

Systematic Review

The Impact of Surgical Timing and Surgical Approach on Outcomes Following Calcaneal Fractures: A Systematic Review

Lorenza Siracusano ¹, Giulia Salvatorelli ², Ilaria Sanzarelli ^{1,*}, Gabriele Di Carlo ¹, Matteo Nanni ¹, Giuseppe Francesco Papalia ^{3,4}, Angela Alibrandi ⁵, Biagio Zampogna ^{3,6} and Danilo Leonetti ¹

- ¹ Department of Biomedical and Dental Sciences and Morphological and Functional Imaging, Section of Orthopaedic and Trauma Surgery, A.O.U. Policlinico "G. Martino", University of Messina, 98124 Messina, Italy; lorenza.siracusano@studenti.unime.it (L.S.); gabriele.dicarlo@polime.it (G.D.C.); matteo.nanni@unime.it (M.N.); dleonetti@unime.it (D.L.)
- ² Minimally Invasive Orthopaedics Surgery Unit, Department of Life Health & Environmental Sciences, University of L'Aquila, 67100 L'Aquila, Italy; giulia.salvatorelli@graduate.univaq.it
- ³ Operative Research Unit of Orthopaedic and Trauma Surgery, Fondazione Policlinico Universitario Campus Bio-Medico, 00128 Rome, Italy; biagio.zampogna@unime.it (B.Z.)
- ⁴ Oncological Orthopaedics Department IFO, IRCCS Regina Elena National Cancer Institute, 00144 Rome, Italy
- ⁵ Department of Human Pathology of Adults and Developmental Age "G. Barresi", University of Messina, 98124 Messina, Italy; angela.alibrandi@unime.it
- ⁶ Research Unit of Orthopaedic and Trauma Surgery, Department of Medicine and Surgery, Università Campus Bio-Medico Di Roma, 00128 Rome, Italy
- * Correspondence: ilaria.sanzarelli@unime.it

Abstract

Introduction: Displaced intra-articular calcaneal fractures (DIACFs) are associated with a high incidence of wound complications. Minimally invasive approaches (MIAs) have enabled earlier intervention compared with the extensile lateral approach (ELA). However, the relationship between surgical timing, approach and outcome remains poorly defined. This systematic review evaluated the relationship between surgical timing, approach, and postoperative outcomes in DIACFs. **Materials and Methods:** A systematic review was conducted in accordance with the PRISMA 2020 guidelines. Studies published between January 1990 and April 2026 were searched through PubMed, Embase and Web of Science. Studies reporting the timing to surgery, approach, and postoperative outcomes in operated DIACFs were included. Patients were stratified into three groups according to timing (0–7 days, 8–21 days, and >21 days). Complication rates, radiographic and functional outcomes were analyzed. **Results:** A total of 25 studies, encompassing 1915 patients, were included. Patients mostly underwent surgery within seven days (60.1%), followed by 8–21 days (37.8%) and >21 days (2.1%). The complication rate was 21.7%, with wound dehiscence (8.9%) and infection (5.2%) being the most prevalent. Dehiscence and necrosis were predominantly associated with the ELA, particularly between days 8–21. Infection rates increased when the delayed sinus tarsi approach was used. No differences were found in radiographic or functional outcomes. **Conclusions:** Surgical timing does not appear to be an independent outcomes predictor. Complications depend on the interplay of timing, approach, and soft-tissue condition. An individualized treatment, with no rigid temporal thresholds, is probably the best approach.

Keywords: calcaneal fractures; timing to surgery; sinus tarsi approach; extended lateral approach; wound-related complications



Academic Editor: Claudio Belvedere

Received: 7 June 2026

Revised: 24 July 2026

Accepted: 27 July 2026

Published: 30 July 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article

distributed under the terms and

conditions of the [Creative Commons](#)

[Attribution \(CC BY\)](#) license.

1. Introduction

Calcaneus fractures account for 2% of all fractures and 50–60% of fractures of the tarsal bones, 75% of which are intra-articular [1,2]. They mostly affect people of working age (30–60 years), representing a socio-economic burden given that the average time to return to work is one year, although it can last up to three years [3,4]. These fractures are associated with a high risk of early postoperative complications, specifically infection and, above all, wound healing issues affecting up to 25% of patients, and late complications, such as chronic pain, stiffness, osteoarthritis, and hindfoot deformities requiring subsequent arthrodesis [5]. Over the last decade, much has been discussed on the most optimal strategy for reducing early and late postoperative complications, including the type of fixation and surgical approach. However, there is still no standard of care, and controversy exists regarding the most effective treatment method for displaced intra-articular fractures of the calcaneus (DIACFs) [6]. The extended lateral approach (ELA) historically required resolution of soft-tissue swelling and the appearance of skin wrinkling, the so-called ‘wrinkle sign’, before surgery could safely be performed, typically necessitating a delay of 7 to up to 21 days from injury [5,7]. Despite this precaution, the ELA has been associated with wound complication rates ranging from 13% to over 37% [8–11]. The sinus tarsi approach (STA) and other minimally invasive approaches (MIAs), such as the percutaneous, have been introduced to reduce wound complications and enable earlier surgery, with a mean time to operating room of approximately 6 days for the STA versus 13 days for the ELA [12,13]. A recent systematic review and meta-analysis confirmed that the STA significantly reduces wound healing complications compared to the ELA, with comparable radiographic and functional outcomes in Sanders type II and III fractures [10,14]. However, the literature agrees that the STA is comparable to the ELA in terms of quality of reduction, but only in the hands of experienced surgeons [15]. Despite this shift in practice, the relationship between surgical timing and outcome remains poorly defined and contradictory across the literature. Alajmi et al. reported a significant correlation between delay time and complication incidence following the STA [16]. Basile et al. found no significant difference in wound complications or quality of reduction when STA fixation was performed within versus beyond 21 days in polytrauma patients [17]. Additionally, Swords et al. demonstrated that ORIF via the ELA performed more than 25 days after injury can still achieve satisfactory anatomical reduction and acceptable functional outcomes with low complication rates [18]. These conflicting findings reflect a fundamental gap in the literature: while timing has long been regarded as an intrinsic advantage of minimally invasive approaches over the ELA, it has never been systematically evaluated as an independent predictor of DIACF outcomes across different fixation techniques and surgical approaches. This systematic review aims to evaluate the role of surgical timing in the outcomes of DIACFs, examining complication rates and radiographic and functional outcomes in relation to time from injury to surgery, accounting for the surgical approach. The present study hypothesized that the influence of surgical timing on postoperative complications differs according to the surgical approach. Specifically, we hypothesized that delaying surgery after injury may reduce wound-related complications when using the extensile lateral approach, whereas surgical timing may have a less pronounced impact on outcomes following minimally invasive approaches.

2. Materials and Methods

2.1. Eligibility Criteria

All the clinical studies investigating treatment and outcomes of DIACFs specifying the timing from trauma to surgery were accessed. Only studies published in peer-reviewed journals, from 1990 onwards, were considered. Studies with levels I, II, and III of evidence, according to the Oxford Centre of Evidence-Based Medicine, were considered [19]. Non-

English language studies, reviews, opinions, letters, and editorials were not considered. Animal, in vitro, biomechanic, computational, and cadaveric studies were not eligible. Studies were eligible for inclusion if they met all of the following criteria: 1) regarded adult patients (≥ 18 years) with a displaced intra-articular calcaneal fracture, managed operatively; 2) had explicit reporting of the timing from trauma to surgery and the type of surgical approach adopted; 3) had a minimum clinical and radiological follow-up period of 6 months; and 4) reported early postoperative outcomes and complications, specifically the incidence and type of wound-related complications. Missing quantitative data under the outcomes of interests warranted the exclusion of the study.

2.2. Search Strategy

This study was conducted according to the 2020 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and the recommendations of the Cochrane Handbook for Systematic Reviews of Interventions [20,21]. The study protocol and supporting methodological documentation were retrospectively deposited in the Open Science Framework (OSF) and are publicly available at <https://osf.io/9usph> (accessed on 25 June 2026). The PICO algorithm was preliminarily established:

- P (Population/Problem): Patients (≥ 18 years) with displaced intra-articular calcaneal fracture treated surgically.
- I (Intervention): Surgical fixation of displaced intra-articular calcaneal fractures performed at different time intervals after injury, 0–7 days, 8–21 days, and >21 days, using either the extensile lateral approach or minimally invasive approach.
- C (Comparison): The complication rate for fixation using the ELA or MIAs, including the sinus tarsi and the percutaneous approaches, across the timing subgroups.
- (Outcomes): Primary outcome: Clinical outcome and wound-related complications according to time to surgery and surgical approach. Secondary outcome: Radiographic outcomes according to time to surgery and surgical approach.

