

Review began 10/03/2026
Review ended 10/11/2026
Published 10/27/2026

© Copyright 2026
Elnewishy et al. This is an open access article distributed under the terms of the Creative Commons Attribution License CC-BY 4.0., which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

DOI: 10.7759/cureus.118689

Primary Tibiototalcalcaneal Nailing Versus Open Reduction and Internal Fixation for Unstable Ankle Fractures in Older and High-Risk Adults: A Systematic Review and Meta-Analysis

Ahmed Elnewishy ¹, Pir Zarak Khan ¹, Yazan Shalan ¹, Harris Mangal ¹, Shajee Ud Din ¹, Sean M. Garcia ², Hagar Teama ³, Styliani Zachari ⁴, Rami Ali Abowali ¹

1. Trauma and Orthopaedics, Maidstone and Tunbridge Wells NHS Trust, Tunbridge Wells, GBR 2. Trauma and Orthopaedics, William Harvey Hospital, Ashford, GBR 3. Pharmacy, Independent Researcher, London, GBR 4. Trauma and Orthopaedics, Tunbridge Wells Hospital, Tunbridge Wells, GBR

Corresponding author: Ahmed Elnewishy, ahmed.elnewishy93@gmail.com

Abstract

Background: Primary tibiototalcalcaneal (TTC) nailing has been proposed as an alternative to open reduction and internal fixation (ORIF) for unstable ankle fractures in older and medically high-risk adults, particularly when poor bone quality, frailty, soft-tissue compromise, or inability to comply with non-weight-bearing restrictions make conventional fixation less suitable. This systematic review and meta-analysis compared primary TTC nailing or tibiototalcalcaneal arthrodesis (TTCA) with ORIF in this population.

Methods: PubMed, Scopus, Web of Science, Embase, and Google Scholar were searched from inception to June 2026. Eligible studies directly compared primary TTC nailing/TTCA with ORIF for unstable ankle fractures in older or high-risk adults and reported extractable quantitative outcomes. Risk ratios were used for dichotomous outcomes and mean differences for continuous outcomes. Study quality was assessed using the modified Downs and Black Checklist.

Results: Eight comparative studies involving 1,443 treatment episodes were included. Pooled analysis showed no statistically significant difference between TTC nailing/TTCA and ORIF in length of hospital stay, overall postoperative infection, implant-related complications, nonunion, reoperation, or mortality. Superficial infection was significantly lower after TTC nailing, and individual studies consistently reported earlier postoperative weight-bearing with TTC fixation. However, some database and cohort studies reported higher readmission, malunion/nonunion, or secondary surgery after TTCA.

Conclusion: Primary TTC nailing may be a reasonable alternative to ORIF for carefully selected older or high-risk patients, especially when early weight-bearing and reduced soft-tissue exposure are priorities. Current evidence does not demonstrate clear overall superiority over ORIF and remains limited by heterogeneity and residual confounding.

Categories: Trauma, Orthopedics

Keywords: a systematic review and meta-analysis, early weight bearing, fragility ankle fractures, geriatric ankle fractures, hindfoot nailing, open reduction and internal fixation (orif), osteoporotic ankle fractures, tibiototalcalcaneal arthrodesis, tibiototalcalcaneal nailing, unstable ankle fractures

Introduction And Background

Ankle fractures represent a substantial and increasing healthcare burden in adults and older populations. A Danish nationwide cohort identified 155,740 ankle fractures between 1997 and 2018, with a mean incidence of 164 per 100,000 person-years [1]. A Swedish registry study recorded 57,443 ankle fractures in 56,439 patients over 10 years, with women accounting for 61% of cases and a mean patient age of 55 years [2]. The clinical burden becomes greater with advancing age because ankle fractures may impair independence, ambulation, and return to preinjury function. Reported mortality after geriatric ankle fracture ranges from 10% to 27%, particularly among frail patients and those with substantial comorbidity [3].

Low-energy falls, reduced bone quality, multimorbidity, and limited physiological reserve make treatment of these injuries distinct from treatment in younger adults [4]. Preinjury mobility, ability to comply with non-weight-bearing restrictions, and patient-centred functional goals should influence operative decision-making [5]. Contemporary reviews emphasize that soft-tissue fragility, medical comorbidity, and frailty may be more important than chronological age alone when selecting fixation strategies [6,7].

Open reduction and internal fixation (ORIF) remains the standard surgical option for most unstable ankle fractures. However, osteoporotic bone can reduce screw fixation strength and increase the risk of

How to cite this article

Elnewishy A, Khan P, Shalan Y, et al. (October 27, 2026) Primary Tibiototalcalcaneal Nailing Versus Open Reduction and Internal Fixation for Unstable Ankle Fractures in Older and High-Risk Adults: A Systematic Review and Meta-Analysis. Cureus 18(10): e118689. DOI 10.7759/cureus.118689

mechanical failure in selected patients [8]. A geriatric surgical cohort identified a substantial burden of postoperative complications after ankle-fracture fixation [9]. Functional recovery after ankle fracture in adults older than 55 years is also influenced by baseline function, age, fracture severity, and treatment-related complications [10]. A systematic review found an association between lower bone mineral density and ankle fractures in older adults, although the relationship was heterogeneous across studies [11].

