ELLA. The implant costs and implant removal rate were significantly higher with the minimally invasive plate application [51].

A systematic literature review, three prospective, randomized controlled trials, and three retrospective studies were conducted to compare ORIF with minimally invasive reduction and percutaneous fixation for Sanders type II, III, or IV DIACF. No statistically significant difference was found between ORIF and percutaneous fixation groups regarding anatomical reduction, functional outcomes, or the need for revision surgery. The minimally invasive method was associated with the ability to perform the procedure immediately without waiting for soft tissue stabilization, significantly shorter surgery and hospital stay, lower rates of postoperative pain syndrome and wound complications, reduced subtalar joint stiffness, faster postoperative rehabilitation, better functional outcomes, and an earlier return to work [24, 34].

Researchers concluded that both techniques – percutaneous reduction and fixation and ORIF – can be considered for the surgical treatment of DIACF, as both are capable of restoring Bohler's angle and have relatively good long-term functional outcomes. Indications for each technique may vary among surgeons, and each has its own set of risk factors and complications; however, both have been shown acceptable reduction outcomes [24].

Four meta-analyses, published in 2017 and 2018, along with other prospective and retrospective cohort studies, suggest that the minimally invasive approach with STA and the extended lateral L-shaped approach (ELLA) are equally effective in treating Sanders type II and III fractures in terms of anatomical structure restoration, radiological outcomes, and functional recovery. However, STA has shown effectiveness in reducing wound complication rates (3.6–6.3% vs. 13.5–31.2%, respectively; $p < 0.05$), rates of pain syndrome, time to surgery ($p < 0.0001$), surgery duration ($p < 0.05$), and length of hospital stay [52-54]. Despite this, heterogeneity among studies and errors in including certain publications have raised doubts about the reliability of these conclusions [38].

A recent meta-analysis published in 2020, which included 17 randomized controlled trials and 10 retrospective studies with 2,179 patients and 2,274 DIACF cases monitored for an average of 22.41 months, evaluated the effectiveness of the minimally invasive incision approach and standard ELLA. Overall, results showed no statistically significant difference in Gissane's angle, calcaneal width and length, deep infection, or subtalar joint stiffness. When only randomized controlled trials were analyzed, there were no statistically significant differences between groups regarding Bohler's or Gissane's angles. A statistically significant difference was observed in wound complication rates, superficial wound infection, sural nerve injuries, AOFAS scores, time to surgery, surgery duration, calcaneal height, and postoperative Bohler's angle (when all studies were considered), all in favor of the minimally invasive incision approach. These results remained statistically significant when only randomized controlled trials were compared, except for Bohler's angle and AOFAS scores. This meta-analysis indicates that the minimally invasive incision approach is a good alternative to standard ELLA [33].

A more recent meta-analysis, published in 2021, found no differences in anatomical structure restoration, functional recovery, and clinical efficacy of DIACF treatment between STA and ELLA [55].

However, two retrospective cohort studies published in 2020 and 2021, along with three more recent meta-analyses from 2020 and 2021 that updated the literature and excluded inadequate studies previously included in meta-analyses, found that STA, compared to ELLA, is superior for treating calcaneal fractures due to improved anatomical reduction of the calcaneus, lower incidence of wound complications ($p < 0.001$), shorter preoperative time, reduced operative time ($p < 0.001$), shorter hospital stay ($p=0.002$), lower rates of secondary surgeries, and faster wound healing. There was no statistical difference in Bohler and Gissane angles, but better foot function scores according to AOFAS and Maryland scores which were significantly higher in the STA group ($p < 0.01$). Therefore, STA was identified as a superior alternative for DIACF treatment [38, 56].

Two recent systematic literature reviews and meta-analyses published in 2023 analyzed 59 studies with over 10,000 calcaneal fractures and 13 studies with 897 patients with calcaneal fractures. According to the results, most researchers agree on the superiority of surgical treatments for calcaneal fractures compared to conservative ones. Furthermore, minimally invasive access to the sinus tarsi showed better outcomes and lower complication rates than traditional ELLA, as it uses a smaller incision and involves less extensive tissue manipulation. In general, reduction and osteosynthesis with percutaneous and/or minimally invasive techniques offer better outcomes compared to open treatments, even when open reduction is contraindicated [12, 45].