In April 2026, the following databases were accessed: PubMed, Web of Science, and Embase. For PubMed, a search strategy with Medical Subject Headings (MeSH) terms as the core was designed, supplemented by free-text terms in the Title/Abstract fields to avoid missing relevant studies. The core MeSH search was: (“Calcaneus/injuries”[Mesh] OR “Calcaneus/surgery”[Mesh]). The supplementary free-text search was: ((calcaneus[Title/Abstract] OR calcaneal[Title/Abstract]) AND (fracture*[Title/Abstract] OR “intra-articular”[Title/Abstract] OR displaced[Title/Abstract]) AND (surg*[Title/Abstract] OR operati*[Title/Abstract] OR fixation[Title/Abstract])). The free search included terms such as calcaneus, fractures, surgical treatment, timing to surgery, complications, wound healing, early fixation and delayed fixation. The two searches were combined with OR, and a publication date filter from January 1990 to April 2026 was applied. As Web of Science does not provide a MeSH vocabulary, free words were used for searching in titles, abstracts, and keywords with selected indexed terms when applicable. A combination of terms such as calcaneal fractures, surgical treatment, timing to surgery, complications, wound healing, early fixation and delayed fixation were used.

For Embase, the search strategy combined Emtree-controlled vocabulary with free-text keywords searched within the title and abstract fields, using a search strategy equivalent to that applied in PubMed.

2.3. Selection and Data Collection

The retrieved records were exported and duplicates were removed. Two authors (LS and GS) independently screened titles and abstracts; the full texts of potentially relevant studies were then assessed against the inclusion and exclusion criteria. Disagreements

were resolved by a senior author (DL). A cross-reference check of the included studies was performed to identify additional relevant papers.

2.4. Data Items

Two authors (LS and GS) independently extracted the data, with disagreements resolved by the senior author (DL). For each study, the following parameters were collected: author, year and journal of publication, study design, level of evidence (LoE) and length of the follow-up (months). The following data at baseline were retrieved: number of patients initially included, patients deceased or lost to follow-up, mean age at the time of surgery and mean body mass index (BMI) at the time of surgery. Outcome-related data was collected: fracture type according to the Sanders classification [22], time from trauma to surgery and the surgical approach adopted. Patients were categorized post hoc into three subgroups according to the time-to-surgery ranges reported in the original studies: within 0–7 days, 8–21 days, or >21 days from trauma. When available, fixation characteristics (type of plate and screws, screw configuration and postoperative instructions) were also collected. Finally, postoperative clinical (AOFAS score) [23] and radiological outcomes, complications and re-interventions were recorded, with emphasis on wound-healing complications and also on sural nerve and peroneal tendon injury, deep infection, implant failure, malunion and non-union. A superficial infection was defined as a wound which showed signs of infection, including erythema and discharge, but which responded to antibiotic treatment with no surgery being required. A deep infection was defined as an infection which required surgical intervention, regardless of the type of surgery. Data extraction was performed using Microsoft Office Excel version 16.0 (Microsoft Corporation, Redmond, WA, USA).

2.5. Methodological Quality Assessment and Quality of the Recommendations

Risk of bias was assessed independently by two authors (LS and GS), with disagreements resolved by the senior author (DL). The Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool was used to assess the risk of bias in non-randomized controlled trials (RCTs) [24]. The following biases were evaluated in seven different domains: bias due to confounding factors and due to patient selection; bias in the classification of interventions; bias due to missing data; deviation from intended interventions; erroneous measurement of outcomes; and bias in the selection of reported outcomes. The Risk of Bias 2 (RoB 2) tool was used to assess the risk of bias in RCTs. The following endpoints were evaluated: randomization process, deviation from intended intervention, missing data, outcome measurement, and bias in the selection of reported outcomes [25].

2.6. Synthesis Methods

All statistical analyses were performed using IBM SPSS for Windows, Version 26 (IBM Corp., Armonk, NY, USA). Descriptive statistics were performed for all demographic and surgical variables. Continuous data were reported as means and standard deviations (SDs), whereas categorical data were expressed as absolute numbers and percentages. The non-parametric approach was used since the numerical variables were not normally distributed, verified by Kolmogorov–Smirnov test. Comparisons in order to identify possible significant differences between the time subgroups were conducted using the Kruskal–Wallis test for continuous parameters and the chi square test for categorical variables. Statistical significance was defined as $p < 0.05$. All analyses were performed at the study level on pooled aggregated data; the complication and outcome counts reported by each study were summed within the relevant timing and approach subgroups.

3. Results

3.1. Study Selection

The systematic literature search identified 12,076 articles. After removing duplicates and screening the titles and abstracts, 5544 articles were assessed for eligibility. Of these, 5422 were excluded for not meeting the predefined study design criteria or due to unavailability of the full text. Of the remaining 122 studies, a further 54 were excluded. A final selection of 68 reports were assessed for eligibility. Ultimately, only 25 studies were included in this systematic review. The results of the literature search are shown in Figure 1.

In patients with displaced intra-articular calcaneus fractures, how does the timing, in relation to the surgical approach, influence outcomes?
 * Title and abstract screening; Full text screening: papers unavailable, written in a language other than English, or that do not meet the predefined study design criteria.

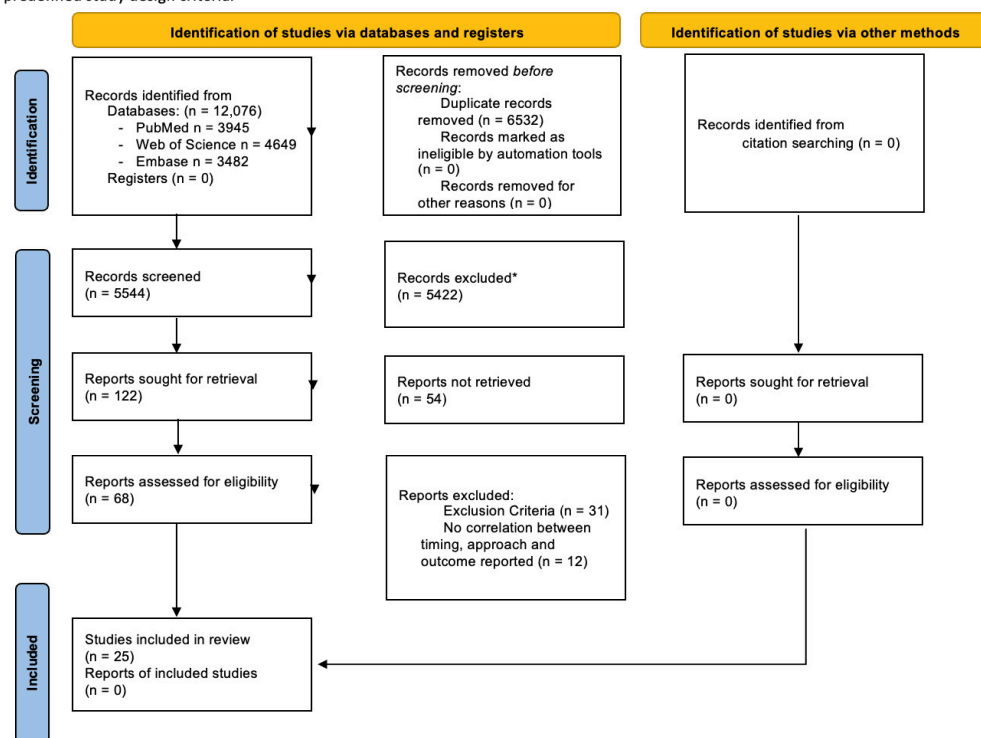


Figure 1. PRISMA flow chart of the literature search.

3.2. Methodological Quality Assessment

Risk of bias in the 20 non-RCTs was assessed with ROBINS-I (Table 1). Confounding was rated serious in six of the 20 studies, owing chiefly to the absence of demographic risk-factor data such as smoking status and diabetes; no study was at serious risk from selection, classification of interventions or from deviations from intended interventions. Missing data were rated low in 14 studies and moderate in six. Overall, six of the 20 non-RCTs (30%) were at serious risk of bias and the remaining 17 at moderate risk, indicating reduced methodological quality. The five RCTs were assessed with RoB 2 (Table 2); concerns arose mainly from measurement of the outcomes and selection of the reported results, yielding an overall rating of “some concerns” in all the studies (80%).

Table 1. Risk of bias assessment of the non-RCTs (ROBINS-I).

Study	D1 Confounding	D2 Selection	D3 Classification	D4 Deviations	D5 Missing Data	D6 Measurement	D7 Reported Result	Overall
Ahmed et al. 2025 [26]	Moderate	Low	Low	Low	Low	Low	Moderate	Moderate
Basile et al. 2023 [17]	Moderate	Low	Low	Low	Low	Moderate	Moderate	Moderate
Cao et al. 2015 [27]	Moderate	Low	Low	Low	Low	Low	Moderate	Moderate
Cho et al. 2021 [28]	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate	Moderate
Chotikkakamthorn et al. 2021 [29]	Serious	Moderate	Low	Low	Low	Low	Moderate	Serious

Table 1. Cont.