Older and high-risk adults may have diabetes mellitus, peripheral neuropathy, peripheral vascular disease, poor skin quality, severe osteoporosis, or limited baseline mobility. These factors increase the risks of wound breakdown, infection, fixation failure, delayed recovery, and loss of independence [12]. Low-energy open ankle fractures in older adults are particularly difficult because soft-tissue damage and medical frailty may require individualized and multidisciplinary treatment pathways [13]. Evidence comparing surgical and conservative strategies remains uncertain in some ankle-fracture populations, supporting individualized treatment that incorporates fracture stability, biological risk, and functional demand [14,15].

Primary tibiototalcanal (TTC) nailing is a retrograde intramedullary stabilization method that spans the ankle and hindfoot. The construct is intended to provide load-sharing fixation through limited surgical exposure and may be useful when conventional fixation is mechanically or biologically unfavourable [16]. TTC nailing can permit early protected or full weight-bearing in selected low-demand older adults while reducing the need for extensive soft-tissue dissection [17]. A prospective study of transplatar nailing described functional recovery during 48 weeks of follow-up in elderly patients with ankle fractures [18].

Evidence supporting TTC nailing has expanded through case series, cohort studies, and systematic reviews. A systematic review of hindfoot nailing for fragility ankle fractures reported bony union rates ranging from 90.3% to 100% across the included studies [19]. TTC nailing has also been used for complicated diabetic ankle fractures, although this group remains at increased risk of infection, nonunion, implant-related complications, and reoperation [20]. A multicentre geriatric cohort further demonstrated that TTC intramedullary nailing is used as a primary stabilization strategy for unstable ankle fractures in selected older adults [21].

Two systematic evidence syntheses identified 14 and 24 eligible studies, respectively, and both highlighted heterogeneous surgical techniques, rehabilitation pathways, and predominantly noncomparative evidence [22,23]. The more recent systematic review reported a mean union rate of 88.36% and a mean healing time of 17.8 weeks after TTC nailing in adults older than 65 years [23]. However, favourable union and early weight-bearing outcomes do not by themselves establish comparative superiority over ORIF because TTC nailing is often selected for patients with greater frailty, poorer soft-tissue condition, or lower preinjury functional demand [22,24]. A focused synthesis comparing primary TTC nailing with ORIF is therefore needed to clarify the relative effects of these strategies on complications, reoperation, mortality, union, mobility, length of stay, and functional recovery in older and high-risk adults.

This systematic review and meta-analysis aimed to compare primary TTC nailing versus ORIF for unstable ankle fractures in older and high-risk adults.

Review

Methods

Search Strategy

In order to detect studies comparing primary TTC nailing or tibiototalcanal arthrodesis (TTCA) with ORIF for unstable ankle fractures in older and high-risk adults, a systematic review was conducted by searching PubMed, Scopus, Web of Science, Embase, and Google Scholar from database inception to June 2026. The search strategy used MeSH terminology and free-text keywords, such as “ankle fracture,” “unstable ankle fracture,” “fragility ankle fracture,” “geriatric ankle fracture,” “elderly,” “older adults,” “high-risk,” “neuropathic ankle fracture,” “trimalleolar fracture,” “fracture-dislocation,” “tibiototalcanal nail,” “tibiototalcanal nailing,” “TTC nailing,” “hindfoot nail,” “hindfoot nailing,” “tibiototalcanal arthrodesis,” “TTCA,” “open reduction and internal fixation,” and “ORIF.” The reference lists of eligible studies and relevant systematic reviews were also screened by hand.

Inclusion Criteria

Prospective or retrospective comparative studies were eligible if they directly compared primary TTC nailing or TTCA with ORIF in older or medically high-risk adults with unstable ankle fractures. Eligible fracture patterns included unstable malleolar, bimalleolar, trimalleolar, fragility, neuropathic, open, or fracture-dislocation ankle fractures when relevant to the review population. Primary TTC treatment included retrograde hindfoot nailing or TTC arthrodesis, with or without formal joint preparation. The comparator treatment was conventional ORIF using plate-and-screw fixation or related internal fixation constructs. Studies were required to report extractable quantitative data for at least one clinical outcome. Only full-text articles published in English were considered [24].

Exclusion Criteria

Studies were excluded if they did not directly compare primary TTC nailing/TTCA with ORIF, lacked extractable numerical outcome data, evaluated TTC nailing only or ORIF only, or included an ineligible population or fracture pattern without separately reported eligible data. Studies evaluating non-primary TTC procedures, delayed salvage arthrodesis, revision surgery after failed fixation, chronic deformity correction, Charcot reconstruction without acute fracture comparison, or non-comparable interventions were also excluded. Case reports, noncomparative case series, reviews, editorials, letters, conference abstracts, cadaveric studies, technical reports, and duplicate or overlapping cohorts were excluded. When overlapping cohorts were identified, the study with the most complete dataset or longest follow-up was included.

Outcome Measures

The primary outcomes were hospital LOS and postoperative complications. Postoperative complications included total postoperative infection, deep infection, superficial infection, implant-related complications, nonunion, and reoperation. Mortality was assessed as an additional major safety outcome. Other outcomes of interest included wound complications, malunion, readmission, secondary surgery, return to mobility, postoperative weight-bearing status, functional scores, operative time, discharge destination, and follow-up duration. These outcomes were selected because they reflect the main clinical concerns in older and high-risk adults undergoing fixation for unstable ankle fractures, including hospitalization burden, infection risk, mechanical failure, bone healing, need for further surgery, functional recovery, and survival [24].