Thus, minimally invasive techniques yield clinical and radiographic outcomes similar to ELLA but with lower wound complication rates for all DIACF types. There is no statistically significant difference between the two groups in terms of restoring anatomical structures, although some surgeons consider posterior facet restoration more challenging with the minimally invasive approach.

There is no universally applicable treatment method for all calcaneal fractures. The consensus among most researchers is as follows: 1) surgical treatment is superior to conservative treatment; 2) minimally invasive access via

STA provides better results and fewer complications than traditional ELLA; 3) reduction and osteosynthesis with percutaneous and/or minimally invasive techniques appear to offer better outcomes than open treatments. Therefore, the current concept in managing calcaneal fractures involves developing an individualized treatment plan based on the patient's characteristics and functional requirements, comorbidities, fracture type, associated injuries, and the surgeon's experience with the selected surgical technique. New technologies may improve calcaneal fracture management [5, 6, 12, 13, 45, 49].

Recent studies, systematic literature reviews, and meta-analyses have shown promising results with minimally invasive techniques in the treatment of Sanders type II, III, and IV DIACF. Although both surgical interventions are effective, the sinus tarsi approach (STA) in the treatment of calcaneal fractures has proven to be significantly safer and more effective, with similar functional and radiological outcomes but lower postoperative complication rates compared to ELLA. The advantages of this treatment method include a much shorter time from fracture to fixation (often 2–3 days), reduced intraoperative bleeding, higher mean AOFAS scores, lower postoperative complication rates, including wound complications, shorter operative time, much earlier active mobilization, shorter hospital stay and recovery periods, and a lower rate of secondary surgeries [15, 22, 32, 34, 36, 45, 51]. Therefore, the minimally invasive sinus tarsi approach is becoming the new "gold standard" in DIACF treatment [14, 37].

According to contemporary guidelines and the views of many researchers, patients with non-displaced Sanders type I and II calcaneal fractures should be treated conservatively. Sanders type II and III DIACF should be treated surgically. There remains debate regarding the treatment method for Sanders type IV fractures, which can be managed surgically or conservatively; however, this group of patients tends to have poor outcomes even after open reduction. Some patients with subtalar arthritis may require subtalar or triple arthrodesis (subtalar, talonavicular, and calcaneocuboid). Despite these general treatment principles, the treatment strategy should be individually tailored on a case-by-case basis, as various factors influence complication development in calcaneal fractures [35, 42].

Conclusions

(1) Over the past two decades, surgical management of calcaneal fractures has become increasingly preferred over conservative management. With advances in surgical techniques and biomechanics, surgical treatment is now the first-line choice for calcaneal fractures, aimed at reducing bone fragments, achieving joint congruence, and stable fixation with early mobilization.

(2) Surgical treatment through open reduction and internal fixation for displaced intra-articular calcaneal fractures has proven superior to non-surgical treatment in restoring Bohler's angle, achieving more stable calcaneal height and width, improving functional recovery, reducing the number of patients requiring orthopedic footwear, and facilitating the resumption of pre-injury activities, though there is a high risk of complications.

(3) The decision to perform surgery is based on three main criteria: displacement or comminution of the posterior facet; the patient's age and contraindications for surgery; and soft tissue trauma and associated injuries, which may influence the timing of surgery and the choice of surgical technique.

(4) The minimally invasive surgical method allows for immediate intervention without waiting for soft tissue consolidation, significantly shorter operative and hospitalization times, reduced rates of postoperative pain syndrome and wound complications, decreased subtalar joint stiffness, faster postoperative rehabilitation with better functional outcomes, and an earlier return to professional activity.

(5) The minimally invasive sinus tarsi approach and the extended lateral L-shaped approach are equally effective for treating Sanders type II and III fractures in terms of anatomical restoration, radiological outcomes, and functional recovery. However, the sinus tarsi approach is more effective in reducing wound complication rates (3.6–6.3% vs. 13.5–31.2%; $p < 0.05$) and rates of pain syndrome, reducing time to surgery ($p < 0.0001$), operative duration ($p < 0.05$), and hospital stay. Thus, the minimal incision approach is a good alternative to the extended lateral L-shaped approach.

(6) The current concept in managing calcaneal fractures involves developing an individualized treatment plan based on the patient's characteristics and functional requirements, comorbidities, fracture type, associated injuries, and the surgeon's experience with the selected surgical technique.

Competing interests

None declared.

Ethics approval

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