Study	D1 Confounding	D2 Selection	D3 Classification	D4 Deviations	D5 Missing Data	D6 Measurement	D7 Reported Result	Overall
Court-Brown et al. 2009 [30]	Serious	Low	Low	Low	Moderate	Low	Moderate	Serious
Cursaru et al. 2022 [31]	Serious	Low	Low	Low	Low	Moderate	Moderate	Serious
Esenkaya et al. 2018 [32]	Moderate	Low	Low	Low	Low	Moderate	Moderate	Moderate
Jansen et al. 2018 [33]	Moderate	Low	Low	Low	Low	Moderate	Moderate	Moderate
Kwon et al. 2015 [34]	Moderate	Low	Low	Low	Moderate	Moderate	Moderate	Moderate
Liao et al. 2025 [35]	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate	Moderate
Peng et al. 2019 [36]	Serious	Low	Low	Low	Low	Moderate	Moderate	Serious
Schepers et al. 2017 [37]	Serious	Low	Low	Low	Low	Moderate	Moderate	Serious
Shams et al. 2023 [38]	Moderate	Low	Low	Low	Low	Moderate	Moderate	Moderate
Shih et al. 2018 [39]	Moderate	Low	Low	Low	Low	Moderate	Moderate	Moderate
Swords et al. 2020 [18]	Moderate	Low	Low	Low	Moderate	Moderate	Moderate	Moderate
Sypien & Grzelecki 2025 [40]	Moderate	Low	Low	Low	Low	Moderate	Moderate	Moderate
Usami et al. 2023 [41]	Moderate	Low	Low	Low	Low	Moderate	Moderate	Moderate
Weng et al. 2020 [42]	Moderate	Moderate	Low	Low	Low	Moderate	Moderate	Moderate
Zhao et al. 2022 [43]	Serious	Moderate	Low	Low	Moderate	Moderate	Moderate	Serious

Table 2. Risk-of-bias assessment of the RCTs (RoB 2).

Study	D1 Randomization	D2 Deviations	D3 Missing Data	D4 Measurement	D5 Reported Result	Overall
Ebrahimpour et al. 2021 [44]	Some concerns	Some concerns	Low	Some concerns	Some concerns	Some concerns
Feng et al. 2016 [45]	Some concerns	Some concerns	Low	Some concerns	Some concerns	Some concerns
Kir et al. 2018 [46]	Some concerns	Some concerns	Low	Some concerns	Some concerns	Some concerns
Li et al. 2018 [47]	Low	Low	Low	Low	Some concerns	Some concerns
Wang et al. 2020 [48]	Some concerns	Some concerns	Low	Some concerns	Some concerns	Some concerns

3.3. Study Characteristics and Results of Individual Studies

A final cohort of 1915 patients treated for DIACFs was included in the analysis. The mean age of the cohort was 42.77 ± 5.04 years, reflecting the typical distribution of these injuries in middle-aged adults. The mean follow-up time was 24.65 months. Table 3 presents the general characteristics and demographics of the included studies.

Table 3. Characteristics and baseline demographics of the included studies (LoE: level of evidence; MoI: mechanism of injury; FFH: fall from height; RTA: road traffic accident; SI: sport injury; other).

Author, Year	DOI	Journal	LoE	Patients (n)	Mean Age (y)	Mean BMI (kg/m ²)	MoI
Ahmed et al. 2025 [26]	10.7417/CT.2025.5196	Clin Ter	3	21	34.1	N/A	FFH; RTA
Basile et al. 2023 [17]	10.3390/jcm12052039	J Clin Med	2	54	38.35	24.84	N/A
Cao et al. 2015 [27]	10.1053/j.jfas.2014.09.003	J Foot Ankle Surg	3	33	36	N/A	FFH; RTA; SI
Cho et al. 2021 [28]	10.3390/ijerph181910400	Int J Environ Res	3	25	55.84	23.45 $\pm$ 2.55	FFH; RTA
Chotikkakamthorn et al. 2021 [29]	10.5152/j.aott.2021.20003	Acta Orthop Traumatol Turc	3	42	43.4	23.2	N/A
Court-Brown et al. 2009 [30]	10.1016/j.injury.2009.03.044	Injury	4	178	41	N/A	N/A
Cursaru et al. 2022 [31]	10.3892/etm.2022.11119	Exp Ther Med	4	60	46.8	N/A	N/A

Table 3. Cont.

Author, Year	DOI	Journal	LoE	Patients (n)	Mean Age (y)	Mean BMI (kg/m ²)	MoI
Ebrahimpour et al. 2021 [44]	10.1007/s12306-019-00635-w	Musculoskelet Surg	3	88	41.11	N/A	FFH; RTA; Other
Esenkaya et al. 2018 [32]	10.5505/tjtes.2017.62355	Ulus Travma Acil Cerrahi Derg	3	14	44.12	N/A	N/A
Feng et al. 2016 [45]	10.1186/s12891-016-1122-8	BMC Musculoskelet Disord	1	80	39.5	N/A	N/A
Jansen et al. 2018 [33]	10.1053/j.jfas.2018.05.015	J Foot Ankle Surg	3	64	50	N/A	N/A
Kir et al. 2018 [46]	10.1177/2309499018792742	J Orthop Surg	2	60	39.2	N/A	FFH; RTA
Kwon et al. 2015 [34]	10.1177/1071100714552483	Foot Ankle Int	3	405	45	N/A	N/A
Li et al. 2018 [47]	10.1177/1071100718774808	Foot Ankle Int	3	52	43	N/A	FFH
Liao et al. 2025 [35]	10.1016/j.injury.2025.112896	Injury	2	133	36.4	23.1	FFH; RTA
Peng et al. 2019 [36]	10.1186/s13018-019-1162-5	J Orthop Surg Res	3	40	39.94	N/A	N/A
Schepers et al. 2017 [37]	10.1097/BOT.0000000000000819	J Orthop Trauma	3	125	46.96	N/A	N/A
Shams et al. 2023 [38]	10.1177/1938640020987750	Foot Ankle Spec	3	70	34.3	N/A	FFH
Shih et al. 2018 [39]	10.1186/s12891-018-1995-9	BMC Musculoskelet Disord	4	20	50	N/A	N/A
Swords et al. 2020 [18]	10.1097/BOT.0000000000001694	J Orthop Trauma	4	20	39.8	N/A	FFH
Sypien & Grzelecki 2025 [40]	10.3390/jcm14041369	J Clin Med	4	48	57	26.35	FFH
Usami et al. 2023 [41]	10.1016/j.heliyon.2023.e14046	Heliyon	4	45	51	N/A	N/A
Wang et al. 2020 [48]	10.1016/j.biopha.2020.110295	Biomed Pharmacother	2	35	40.1	N/A	FFH; RTA; Other
Weng et al. 2020 [42]	10.1111/os.12597	Orthop Surg	3	150	39	N/A	FFH; RTA
Zhao et al. 2022 [43]	10.1097/MD.00000000000030847	Medicine	3	52	46.03	N/A	FFH

3.4. Results Synthesis

The analysis included a total of 1915 patients who had been treated for displaced intra-articular calcaneus fractures. The mean time from trauma to surgery could be extracted for 1280 patients and was 6.47 ± 5.78 days (0–35 days). For the remaining 635 patients, individual timing data or a study-level overall mean were not reported. However, these patients were presented within predefined timing groups in the original studies, each characterized by a reported mean time to surgery and an associated time range or interval. Because these reported intervals were fully consistent with the timing categories adopted in the present review, patients were assigned to the corresponding timing subgroup according to the classification provided by the original authors. Therefore, allocation was based on reported group-level timing data. Overall, the majority of patients were treated within seven days of injury (60.1%, $n = 1151$). A total of 37.8% ($n = 724$) fell into the 8–21-day subgroup and only 2.1% ($n = 40$) into the >21-day subgroup. Age differed significantly across timing subgroups ($p < 0.001$); the 8–21-day subgroup was the oldest (0–7 days, 41.4 ± 5.4 y; 8–21 days, 45.2 ± 3.2 y; >21 days, 39.1 ± 0.7 y). Surgical approaches were distributed as follows: the ELA was used in 36.7% of patients ($n = 703$), the STA in 46.4% of cases ($n = 889$), and a percutaneous approach in 16.9% of cases ($n = 323$). The distribution of approaches differed significantly across timing subgroups: the proportion treated with the ELA was the lowest in the 0–7-day subgroup, and the percutaneous approach was used exclusively within 7 days. The distribution of approaches across the timing subgroups is shown in Table 4.