Data Extraction and Quality Assessment

Study design, sample size, patient demographics, fracture characteristics, eligibility criteria, intervention details, comparator treatment, follow-up duration, and reported outcomes were extracted from each included study using standardized data extraction forms customized for this review. Data extraction for each publication was carried out by two independent reviewers and cross-checked for discrepancies. Any disagreements were resolved through discussion and consensus. Methodological quality was assessed using the modified Downs and Black Checklist, which evaluates reporting, external validity, internal validity related to bias, internal validity related to confounding, and statistical power [25].

Statistical Analysis

Review Manager (RevMan v5.4, The Cochrane Collaboration, London, UK) was used for all analyses [26–28]. Risk ratios (RRs) with 95% confidence intervals were calculated for dichotomous data. Mean differences with 95% confidence intervals were calculated for continuous data measured on the same scale. The chi-square test and I^2 statistic were used to assess heterogeneity. A fixed-effect model was used when heterogeneity was low or moderate ($I^2 \leq 50\%$), whereas a random-effects model was used when heterogeneity was substantial ($I^2 > 50\%$). A p-value of less than 0.05 was considered statistically significant.

Results

Search Results and Study Selection

A systematic search of PubMed, Scopus, Web of Science, Embase, and Google Scholar was conducted to identify comparative studies evaluating primary TTC nailing or TTCA versus ORIF for unstable ankle fractures in older or medically high-risk adults. Search terms included “ankle fracture,” “fragility ankle fracture,” “geriatric ankle fracture,” “neuropathic ankle fracture,” “trimalleolar fracture,” “tibiototalcaneal nail,” “hindfoot nail,” “TTC nailing,” “tibiototalcaneal arthrodesis,” “TTCA,” “open reduction internal fixation,” and “ORIF.” The reference lists of eligible studies and relevant systematic reviews were manually screened to identify additional comparative reports.

The search identified 361 records, of which 106 duplicates were removed. After screening 255 titles and abstracts, 210 records were excluded. Forty-five full-text articles were assessed for eligibility, and 37 were excluded because they were not direct comparisons between TTC nailing/TTCA and ORIF ($n = 15$), involved an ineligible population or fracture pattern ($n = 7$), reported insufficient numerical data for the outcomes of interest ($n = 7$), evaluated non-primary TTC procedures or non-comparable interventions ($n = 5$), or represented duplicate or overlapping cohorts ($n = 3$). Ultimately, eight comparative studies were included in the systematic review and meta-analysis. Two reviewers independently screened all records and extracted data using a standardized data extraction form. Disagreements were resolved through discussion and consensus. The study selection process is summarized in Figure 1.

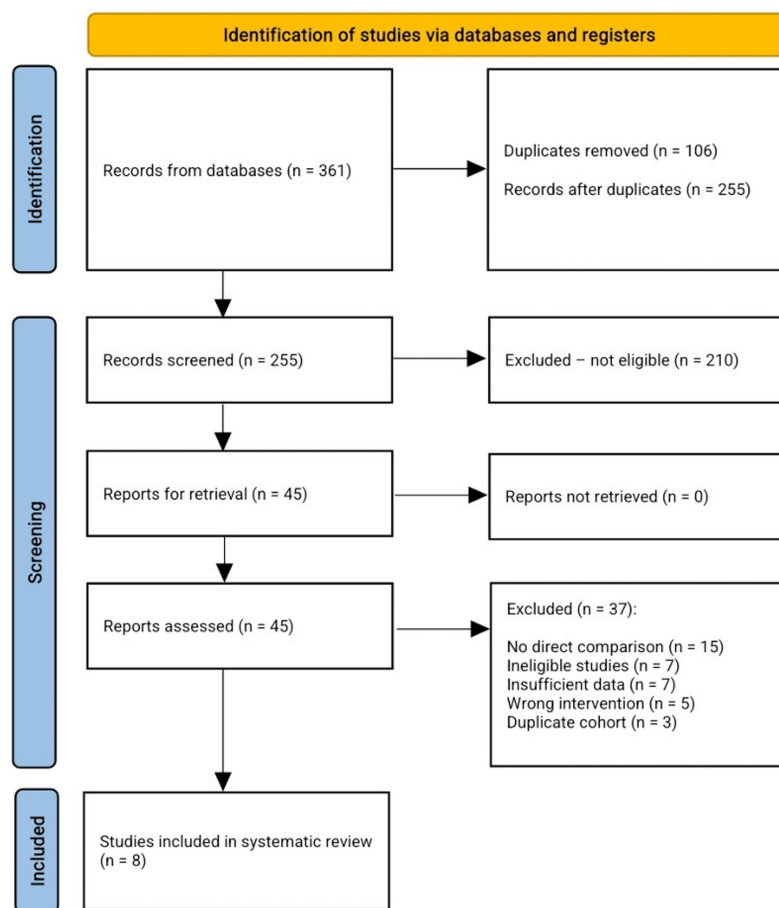


FIGURE 1: PRISMA flow chart for the included studies.