Table 4. Surgical approaches stratified by timing subgroup, n (% within timing subgroup). ELA = extensile lateral approach; STA = sinus tarsi approach.

Surgical Approach	0–7 Days	8–21 Days	>21 Days	Total
ELA	279 (24.2%)	404 (55.8%)	20 (50.0%)	703 (36.7%)
STA	549 (47.7%)	320 (44.2%)	20 (50.0%)	889 (46.4%)
Percutaneous	323 (28.1%)	0 (0.0%)	0 (0.0%)	323 (16.9%)
Total	1151 (100%)	724 (100%)	40 (100%)	1915 (100%)

Internal fixation with screws, plates or K-wires was used in 98.2% of cases (n = 1881) and primary arthrodesis in 1.0% (n = 19); the treatment was not specified in the remaining 0.8% (n = 15). A fixation sub-analysis was not possible because (1) the fixation strategy was not specified in four studies [18,31,33,37] and (2) the specific type of implant was not reported in any included study. Primary arthrodesis versus internal fixation did not differ across timing subgroups.

The overall complication rate was 21.7% (416 events in 1915 patients). Wound dehiscence and necrosis were observed in 8.9% (n = 170) and 1.6% (n = 31) of patients, respectively. The most common complications were wound dehiscence (8.9%, n = 170), infection (5.2%, n = 100) and wound necrosis (1.6%, n = 31). Other complications were malunion (1.1%), sural nerve injury (0.9%), osteoarthritis (0.8%), implant failure (0.6%), peroneal tendon injury (0.4%), residual pain (0.3%) and non-union (0.1%). A rate of 1.8% for miscellaneous complications was also recorded, including tarsal tunnel syndrome, algodystrophy, and lateral impingement. Table 5 presents a summary of population complications.

Table 5. Overall complications among the population.

Complication	Patients (n)	Percentage (%)
Wound dehiscence	170	8.9
Wound necrosis	31	1.6
Infection	100	5.2
Sural nerve injury	17	0.9
Peroneal tendon injury	8	0.4
Residual pain	5	0.3
Implant failure	12	0.6
Osteoarthritis	16	0.8
Malunion	22	1.1
Non-union	1	0.1
Other	34	1.8
Total	416	21.7
<i>Percentages were calculated over the whole population (n = 1915). Counts represent complication events; a patient with more than one complication is counted more than once.</i>		

The complication events were then stratified by timing subgroup (Table 6).

The lowest rate of complications was observed in the >21-day subgroup, with a rate of 0.96% (two infections, one wound dehiscence and one malunion). However, it should be noted that this subgroup was smaller in size than the other two. In both the 0–7-day and 8–21-day subgroups, the events were more evenly distributed, with wound dehiscence the most frequent in each. Infection represented the largest share of events in the >21-day subgroup (50.0%). Sural nerve injury and implant failure occurred at higher rates (5.3% and 5.8%, respectively) in the 0–7-day group, as did osteoarthritis (7.3%). Malunion occurred in a higher percentage (9.7%) of cases in the 0–7-day group (Table 6).

Table 6. Complications stratified by timing subgroup, n (% of complication events within subgroup).

Complication	0–7 Days	8–21 Days	>21 Days	Total
Wound dehiscence	55 (26.7%)	114 (55.3%)	1 (25.0%)	170 (40.9%)
Wound necrosis	20 (9.7%)	11 (5.3%)	0 (0.0%)	31 (7.5%)
Infection	43 (20.9%)	55 (26.7%)	2 (50.0%)	100 (24.0%)
Sural nerve injury	12 (5.8%)	5 (2.4%)	0 (0.0%)	17 (4.1%)
Peroneal tendon injury	8 (3.9%)	0 (0.0%)	0 (0.0%)	8 (1.9%)
Residual pain	2 (1.0%)	3 (1.5%)	0 (0.0%)	5 (1.2%)
Implant failure	11 (5.3%)	1 (0.5%)	0 (0.0%)	12 (2.9%)
Osteoarthritis	15 (7.3%)	1 (0.5%)	0 (0.0%)	16 (3.8%)
Malunion	20 (9.7%)	1 (0.5%)	1 (25.0%)	22 (5.3%)
Non-union	1 (0.5%)	0 (0.0%)	0 (0.0%)	1 (0.2%)
Other	19 (9.2%)	15 (7.3%)	0 (0.0%)	34 (8.2%)
Total events	206 (100%)	206 (100%)	4 (100%)	416 (100%)
<i>Values are column percentages (share of complication events within each timing subgroup), not per-patient incidence. Counts are complication events, not patients.</i>				

Subsequently, complication rate was stratified by surgical approach within each timing subgroup (Table 7).

Table 7. Complication events stratified by surgical approach within each timing subgroup, n (% within timing subgroup).

Complication	0–7			8–21		>21	
	ELA N = 279	STA N = 549	Perc N = 323	ELA N = 404	STA N = 320	ELA N = 20	STA N = 20
Wound dehiscence	24/279 (8.6%)	24/549 (4.4%)	7/323 (2.2%)	93/404 (23.0%)	21/320 (6.6%)	0/20 (0.0%)	1/20 (5.0%)
Wound necrosis	12/279 (4.3%)	7/549 (1.3%)	1/323 (0.3%)	11/404 (2.7%)	0/320 (0.0%)	0/20 (0.0%)	0/20 (0.0%)
Infection	17/279 (6.1%)	22/549 (4.0%)	4/323 (1.2%)	6/404 (1.5%)	49/320 (15.3%)	0/20 (0.0%)	2/20 (10.0%)
Sural nerve injury	2/279 (0.7%)	9/549 (1.6%)	1/323 (0.3%)	0/404 (0.0%)	5/320 (1.6%)	0/20 (0.0%)	0/20 (0.0%)
Peroneal tendon injury	0/279 (0.0%)	5/549 (0.9%)	3/323 (0.9%)	0/404 (0.0%)	0/320 (0.0%)	0/20 (0.0%)	0/20 (0.0%)
Residual pain	1/279 (0.4%)	1/549 (0.2%)	0/323 (0.0%)	0/404 (0.0%)	3/320 (0.9%)	0/20 (0.0%)	0/20 (0.0%)
Implant failure	0/279 (0.0%)	9/549 (1.6%)	2/323 (0.6%)	0/404 (0.0%)	1/320 (0.3%)	0/20 (0.0%)	0/20 (0.0%)
Osteoarthritis	5/279 (1.8%)	7/549 (1.3%)	3/323 (0.9%)	0/404 (0.0%)	1/320 (0.3%)	0/20 (0.0%)	0/20 (0.0%)
Malunion	5/279 (1.8%)	11/549 (2.0%)	4/323 (1.2%)	1/404 (0.2%)	0/320 (0.0%)	1/20 (5.0%)	0/20 (0.0%)
Non-union	0/279 (0.0%)	1/549 (0.2%)	0/323 (0.0%)	0/404 (0.0%)	0/320 (0.0%)	0/20 (0.0%)	0/20 (0.0%)
Other	0/279 (0.0%)	17/549 (3.1%)	2/323 (0.6%)	15/404 (3.7%)	0/320 (0.0%)	0/20 (0.0%)	0/20 (0.0%)
Total complication events	66/279 (23.7%)	113/549 (20.6%)	27/323 (8.4%)	126/404 (31.2%)	80/320 (25.0%)	1/20 (5.0%)	3/20 (15.0%)

Overall, the highest proportion of reported complication events was observed in patients treated with the ELA between 8 and 21 days, with 126 events among 404 patients (31.2%). This was followed by the STA performed between 8 and 21 days, with 80 events among 320 patients (25.0%); the ELA within 7 days, with 66 events among 279 patients (23.7%); and the STA within 7 days, with 113 events among 549 patients (20.6%). The percutaneous approach, which was performed only within the first 7 days, showed 27 events among 323 patients (8.4%). In the >21-day subgroup, complication events were uncommon, although the interpretation is limited by the very small sample size, with one event among 20 ELA patients (5.0%) and three events among 20 STA patients (15.0%).

Wound dehiscence was the most frequent wound-related complication and was most commonly observed after the ELA performed between 8 and 21 days, occurring in 93 of 404 patients (23.0%), or within 7 days (24/279, 8.6%). Lower rates of wound dehiscence

were observed after the STA between 8 and 21 days (21/320, 6.6%) and within 7 days (24/549, 4.4%) and percutaneous fixation within 7 days (7/323, 2.2%).

Overall, wound dehiscence was more prevalent following the ELA than the STA or the percutaneous approach.

A similar trend was observed for wound necrosis, which was mainly observed after the ELA, occurring in 12 of 279 patients treated within 7 days (4.3%) and in 11 of 404 patients treated between 8 and 21 days (2.7%). It was uncommon after the STA within 7 days (7/549, 1.3%) and after percutaneous fixation (1/323, 0.3%), and no cases were reported after the STA between 8 and 21 days.