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

Study Characteristics

Eight comparative studies involving 1,443 treatment episodes were included, comprising 664 primary TTC nailing/TTCA procedures and 779 ORIF procedures. One study was a prospective randomized controlled trial, whereas seven were retrospective comparative cohorts, including single-centre case-control studies, matched cohorts, and propensity score-matched national or multicentre database analyses. Most studies enrolled older or medically high-risk adults with unstable, displaced, fragility, neuropathic, open, or fracture-dislocation ankle fractures. Age thresholds ranged from >50 years to ≥75 years in the predominantly geriatric cohorts; however, three studies included broader adult populations with high-risk clinical characteristics or trimalleolar fractures. Participants were generally medically complex, with frequent diabetes mellitus, peripheral neuropathy, obesity, osteoporosis, peripheral vascular disease, frailty, smoking history, open fractures, and fracture-dislocation patterns.

Primary TTC treatment consisted of retrograde hindfoot nailing or TTC arthrodesis, often performed without formal joint preparation and intended to facilitate earlier postoperative weight-bearing. However, joint preparation was performed in a substantial proportion of patients in the neuropathic fracture cohort of DeMedal et al. Conventional ORIF generally involved plate-and-screw fixation followed by temporary non-weight-bearing restrictions. Follow-up ranged from a minimum of six weeks to approximately 46 months, while database studies reported outcomes between 30 days and 2 years after surgery. Reported outcomes included length of hospital stay (LOS), postoperative weight-bearing status, mobility, functional scores, infection, wound complications, implant-related complications, nonunion or malunion, reoperation, readmission, secondary surgery, and mortality. Overall, TTC fixation consistently enabled earlier weight-bearing and demonstrated lower wound-related complications in selected elderly cohorts; however, some comparative studies reported higher overall complications, nonunion or malunion, readmission, reoperation, or long-term secondary surgery after TTCA. Table 1 summarizes the characteristics and principal findings of the included studies.

Study	Study design/level of evidence	Sample size (primary TTC/ORIF)	Patient demographics and eligibility	Intervention details	Follow-up duration	Outcome measures	Results	Complications	Conclusion
Balziano et al. [27]	Retrospective single-centre comparative cohort; Level III	18/28; total n = 46	Patients aged ≥75 years with surgically treated unstable ankle fractures. TTC patients were older than ORIF patients: 88.6 ± 4.6 vs 81.8 ± 4.8 years. Diabetes: 27.8% vs 17.9%; open fractures: 5.6% vs 10.7%.	Primary TTC hindfoot nail without tibiotalar or subtalar joint preparation, with immediate weight -bearing; compared with standard ORIF.	Mean 46.4 ± 25.3 months; median 49.5 months	Primary: overall and major complications; revision surgery. Secondary: LOS, operative time, FAAM-ADL, OMAS, return to mobility.	Overall complications were lower after TTC: 22.2% vs 50.0%; major complications: 5.6% vs 28.6%. Revision: 11.1% vs 28.6%. LOS and operative duration were similar. Functional scores favoured ORIF: FAAM-ADL 62.6% vs 32.4%; OMAS 60.0 vs 32.8.	TTC: fewer overall and major complications; ORIF: more infections, wound-related complications, nonunion, and revision procedures.	TTC nailing without joint preparation produced a more favourable complication profile in extremely elderly patients, but patient-reported functional outcomes were inferior to ORIF.
Dawar et al. [28]	Retrospective nationwide database analysis using propensity-score matching; Level III prognostic study	295/307; total n = 602 after matching	Adults aged ≥18 years with trimalleolar ankle fractures treated from 2016 to 2021. Matching included age, sex, diabetes, hypertension, chronic kidney disease, osteoporosis, obesity, morbid obesity, and heart failure. High-risk subgroup: age ≥60 years plus ≥1 specified comorbidity.	TTCA identified through ICD-10 procedure coding for ankle and tarsal fusion; compared with ORIF identified through open internal fixation procedure coding. Specific implant, joint preparation, and weight-bearing protocol were unavailable.	Database outcome windows of 30 and 90 days; nonunion and malunion evaluated in patients with ≥90 days of follow-up	Any complication, infection, cellulitis, wound dehiscence, implant complication, nonunion, malunion, thromboembolism, and 30-/90-day readmission.	TTCA had higher any-complication rate: 35% vs 13%; higher nonunion: 10% vs 2%; higher malunion: 13% vs 1%; higher 30-day readmission: 25% vs 13%; and higher 90-day readmission: 20% vs 10%.	TTCA was associated with more nonunion, malunion, readmission, and overall postoperative morbidity. Infection and implant-complication rates were not significantly different.	In this database cohort, ORIF was associated with fewer complications and readmissions than TTCA; TTCA should be reserved for carefully selected patients when conventional fixation is unlikely to succeed.
DeMedal et al. [29]	Retrospective single-centre comparative cohort; Level III	19 / 26; total n = 45	Adults aged >18 years with lower-extremity neuropathy and operatively treated ankle fractures, including unimalleolar, bimalleolar, trimalleolar, and distal fibular fractures. Median age: 66.0 years in TTC vs 64.5 years in ORIF. Diabetes: 89.5% vs 100.0%; vascular comorbidity: 89.5% versus 96.2%; open fractures: 10.5% vs 7.7%, respectively.	Primary TTC fusion using a retrograde hindfoot nail; 14/19 (73.7%) underwent joint preparation before nail placement. Comparator: conventional plate-and-screw ORIF without joint preparation.	Median follow-up: 266 days (IQR 90-349) for TTC vs 419 days (IQR 135-692) for ORIF. Minimum follow-up: 3 months	Reoperation, infection, wound dehiscence/poor wound healing, readmission, nonunion, hardware failure, postoperative weight-bearing status, opioid use, and discharge time.	TTC enabled earlier weight-bearing at 2 weeks: WBAT in 42.1% vs 7.7% after ORIF; non-weight-bearing in 36.8% vs 80.8% (p = 0.007). No statistically significant between-group differences in reoperation (55.6% vs 53.8%), infection (42.1% vs 26.9%), wound problems (47.4% vs 42.3%), readmission (36.8% vs 42.3%), nonunion (16.7% vs 11.5%), or failed hardware (22.2% vs 42.3%).	Both strategies had a high postoperative complication burden. TTC had numerically higher infection, wound complications, nonunion, and reoperation, whereas ORIF had more hardware failure and readmission; none of these differences were statistically significant.	In neuropathic, predominantly diabetic ankle fracture patients, TTC fusion permitted earlier postoperative weight-bearing but showed no clear difference in subsequent complication or reoperation outcomes compared with ORIF.
Georgiannos et al. [30]	Prospective single-centre randomized controlled trial; Level I	43 / 44; total n = 87	Patients aged >70 years with closed unstable bimalleolar or trimalleolar ankle fractures or fracture-dislocations. Excluded open fractures, high-energy trauma, cognitive impairment, pathological fractures, severe peripheral vascular disease, and diabetic angiopathy. Mean age: 78 vs 77 years.	TTC group: closed reduction and Trigen hindfoot nail, without joint preparation; immediate full weight-bearing as tolerated and no postoperative immobilization. ORIF group: lateral plate and screws with medial malleolar screws; non-weight-bearing cast for 6 weeks, then walking boot and range-of-motion exercises.	Mean 14 months; range 12-18 months. Clinical assessments at 2 and 6 weeks, and 3 and 12 months	Postoperative complications, LOS, mobility status, reoperation, OMAS, and 1-year mortality.	TTC reduced LOS: 5.2 ± 3.1 vs 8.4 ± 5.2 days. Postoperative complications: 8.1% vs 33.3%. Similar postoperative OMAS: 56.9 vs 56.6. Return to preinjury mobility: 75.6% vs 72.2%. One-year mortality: 13.9% vs 18.1%.	TTC: 3 postoperative complications and 1 reoperation. ORIF: 12 postoperative complications and 5 reoperations.	Primary TTC nailing was associated with fewer complications and shorter hospitalization, while preserving mobility and functional outcome comparable with ORIF.
	Retrospective		Patients aged ≥60 years with	TTC hindfoot nail without formal arthrodesis or	Minimum	Reoperation,			TTC fixation allowed earlier