Likewise, the distribution of infections differed according to both timing and surgical approach. The highest infection rate was observed after the STA performed between 8 and 21 days, with 49 infections among 320 patients (15.3%). Infection was also reported in two of 20 patients treated with the STA after 21 days (10.0%), although this estimate is based on a very small subgroup. Lower rates were observed after the ELA within 7 days (17/279, 6.1%), the STA within 7 days (22/549, 4.0%), the ELA between 8 and 21 days (6/404, 1.5%), and percutaneous fixation within 7 days (4/323, 1.2%).

Additional complications were less frequent across all timing-and-approach subgroups. Sural nerve injury was mainly reported after the STA, occurring in nine of 549 patients treated within 7 days (1.6%) and in five of 320 patients treated between 8 and 21 days (1.6%). Lower rates were observed after the ELA within 7 days (2/279, 0.7%) and percutaneous fixation within 7 days (1/323, 0.3%), whereas no cases were reported after the ELA between 8 and 21 days.

Osteoarthritis was uncommon and was reported mainly in the 0–7-day subgroup, with rates of 1.8% after the ELA (5/279), 1.3% after the STA (7/549), and 0.9% after percutaneous fixation (3/323). Only one case was reported after the STA between 8 and 21 days (1/320, 0.3%), and no cases were observed after the ELA between 8 and 21 days.

Malunion was also infrequent, occurring in five of 279 patients treated with the ELA within 7 days (1.8%), 11 of 549 patients treated with the STA within 7 days (2.0%), and four of 323 patients treated percutaneously within 7 days (1.2%). In the 8–21-day subgroup, malunion was reported only after the ELA (1/404, 0.2%).

Finally, other complications, including peroneal tendon injury, residual pain, implant failure and non-union were rare across all subgroups.

No significant differences were recorded in the clinical (AOFAS score) and radiographic outcomes between timing subgroups or approaches. However, the analysis is limited by incomplete reporting, as 12 out of the 25 papers did not specify the clinical outcome in terms of AOFAS score [17,18,26,29,30,33,37,38,40–42], and six out of the 25 did not specify the radiographic outcome [30,31,33,46–48].

4. Discussion

The aim of this systematic review was to evaluate the role of surgical timing in the outcome of DIACFs, assessing complication rates and radiographic and functional outcomes in relation to the time from injury to surgery and to the surgical approach adopted.

An important difference between our review and previous reviews is the way surgical timing was evaluated. While earlier studies comparing minimally invasive and extensile approaches considered timing as a secondary variable, they did not specifically investigate its impact as a primary outcome. For example, previous reviews often reported only mean time-to-surgery values, despite substantial variability within the included cohorts, with treatment intervals ranging from a few days to several weeks after injury [10,14]. Such an approach might mask potential differences associated with specific surgical windows and introduce bias when interpreting outcomes. In contrast, the present study was specifically

designed to assess surgical timing as the primary outcome and to analyze outcomes according to distinct time intervals, thereby providing a more focused evaluation of the role of timing in the management of these injuries.

Our findings suggest that timing cannot be interpreted as an independent predictor of postoperative complications. Instead, they indicate that timing should be interpreted in conjunction with the surgical approach adopted.

Differences were observed between the timing subgroups in terms of complications. The 0–7-day subgroup demonstrated a higher incidence of wound necrosis, sural nerve injury, implant failure, malunion and osteoarthritis. In contrast, wound dehiscence occurred at a higher rate in the 8–21-day subgroup, while infection and malunion were the most common complications in the >21-day group. These differences, however, must consider the uneven distribution of surgical techniques across timing subgroups. The sinus tarsi approach and percutaneous approach were predominantly utilized during the first week after injury, whereas the extensile lateral approach was more frequently adopted between 8 and 21 days after trauma. In relation to this, it should be noted that the highest rates of complication in both the STA and the ELA subgroups were recorded in the time group where each approach was utilized the most, i.e., in the 0–7-day and 8–21-day groups, respectively. Furthermore, the population size is limited; specifically, the population of the >21-day group was lower than that of the other two subgroups, which restricts the ability to draw definitive conclusions. In addition, the population of the 8–21-day group was older than that of the other subgroups, suggesting a reduced capacity of soft-tissue healing which necessitated a longer timeframe for resolving soft-tissue issues prior to undertaking an open approach. On the other hand, the younger age of the >21-day subgroup was probably due to polytrauma patients whose surgery was deferred until their overall clinical condition stabilized rather than for soft-tissue reasons alone.

These findings suggest that this apparent association between timing and complications is therefore strongly confounded by approach, population and age distribution.

Complications were stratified by approach within each timing window. The soft-tissue complications of wound dehiscence and necrosis were predominantly associated with the ELA and clustered in the 8–21-day window. This is consistent with the established understanding that extensile exposure is the principal driver of wound morbidity and that the outcome depends more on the readiness of the soft tissues than on the time since the injury [49]. Moreover, these findings are in line with those reported by Kwon et al., who observed that delaying surgery did not reduce complication rates among patients treated with the ELA [34].

As for the STA, there was an opposite trend with a progressive reduction in the wound-related complication rate from the 0–7-day to the 8–21-day subgroup, particularly in wound necrosis. Accordingly, although the sinus tarsi approach is generally associated with a relatively low rate of surgical-site infection and wound complications, Schepers et al. reported that operating within the first week after injury significantly increases the risk of surgical-site infection intra-approach [3]. These findings, however, differ from the ones found by Kwon et al., who observed that fixation performed more than 14 days after injury significantly increased wound complications in minimally invasive procedures [34].

Interestingly, our results showed that infections occurred more frequently within the STA subgroup. In addition, the infection rate in the ELA group decreased when surgery was delayed, probably due to the resolution of soft-tissue problems. The STA, by contrast, showed the opposite behavior with respect to infection. Expressed as a rate within the approach, the STA infection rate rose from approximately 4.0% (22/549) in the first week to 15.3% (49/320) between 8 and 21 days, whereas the ELA infection rate fell over the same interval, from 6.1% (17/279) to 1.5% (6/404). Contrary to the traditional belief that postponing surgery reduces overall complications, this increase in the STA subgroup may

be explained by the greater technical difficulty of obtaining reduction through limited exposure once an early callus has developed, with a consequent increase in operative time, itself a recognized predictor of poorer outcomes in DIACFs treated through the STA [3,34]. The same direction was reported by Alajmi et al., who described a direct correlation between delay and complications following the STA [16].

These observations suggest that rigid temporal thresholds may not be applicable, and that timing should be guided by soft-tissue status and the selected technique. This perspective is shared by many authors. Court-Brown et al., in a series of 178 operatively treated fractures, found no correlation between surgical delay and deep infection [30]. Ho et al. similarly demonstrated that early fixation can be safely performed when careful attention is paid to soft-tissue management. In their series, surgery was undertaken within 72 h whenever fracture blisters and soft-tissue compromise were absent, resulting in a remarkably low infection rate [50]. De Boer et al. demonstrated that the severity of soft-tissue injury and patient-related risk factors are stronger predictors of postoperative complications than timing itself [51]. Therefore, the concept of a universally optimal surgical window is unlikely to be applicable to all patients. The concept of individualized timing is further supported by Rammelt et al., who emphasized that there is no single treatment strategy suitable for all calcaneal fractures. According to these authors, the decision regarding when to operate should depend on fracture morphology, patient characteristics, and local soft-tissue conditions [52].

Sural nerve injury also varied according to the surgical approach. As expected, the STA was more frequently associated with sural nerve injury across timing groups. Peroneal tendon injury was observed exclusively after the STA or percutaneous fixation. Therefore, nerve- and tendon-related complications followed an approach-dependent rather than a timing-dependent pattern.

With regard to the clinical and radiographic outcomes and long-term complications, the present review was not sufficient to provide a definitive opinion. The AOFAS score was reported in only 13 of the 25 studies, the radiographic parameters in 19, and the follow-up period was not sufficiently long to evaluate long-term complications such as osteoarthritis. The present literature on this subject and the analyzed studies in this paper include studies that evaluate the role of the surgical approach with regard to wound-related complications only, not extending the analysis to the evaluation of long-term or other complications, such as residual pain, which therefore were not possible to detect in this review. For example, only four studies mentioned residual pain [11,26,33]. This explains the low rate of residual pain, osteoarthritis and other complications recorded in this analysis.

On the other hand, all authors concur that the radiographic equivalence between the ELA and MIAs is contingent on the expertise of the surgeon and that an extended waiting period may result in fracture reduction difficulties, especially after 21 days [52,53]. Court-Brown et al. found no statistical correlation between surgical delay and deep infection rate in 178 operatively managed intra-articular calcaneal fractures, identifying surgeon experience as the primary determinant of infectious complications [30]. Rodemund et al. evaluated percutaneous screw-only osteosynthesis, finding that surgery within seven days of admission had no significant impact on radiographic or functional outcomes [12]. In contrast, the limited number of studies that have evaluated the percutaneous approach versus the STA in our study demonstrated an improvement in length, height, and width in patients undergoing the STA compared to percutaneous treatment within the same subgroups [45]. Therefore, these findings should be regarded as hypothesis-generating rather than conclusive.