Hussien et al. [31]	single-centre comparative cohort with propensity-score matching; Level III by design	Unmatched: 39/91; total n = 130. Matched cohort: 21/21	rotational malleolar ankle fractures and radiographic tibiotalar instability. Excluded tibial plafond/pilon fractures and follow-up <6 weeks. TTC patients were older, had higher Charlson Comorbidity Index scores, and more peripheral neuropathy.	cartilage preparation; selected mainly for frail patients, anticipated difficulty complying with weight-bearing restrictions, or concern for wound healing. Comparator: conventional plate-and-screw ORIF constructs.	radiographic follow-up of 6 weeks; postoperative complications and mortality assessed to 90 days	implant failure, culture-positive/deep infection, death within 90 days, time to weight-bearing, and discharge destination.	TTC patients commenced weight-bearing earlier: 1.6 vs 9.8 weeks; p < 0.001. After matching, no significant difference in reoperation, implant failure, deep infection, death, or adjusted discharge destination.	TTC and ORIF had comparable early complication rates despite greater medical complexity in the TTC cohort.	weight-bearing without an increase in early complications, but did not independently improve discharge-to-home rates.
Large et al. [32]	Retrospective case-control cohort using prospectively collected trauma-registry data; Level III	14/47 fractures; total n = 61 fractures in 60 patients. TTC involved 14 nails in 13 patients	Patients aged >50 years with either open ankle fracture or >50% talar subluxation/dislocation, plus ≥1 high-risk factor: diabetes, peripheral vascular disease, active smoking, immunosuppression, or BMI >35 kg/m². Mean age: 68.0 vs 71.0 years. Diabetes was more common in TTC patients: 78.6% vs 42.6%.	TTC fusion nail or plate-and-screw ORIF. Treatment selection was based on surgeon preference, injury characteristics, and patient medical risk.	Mean 17.9 months; IQR 7.44–24.59 months. Forty-three of 60 patients had >1-year follow-up	Primary: 1-year reoperation. Secondary: infection, union, nonunion/malunion, peri-implant fracture, LOS, discharge disposition, medical complications, mortality, time to weight-bearing, PROMIS, and OMAS.	No significant difference in reoperation: 21.4% vs 17.0%; infection: 14.3% vs 12.8%; or union: 85.7% vs 76.6%. Functional outcome data were incomplete.	One TTC patient sustained a peri-implant fracture treated nonoperatively. Overall complication, infection, reoperation, and union outcomes were comparable.	In high-risk ankle fractures among older adults, TTC fusion nailing and ORIF showed comparable short-term reoperation, infection, and union rates.
Mahatme et al. [33]	Retrospective multicentre database cohort using TriNetX with 1:1 propensity-score matching; Level III by design	210/210; total n = 420 after matching	Adults aged ≥18 years with trimalleolar ankle fractures and at least 2 years of follow-up. Matching included age, sex, obesity, tobacco use, osteoporosis, diabetes, dementia, and peripheral vascular disease. Closed-fracture sensitivity cohort: 147 / 147.	TTCA versus ORIF identified from procedure codes in TriNetX. Surgical implant, joint preparation, postoperative immobilization, and weight-bearing protocols were not available.	Outcomes assessed at 90 days, 1 year, and 2 years	Primary: secondary surgery, including revision, irrigation and debridement, hardware removal, amputation, and other fracture-related procedures. Secondary: 90-day infection, wound dehiscence, nonunion/malunion, and mortality.	At 90 days, infection rates were similar: 5.7% vs 5.7%. TTCA had higher secondary surgery at 1 year: 28.1% vs 17.1%; and at 2 years: 31.4% vs 21.0%. Irrigation and debridement were also more frequent after TTCA at 1 and 2 years.	TTCA had a higher burden of secondary surgery, particularly irrigation and debridement. Early infection and wound complications were similar.	TTCA was associated with greater long-term secondary surgery than ORIF, despite similar early wound and infection outcomes; residual confounding remained possible.
Ou and Baker [34]	Retrospective matched case-control study; Level III	26/26; total n = 52	Patients aged >65 years with displaced ankle fractures. ORIF patients matched to TTC patients by age, sex, Charlson Comorbidity Index, and preinjury KPS. Mean age: 84 vs 83 years. Diabetes: 30.8% vs 26.9%; open fractures: 15.4% vs 19.2%.	TTC/hindfoot nailing with preserved joint surfaces and no formal joint preparation; most nails were Valor or Expert hindfoot fusion nails. Comparator: standard ORIF with plate-and-screw fixation.	One-year mobility and mortality outcomes reported	Complication rate, return to theatre, infection, metalwork failure, wound complications, LOS, operative time, mortality, weight-bearing timing, mobility, and discharge disposition.	TTC allowed earlier weight-bearing: 22 vs 59 days; p < 0.001. No significant difference in LOS, operation time, mortality, discharge disposition, or return to previous mobility. Return to theatre: 7 vs 2 cases; p = 0.07.	TTC group had 12 recorded complications, including deep infection, metalwork failure, and wound problems; ORIF had 11 complications. More TTC patients required reoperation.	Hindfoot nailing enabled earlier weight-bearing but was associated with a higher tendency toward complications and return to theatre than matched ORIF.