A major factor influencing the timing of surgery after calcaneal fractures is the condition of the surrounding soft tissues. Among the available assessment tools, the

Tscherne–Oestern classification provides a structured evaluation of soft-tissue injury severity in both closed (C0–C3) and open (O1–O4) fractures and has been associated with postoperative complications and outcomes in several fracture types [54]. However, none of the studies included in the present review systematically reported soft-tissue injury according to a validated classification system, preventing a stratified analysis based on soft-tissue severity. Moreover, although the Tscherne–Oestern classification represents a useful framework for describing soft-tissue damage and predicting functional outcomes, some authors have highlighted the potential difficulty and inter-operator variability of applying the Tscherne classification to closed fractures [55]. In addition, this classification does not take into account the location of soft-tissue injury and patient host factors, which can influence the prognosis [56].

Hence, the current evidence does not allow the formulation of evidence-based recommendations or a standardized decision-making algorithm; the findings of the present review are in line with the AO Principles of Fracture Management, which state that soft-tissue recovery should remain the primary determinant of surgical timing. The return of skin wrinkles is the most widely accepted indicator of when surgery can be performed. Although this typically occurs 7–14 days after injury, the AO guidelines present this timeframe as a practical guide rather than a mandatory temporal threshold. They also recognize that less invasive techniques may be suitable when soft-tissue conditions prevent extensive exposure. Our findings extend this concept by suggesting that the relationship between surgical timing and postoperative complications should be considered in relation to the surgical approach employed. In particular, as minimally invasive techniques have become more widely adopted, greater flexibility in surgical timing may be feasible for certain patients, provided careful assessment of the soft tissues remains central to decision-making. Therefore, our findings support an individualized rather than a strictly time-based approach. Soft-tissue assessment should be used to provide a guide for surgical timing, with patients presenting minimal soft-tissue compromise potentially being suitable for earlier intervention, particularly when less invasive approaches are planned. Conversely, in the presence of marked swelling, fracture blisters, skin compromise, or more severe soft-tissue injury, surgery should be deferred until adequate soft-tissue recovery has occurred, regardless of the number of days elapsed since injury. Despite tools such as the Tscherne–Oestern classification, in current clinical practice, the wrinkle sign remains the most widely adopted indicator of soft-tissue readiness for surgery. Finally, from a practical perspective, clinicians may consider, whenever feasible, less invasive techniques to minimize soft-tissue complications. Nevertheless, it is important to highlight that the extensile lateral approach should not be regarded as inherently unsafe or “invasive”, as meticulous soft-tissue handling, strict adherence to the “no-touch technique”, and careful preservation of the lateral flap can allow this approach to be performed safely with satisfactory outcomes [57].

This review has several limitations. First, the predominance of retrospective and heterogeneous studies, in conjunction with the incomplete reporting of functional scores, precluded a formal meta-analysis. Second, established risk factors for wound complications, such as smoking and diabetes, were seldom reported, a deficiency reflected in the high proportion of studies rated at serious risk of confounding on ROBINS-I. Another limitation relates to the availability of timing data. For a subset of patients, individual time-to-surgery values were not reported, and allocation was based on timing groups provided in the original studies. Although these groups were consistent with the predefined categories adopted in the present review, this approach may have introduced some degree of misclassification and between-study heterogeneity. Furthermore, the data on the classification of the fracture or the implant and the type of fixation was not reported on a per-patient basis. Consequently, it was not possible to stratify according to classification or perform a

fixation-based sub-analysis. Soft-tissue conditions were not uniformly classified across the included studies. As a result, we were unable to stratify patients according to the severity of soft-tissue injury, which may represent an important factor influencing both surgical timing and postoperative outcomes. Importantly, all analyses were conducted at the study level rather than at the patient level; complication rates were derived from data aggregated within each study rather than from individual patient data, so the observed associations between timing, approach and complications may be confounded by between-study differences in age, fracture severity, comorbidities and surgeon experience and cannot be assumed to hold at the individual-patient level.

Furthermore, the follow-up period documented in the included papers was insufficient to accurately evaluate long-term complications, such as osteoarthritis. The majority of the included studies were wound complications-oriented, with a paucity of attention given to other “minor complications”, such as residual pain. Ultimately, the distribution of the included population differed substantially across the timing subgroups, and the >21-day group comprised only 40 patients. This marked imbalance limited the statistical power of comparisons involving this subgroup. Therefore, findings related to the >21-day group should be interpreted with caution and regarded primarily as descriptive observations rather than definitive evidence for statistical inference.

Interestingly, our findings only partially confirmed our initial hypothesis. While the influence of surgical timing appeared to differ according to the surgical approach, delaying surgery did not consistently reduce wound-related complications following the extensile lateral approach. Moreover, minimally invasive approaches also appeared to be influenced by surgical timing more than expected.

Rather than supporting a simple “earlier versus later” paradigm, our results suggest that the interaction between surgical timing, soft-tissue condition, and operative technique is likely to be the main determinant of postoperative outcomes.

These findings further reinforce the concept that timing should be individualized according to the overall clinical scenario rather than determined by predefined temporal thresholds.

5. Conclusions

To the best of our knowledge, this is the first systematic review specifically investigating the role of surgical timing in the management of displaced intra-articular calcaneal fractures. The available evidence suggests that, when planning operative treatment for displaced intra-articular calcaneal fractures, timing must be considered alongside soft-tissue conditions, surgical approaches and patient-specific factors in order to achieve good outcomes and predict postoperative complications. Future prospective studies are needed to further clarify the relationship between timing and outcomes. In particular, these should systematically evaluate important confounding factors associated with wound complications and postoperative outcomes, including diabetes, smoking status, preoperative skin and soft-tissue conditions, fracture type and severity, and fixation method. In addition, they should incorporate standardized soft-tissue classifications such as the Tscherne–Oestern system to better define the relationship with soft-tissue status, ultimately facilitating the development of evidence-based treatment algorithms for calcaneal fractures.

Author Contributions: Conceptualization, D.L.; methodology, L.S., G.S. and I.S.; software, A.A.; validation, A.A., L.S. and G.S.; formal analysis, A.A., G.F.P., L.S. and G.S.; investigation, L.S. and G.S.; resources, L.S. and G.S.; data curation, L.S., G.S., G.F.P. and G.D.C.; writing—original draft preparation, L.S. and G.S.; writing—review and editing, L.S. and G.S.; visualization, G.S.; supervision, D.L., B.Z., M.N. and I.S.; project administration, D.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The committee review was waived, as such reviews are not required under our local regulation.