TABLE 1: Characteristics of included studies comparing primary TTC nailing/arthrodesis with ORIF for unstable ankle fractures in older and high-risk adults.

TTC: tibiototalcanal; TTCA: tibiototalcanal arthrodesis; ORIF: open reduction and internal fixation; LOS: length of hospital stay; FAAM-ADL: Foot and Ankle Ability Measure—Activities of Daily Living; OMAS: Olerud-Molander Ankle Score; CCI: Charlson Comorbidity Index; KPS: Karnofsky Performance Scale; CFS: Clinical Frailty Scale; PROMIS: Patient-Reported Outcomes Measurement Information System; BMI: body mass index; DM: diabetes mellitus; ASA: American Society of Anesthesiologists physical status classification; IQR: interquartile range; SD: standard deviation; PSM: propensity score matching.

Quality Assessment of Included Studies

Methodological quality was assessed using the modified 28-point Downs and Black Checklist, which is

applicable to randomized and non-randomized comparative intervention studies. The checklist evaluates reporting, external validity, internal validity-bias, internal validity-confounding, and statistical power. Total scores were categorized as Excellent (≥ 25), Good (21–24), Fair (17–20), and Poor (< 17).

The eight included studies were of fair-to-good methodological quality. One study was a prospective randomized controlled trial, whereas the remaining seven were retrospective comparative cohorts, including matched single-centre cohorts and propensity-score-matched national or multicentre database studies. The main strengths were clear reporting of objectives, eligibility criteria, interventions, and principal postoperative outcomes.

Important limitations included retrospective treatment allocation, incomplete adjustment for confounding, preferential selection of frailer and medically complex patients for TTC fixation, small sample sizes in several single-centre studies, heterogeneity in fracture characteristics and operative techniques, lack of blinding, and inconsistent follow-up durations. Three studies were rated Good and five were rated Fair, with no study rated Excellent or Poor. Fair-quality studies were retained in the quantitative meta-analysis but interpreted cautiously, particularly when considering clinical heterogeneity and the risk of residual confounding. The detailed quality assessment of all included studies is presented in Table 2.

Study	Study design	Reporting (0–11)	External validity (0–3)	Internal validity – bias (0–7)	Internal validity – confounding (0–6)	Power (0–1)	Total score (max 28)	Quality rating
Balziano et al. [27]	Retrospective single-centre comparative cohort	9	1	4	3	0	17	Fair
Dawar et al. [28]	Retrospective nationwide database cohort with propensity-score matching	10	3	4	5	0	22	Good
DeMedal et al. [29]	Retrospective single-centre comparative cohort	9	1	4	3	0	17	Fair
Georgiannos et al. [30]	Prospective single-centre randomized controlled trial	10	1	5	5	1	22	Good
Hussien et al. [31]	Retrospective single-centre comparative cohort with propensity-score matching	10	1	4	4	0	19	Fair
Large et al. [32]	Retrospective comparative cohort using prospectively collected trauma registry data	9	1	4	3	0	17	Fair
Mahatme et al. [33]	Retrospective multicentre TriNetX database cohort with propensity-score matching	10	3	4	5	0	22	Good
Ou and Baker [34]	Retrospective matched case-control cohort	9	1	4	4	0	18	Fair

TABLE 2: Quality assessment of included studies using the modified Downs and Black Checklist.