Data Availability Statement: The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Acknowledgments: During the preparation of this work, the authors did not use any AI or AI-assisted technologies to improve the scientific work.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Mitchell, M.J.; McKinley, J.C.; Robinson, C.M. The epidemiology of calcaneal fractures. *Foot* **2009**, *19*, 197–200. [[CrossRef](#)] [[PubMed](#)]
2. Bibbo, C.; Siddiqui, N.; Fink, J.; Powers, J.; Ehrlich, D.A.; Kovach, S.J. Wound Coverage Options for Soft Tissue Defects Following Calcaneal Fracture Management (Operative/Surgical). *Clin. Podiatr. Med. Surg.* **2019**, *36*, 323–337. [[CrossRef](#)] [[PubMed](#)]
3. Schepers, T. Calcaneal Fractures: Looking Beyond the Meta-Analyses. *J. Foot Ankle Surg.* **2016**, *55*, 897–898. [[CrossRef](#)] [[PubMed](#)]
4. Sangeorzan, B.J.; Benirschke, S.K.; Carr, J.B. Surgical management of fractures of the os calcis. *Instr. Course Lect.* **1995**, *44*, 359–370. [[PubMed](#)]
5. Benirschke, S.K.; Kramer, P.A. Wound healing complications in closed and open calcaneal fractures. *J. Orthop. Trauma* **2004**, *18*, 1–6. [[CrossRef](#)] [[PubMed](#)]
6. Abrishami, A.; Arjmand, G.; Zadeh, A.H.; Ghanaati, H. Treatment of a calcaneal unicameral bone cyst by percutaneous CT-guided cement injection using a double-needle technique: A case report. *Radiol. Case Rep.* **2023**, *18*, 3299–3303. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
7. Letournel, E. Open treatment of acute calcaneal fractures. *Clin. Orthop. Relat. Res.* **1993**, *290*, 60–67. [[CrossRef](#)] [[PubMed](#)]
8. Yeo, J.H.; Cho, H.J.; Lee, K.B. Comparison of two surgical approaches for displaced intra-articular calcaneal fractures: Sinus tarsi versus extensile lateral approach. *BMC Musculoskelet. Disord.* **2015**, *16*, 63. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
9. Jin, C.; Weng, D.; Yang, W.; He, W.; Liang, W.; Qian, Y. Minimally invasive percutaneous osteosynthesis versus ORIF for Sanders type II and III calcaneal fractures: A prospective, randomized intervention trial. *J. Orthop. Surg. Res.* **2017**, *12*, 10. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
10. Seat, A.; Seat, C. Lateral Extensile Approach Versus Minimal Incision Approach for Open Reduction and Internal Fixation of Displaced Intra-articular Calcaneal Fractures: A Meta-analysis. *J. Foot Ankle Surg.* **2020**, *59*, 356–366. [[CrossRef](#)] [[PubMed](#)]
11. Peng, Y.; Wang, J.; Feng, B.; Li, Y.; Zhu, Y.; Yuan, W.; Teng, L.; Zhu, C.; Shi, B.; Zhang, L. Calcaneous interlocking nail treatment for calcaneous fracture: A multiple center retrospective study. *BMC Musculoskelet. Disord.* **2022**, *23*, 911. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
12. Rodemund, C.; Krenn, R.; Kihm, C.; Leister, I.; Ortmaier, R.; Litzlbauer, W.; Schwarz, A.M.; Mattiassich, G. Minimally invasive surgery for intra-articular calcaneus fractures: A 9-year, single-center, retrospective study of a standardized technique using a 2-point distractor. *BMC Musculoskelet. Disord.* **2020**, *21*, 753. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
13. Joseph, N.M.; Sinkler, M.A.; Magister, S.; Bacharach, A.; Pang, A.; Boes, K.; Vallier, H.A.; Hirschfeld, A.G.; Ochenjele, G. Fixation of displaced intra-articular calcaneus fractures is safe using either sinus tarsi or extensile lateral approach. *Injury* **2023**, *54*, 1824–1830. [[CrossRef](#)] [[PubMed](#)]
14. Bandyopadhyay, A.; Kumar, S.; Mandal, P. Calcaneal Fractures Management, Change of Clinical Practice in Recent Years from ELA to STA: A Systematic Review and Meta-Analysis. *Indian. J. Orthop.* **2023**, *57*, 800–817. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
15. Ma, C.; Zhao, J.; Zhang, Y.; Yi, N.; Zhou, J.; Zuo, Z.; Jiang, B. Comparison of the modified sinus tarsi approach versus the extensile lateral approach for displaced intra-articular calcaneal fractures. *Ann. Transl. Med.* **2021**, *9*, 695. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
16. Alajmi, T.; Sharif, A.F.; Majoun, M.A.; Alshehri, F.S.; Albaqami, A.M.; Alshouli, M. Minimally Invasive Sinus Tarsi Approach for Open Reduction and Internal Fixation of Calcaneal Fractures: Complications, Risk Factors, and Outcome Predictors. *Cureus* **2022**, *14*, e21791. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
17. Basile, A.; Lanzetti, R.M.; Via, A.G.; Venditto, T.; Spoliti, M.; Sessa, P.; Tortora, M.; Maffulli, N. Delayed Surgical Treatment of Displaced Intra-Articular Calcaneal Fractures in Major Trauma Is Safe and Effective. *J. Clin. Med.* **2023**, *12*, 2039. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
18. Swords, M.; Shank, J.; Fraticelli, N.; Benirschke, S. Late Treatment of Displaced Intra-Articular Calcaneus Fractures: Successful Management with Anatomic Reduction. *J. Orthop. Trauma* **2020**, *34*, S21–S25. [[CrossRef](#)] [[PubMed](#)]

19. Howick, J.; Chalmers, I.; Glasziou, P.; Greenhalgh, T.; Heneghan, C.; Liberati, A.; Moschetti, I.; Phillips, B.; Thornton, H. Explanation of the 2011 Oxford Centre for Evidence-Based Medicine (OCEBM) Levels of Evidence (Background Document). Available online: <https://www.cebm.ox.ac.uk/resources/levels-of-evidence/explanation-of-the-2011-ocedb-levels-of-evidence> (accessed on 26 July 2026).
20. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ* **2021**, *372*, n71. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
21. Cumpston, M.; Li, T.; Page, M.; Chandler, J.; Welch, V.; Higgins, J.P.; Thomas, J. Updated guidance for trusted systematic reviews: A new edition of the Cochrane Handbook for Systematic Reviews of Interventions. *Cochrane Database Syst. Rev.* **2019**, *10*, ED000142. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
22. Jiménez-Almonte, J.H.; King, J.D.; Luo, T.D.; Aneja, A.; Moghadamian, E. Classifications in Brief: Sanders Classification of Intraarticular Fractures of the Calcaneus. *Clin. Orthop. Relat. Res.* **2019**, *477*, 467–471. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
23. Paget, L.D.A.; Sierevelt, I.N.; Tol, J.L.; Kerkhoffs, G.M.M.J.; Reurink, G. The completely patient-reported version of the American Orthopaedic Foot and Ankle Society (AOFAS) score: A valid and reliable measurement for ankle osteoarthritis. *J. ISAKOS* **2023**, *8*, 345–351. [[CrossRef](#)] [[PubMed](#)]
24. Sterne, J.A.C.; Hernán, M.A.; Reeves, B.C.; Savović, J.; Berkman, N.D.; Viswanathan, M.; Henry, D.; Altman, D.G.; Ansari, M.T.; Boutron, I.; et al. ROBINS-I: A tool for assessing risk of bias in non-randomised studies of interventions. *BMJ* **2016**, *355*, i4919. [[CrossRef](#)] [[PubMed](#)]
25. Sterne, J.A.C.; Savović, J.; Page, M.J.; Elbers, R.G.; Blencowe, N.S.; Boutron, I.; Cates, C.J.; Cheng, H.Y.; Corbett, M.S.; Eldridge, S.M.; et al. RoB 2: A revised tool for assessing risk of bias in randomised trials. *BMJ* **2019**, *366*, l4898. [[CrossRef](#)] [[PubMed](#)]
26. Ahmed, S.A.E.; Mohamed, A.A.; Mohammed, A.I.E.; Ali, A.Z.; Mohamed, N.A.I.; Mohamed, H.A.E.; Yaser, E.H.W.; Mahmoud, A.I.M.; Mohamed, A.O.; Ibrahim, E.M.; et al. The Reproducibility of Conventional Minimally Invasive Osteosynthesis for the treatment of Intra articular Calcaneal fractures: The Traditional Technique is Regaining Popularity (prospective interventional study). *Clin. Ter.* **2025**, *176*, 136–147. [[CrossRef](#)] [[PubMed](#)]
27. Cao, L.; Weng, W.; Song, S.; Mao, N.; Li, H.; Cai, Y.; Zhou, Q.; Su, J. Surgical treatment of calcaneal fractures of Sanders type II and III by a minimally invasive technique using a locking plate. *J. Foot Ankle Surg.* **2015**, *54*, 76–81. [[CrossRef](#)] [[PubMed](#)]
28. Cho, J.; Kim, J.; Kang, E.M.; Lee, J.S.; Min, T.-H.; Won, S.H.; Yi, Y.; Chun, D.-I. Surgical Treatment Using Sinus Tarsi Approach with Anterolateral Fragment Open-Door Technique in Sanders Type 3 and 4 Displaced Intraarticular Calcaneal Fracture. *Int. J. Environ. Res. Public Health* **2021**, *18*, 10400. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
29. Chotikkakamthorn, N.; Chanajit, A.; Tharmviboonsri, T.; Chuckpaiwong, B.; Harnroongroj, T. Minimal invasive surgery in the management of intra-articular calcaneal fractures: A retrospective comparison of screw fixation alone versus screw with small locking plate fixation techniques. *Acta Orthop. Traumatol. Turc.* **2021**, *55*, 258–264. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
30. Court-Brown, C.M.; Schmied, M.; Schutte, B.G. Factors affecting infection after calcaneal fracture fixation. *Injury* **2009**, *40*, 1313–1315. [[CrossRef](#)] [[PubMed](#)]
31. Cursaru, A.; Crețu, B.; Șerban, B.; Iordache, S.; Popa, M.; Smarandache, C.G.; Orban, C.; Cîrstoiu, C. Minimally invasive treatment and internal fixation vs. extended lateral approach in calcaneus fractures of thalamic interest. *Exp. Ther. Med.* **2022**, *23*, 196. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
32. Esenkaya, I.; Türkmensoy, F.; Kemah, B.; Poyanlı, O.Ş. Surgical treatment of displaced intraarticular calcaneus fractures using anatomical lateral frame plate. *Ulus. Travma Acil Cerrahi Derg.* **2018**, *24*, 156–161. [[CrossRef](#)] [[PubMed](#)]
33. Jansen, S.C.P.; Bransen, J.; van Montfort, G.; Besselaar, A.T.; van der Veen, A.H. Should the Extended Lateral Approach Remain Part of Standard Treatment in Displaced Intra-articular Calcaneal Fractures? *J. Foot Ankle Surg.* **2018**, *57*, 1120–1124. [[CrossRef](#)] [[PubMed](#)]
34. Kwon, J.Y.; Zurakowski, D.; Ellington, J.K. Influence of contralateral radiographs on accuracy of anatomic reduction in surgically treated calcaneus fractures. *Foot Ankle Int.* **2015**, *36*, 75–82. [[CrossRef](#)] [[PubMed](#)]
35. Liao, X.; Deng, J.; Liu, W.; You, D. Better management of Sanders II and III calcaneus fractures via a tailored distractor-assisted percutaneous approach versus sinus tarsi approach: A comparative cohort study with 2-year follow-up. *Injury* **2025**, *57*, 112896. [[CrossRef](#)] [[PubMed](#)]
36. Peng, Y.; Liu, J.; Zhang, G.; Ji, X.; Zhang, W.; Zhang, L.; Tang, P. Reduction and functional outcome of open reduction plate fixation versus minimally invasive reduction with percutaneous screw fixation for displaced calcaneus fracture: A retrospective study. *J. Orthop. Surg. Res.* **2019**, *14*, 124. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
37. Schepers, T.; Backes, M.; Dingemans, S.A.; de Jong, V.M.; Luitse, J.S.K. Similar Anatomical Reduction and Lower Complication Rates with the Sinus Tarsi Approach Compared with the Extended Lateral Approach in Displaced Intra-Articular Calcaneal Fractures. *J. Orthop. Trauma* **2017**, *31*, 293–298. [[CrossRef](#)] [[PubMed](#)]