Scores reflect performance across the five Downs and Black domains. Ratings: Excellent (≥ 25), Good (21–24), Fair (17–20), and Poor (< 17).

TTC: tibiototalcanal; TTCA: tibiototalcanal arthrodesis; ORIF: open reduction and internal fixation.

Results of the meta-analysis

Comparison of LOS Between Primary TTC Nailing and ORIF

A pooled analysis of LOS showed no statistically significant difference between primary TTC nailing and ORIF (mean difference = 0.81 days, 95% CI: -1.44 to 3.07 ; $p = 0.48$). Heterogeneity was substantial ($I^2 = 81\%$, $p < 0.0001$) (Figure 2). The pooled estimate numerically favoured ORIF, but the confidence interval crossed the line of no effect.

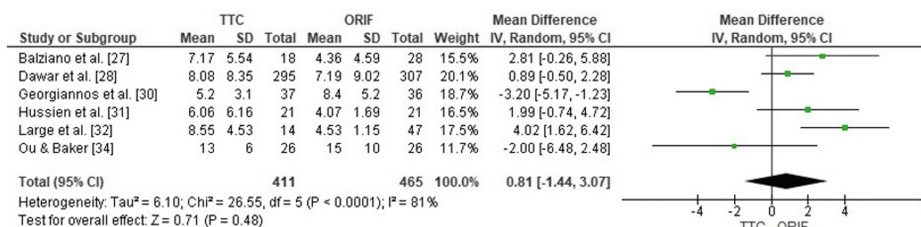


FIGURE 2: Forest plot comparing LOS between primary TTC nailing and ORIF for unstable ankle fractures in older and high-risk adults.

CI: confidence interval; TTC: tibiototalcanal; ORIF: open reduction and internal fixation; LOS: length of hospital stay.

Comparison of Postoperative Infection Between Primary TTC Nailing and ORIF

A pooled analysis of postoperative infection outcomes showed no statistically significant difference between primary TTC nailing and ORIF (RR = 0.86, 95% CI: 0.61 to 1.23; $p = 0.41$). Heterogeneity was low ($I^2 = 7\%$, $p = 0.37$) (Figure 3). In the subgroup analysis, total infection showed no statistically significant difference between groups (RR = 0.96, 95% CI: 0.63 to 1.45; $p = 0.84$), with low heterogeneity ($I^2 = 4\%$, $p = 0.39$). Deep infection also showed no statistically significant difference (RR = 1.47, 95% CI: 0.57 to 3.77; $p = 0.43$), with absent heterogeneity ($I^2 = 0\%$, $p = 0.46$). However, superficial infection was significantly lower with primary TTC nailing (RR = 0.26, 95% CI: 0.08 to 0.85; $p = 0.03$), with absent heterogeneity ($I^2 = 0\%$, $p = 0.77$). The test for subgroup differences was not statistically significant ($p = 0.07$).

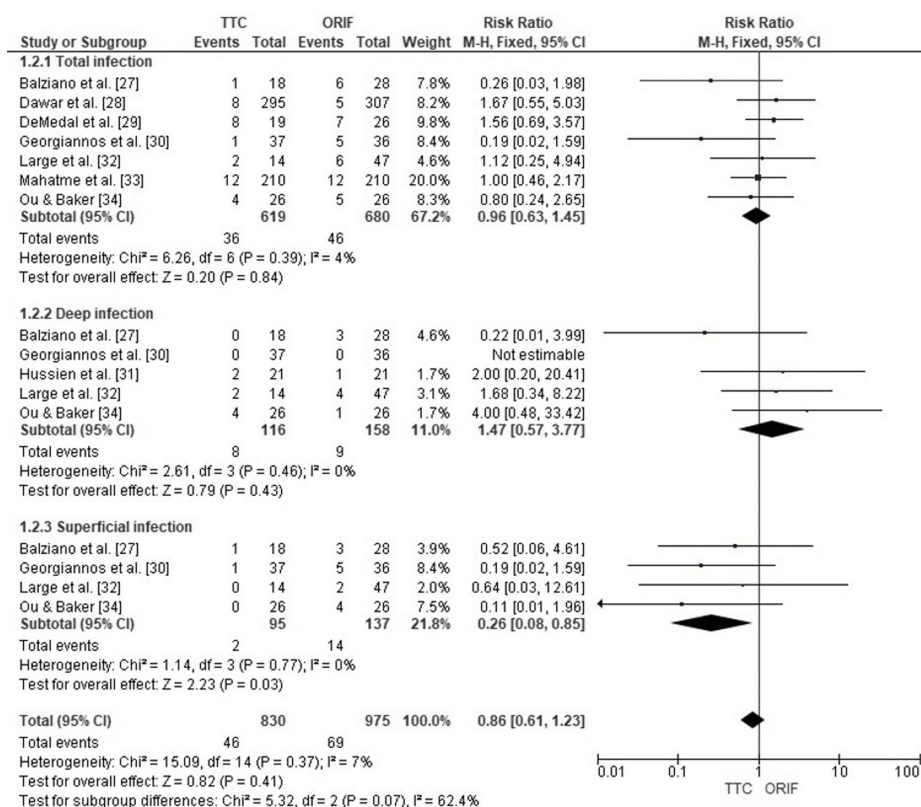


FIGURE 3: Forest plot comparing postoperative infection, including total infection, deep infection, and superficial infection, between primary TTC nailing and ORIF for unstable ankle fractures in older and high-risk adults.