38. Shams, A.; Gamal, O.; Mesregah, M.K. Minimally Invasive Reduction of Intraarticular Calcaneal Fractures with Percutaneous Fixation Using Cannulated Screws Versus Kirschner Wires: A Retrospective Comparative Study. *Foot Ankle Spec.* **2023**, *16*, 28–35. [[CrossRef](#)] [[PubMed](#)]
39. Shih, J.T.; Kuo, C.L.; Yeh, T.T.; Shen, H.C.; Pan, R.Y.; Wu, C.C. Modified Essex-Lopresti procedure with percutaneous calcaneoplasty for comminuted intra-articular calcaneal fractures: A retrospective case analysis. *BMC Musculoskelet. Disord.* **2018**, *19*, 77. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
40. Sypien, P.; Grzelecki, D. A Mid-Term Result of the Treatment of Intra-Articular Calcaneal Fractures with the Use of Intramedullary Nailing. *J. Clin. Med.* **2025**, *14*, 1369. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
41. Usami, T.; Takada, N.; Nishida, K.; Sakai, H.; Iwata, H.; Yonezu, H.; Sekiya, I.; Nagaya, Y.; Ueki, Y.; Murakami, H.; et al. Fixation of intra-articular calcaneal fractures: A comparative study of the postoperative outcome between HA/PPLA screws and locking plates. *Heliyon* **2023**, *9*, e14046. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
42. Weng, Q.; Dai, G.; Tu, Q.; Liu, Y.; Lutchooman, V.; Hong, J.; Yu, Y. Comparison between Percutaneous Screw Fixation and Plate Fixation via Sinus Tarsi Approach for Calcaneal Fractures: An 8-10-Year Follow-up Study. *Orthop. Surg.* **2020**, *12*, 124–132. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
43. Zhao, B.; Zhao, W.; Liu, C.; Assan, I.; Bi, R. Steinmann pin retractor: An auxiliary reduction equipment for the minimally invasive treatment of calcaneal fractures. *Medicine* **2022**, *101*, e30847. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
44. Ebrahimpour, A.; Kord, M.H.C.; Sadighi, M.; Chehrassan, M.; Najafi, A.; Sajjadi, M.M. Percutaneous reduction and screw fixation for all types of intra-articular calcaneal fractures. *Musculoskelet. Surg.* **2021**, *105*, 97–103. [[CrossRef](#)] [[PubMed](#)]
45. Feng, Y.; Shui, X.; Wang, J.; Cai, L.; Yu, Y.; Ying, X.; Kong, J.; Hong, J. Comparison of percutaneous cannulated screw fixation and calcium sulfate cement grafting versus minimally invasive sinus tarsi approach and plate fixation for displaced intra-articular calcaneal fractures: A prospective randomized controlled trial. *BMC Musculoskelet. Disord.* **2016**, *17*, 288. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
46. Kir, M.C.; Ayanoglu, S.; Cabuk, H.; Dedeoglu, S.S.; Imren, Y.; Karslioglu, B.; Yuce, A.; Gurbuz, H. Mini-plate fixation via sinus tarsi approach is superior to cannulated screw in intra-articular calcaneal fractures: A prospective randomized study. *J. Orthop. Surg.* **2018**, *26*, 2309499018792742. [[CrossRef](#)] [[PubMed](#)]
47. Li, S. Wound and Sural Nerve Complications of the Sinus Tarsi Approach for Calcaneus Fractures. *Foot Ankle Int.* **2018**, *39*, 1106–1112. [[CrossRef](#)] [[PubMed](#)]
48. Wang, J.; Qin, S.; Wang, T.; Wang, Z.; Xia, C.; Zhao, D. Calcaneus traction compression with orthopaedic reduction forceps combined with percutaneous minimally invasive treatment of intra-articular calcaneal fractures: An analysis of efficacy. *Biomed. Pharmacother.* **2020**, *128*, 110295. [[CrossRef](#)] [[PubMed](#)]
49. Leighab, M.; Codori, F.; Samaila, E.M.; Mazzotti, A.; Villafañe, J.H.; Bosetti, M.; Ceccarini, P.; Cochis, A.; Daou, F.; Ronga, M.; et al. Current Concepts about Calcaneal Fracture Management: A Review of Metanalysis and Systematic Reviews. *Appl. Sci.* **2023**, *13*, 12311. [[CrossRef](#)]
50. Ho, C.J.; Huang, H.T.; Chen, C.H.; Chen, J.C.; Cheng, Y.M.; Huang, P.J. Open reduction and internal fixation of acute intra-articular displaced calcaneal fractures: A retrospective analysis of surgical timing and infection rates. *Injury* **2013**, *44*, 1007–1010. [[CrossRef](#)] [[PubMed](#)]
51. De Boer, A.S.; Van Lieshout, E.M.M.; Van Moolenbroek, G.; Den Hartog, D.; Verhofstad, M.H.J. The effect of time to post-operative weightbearing on functional and clinical outcomes in adults with a displaced intra-articular calcaneal fracture; A systematic review and pooled analysis. *Injury* **2018**, *49*, 743–752. [[CrossRef](#)] [[PubMed](#)]
52. Rammelt, S.; Sangeorzan, B.J.; Swords, M.P. Calcaneal Fractures—Should We or Should We not Operate? *Indian. J. Orthop.* **2018**, *52*, 220–230. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]
53. Tennent, T.D.; Calder, P.R.; Salisbury, R.D.; Allen, P.W.; Eastwood, D.M. The operative management of displaced intra-articular fractures of the calcaneum: A two-centre study using a defined protocol. *Injury* **2001**, *32*, 491–496. [[CrossRef](#)] [[PubMed](#)]
54. Ibrahim, D.A.; Swenson, A.; Sassoon, A.; Fernando, N.D. Classifications In Brief: The Tscherne Classification of Soft Tissue Injury. *Clin. Orthop. Relat. Res.* **2017**, *475*, 560–564. [[CrossRef](#)] [[PubMed](#)]
55. Gaston, P.; Will, E.; Elton, R.A.; McQueen, M.M.; Court-Brown, C.M. Fractures of the tibia: CAN THEIR OUTCOME BE PREDICTED? *J. Bone Jt. Surg. Br. Vol.* **1999**, *81-B*, 71–76. [[CrossRef](#)]
56. Folk, J.W.; Starr, A.J.; Early, J.S. Early wound complications of operative treatment of calcaneus fractures: Analysis of 190 fractures. *J. Orthop. Trauma* **1999**, *13*, 369–372. [[CrossRef](#)] [[PubMed](#)]
57. Schweitzer, K.M.J.; Gaskill, T.R.; Easley, M.E.; Nunley, J.A., 2nd. Open Reduction and Internal Fixation of Intra-Articular Calcaneal Fractures Via an Extensile Lateral Approach. *JBJS Essent. Surg. Tech.* **2011**, *1*, e7. [[CrossRef](#)] [[PubMed](#)] [[PubMed Central](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.