CI: confidence interval; TTC: tibiototalcanal; ORIF: open reduction and internal fixation; M-H, Mantel-Haenszel.

Comparison of Implant-Related Complications Between Primary TTC Nailing and ORIF

A pooled analysis of implant-related complications showed no statistically significant difference between primary TTC nailing and ORIF (RR = 0.80, 95% CI: 0.47 to 1.38; $p = 0.42$). Heterogeneity was absent ($I^2 = 0\%$, $p = 0.67$) (Figure 4). Implant-related complications were comparable between the two treatment groups, although they were numerically lower with primary TTC nailing.

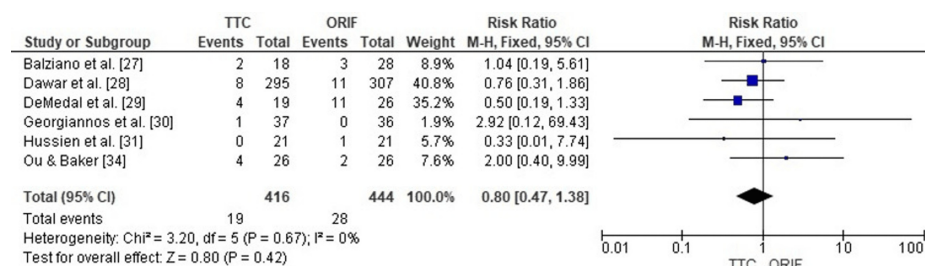


FIGURE 4: Forest plot comparing implant-related complications between primary TTC nailing and ORIF for unstable ankle fractures in older and high-risk adults.

CI: confidence interval; TTC: tibiototalcaneal; ORIF: open reduction and internal fixation; M-H, Mantel-Haenszel.

Comparison of Nonunion Between Primary TTC Nailing and ORIF

A pooled analysis of nonunion showed no statistically significant difference between primary TTC nailing and ORIF (RR = 0.99, 95% CI: 0.35 to 2.74; $p = 0.98$). Heterogeneity was moderate to substantial ($I^2 = 58\%$, $p = 0.03$) (Figure 5). Nonunion rates were comparable between the two treatment groups.

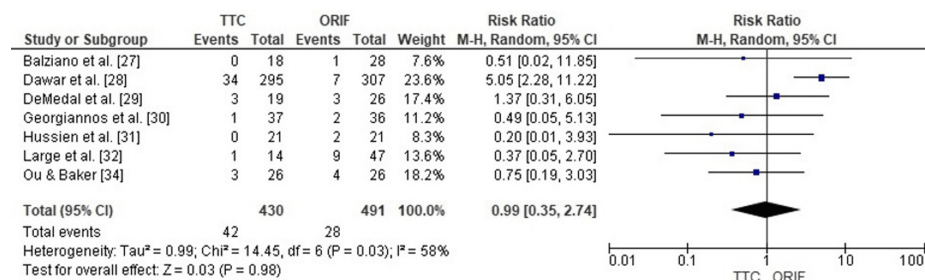


FIGURE 5: Forest plot comparing nonunion between primary TTC nailing and ORIF for unstable ankle fractures in older and high-risk adults.

CI: confidence interval; TTC: tibiototalcaneal; ORIF: open reduction and internal fixation; M-H, Mantel-Haenszel.

Comparison of Reoperation Between Primary TTC Nailing and ORIF

A pooled analysis of reoperation showed no statistically significant difference between primary TTC nailing and ORIF (RR = 1.24, 95% CI: 0.96 to 1.62; $p = 0.10$). Heterogeneity was moderate ($I^2 = 38\%$, $p = 0.14$) (Figure 6). Reoperation was numerically higher with primary TTC nailing, but the difference did not reach statistical significance.

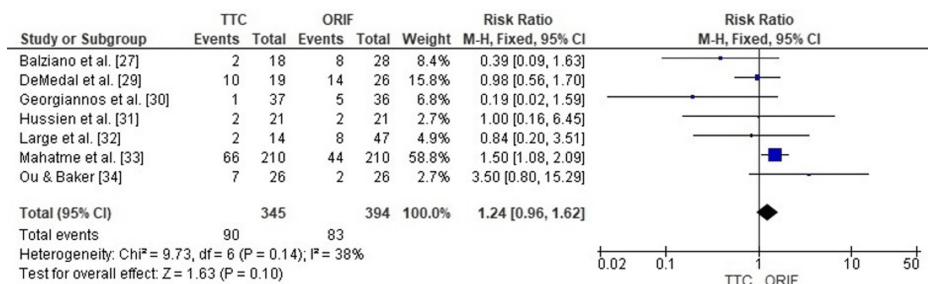


FIGURE 6: Forest plot comparing reoperation between primary TTC nailing and ORIF for unstable ankle fractures in older and high-risk adults.

CI: confidence interval; TTC: tibiototalcanal; ORIF: open reduction and internal fixation; M-H, Mantel-Haenszel.

Comparison of Mortality Between Primary TTC Nailing and ORIF

A pooled analysis of mortality showed no statistically significant difference between primary TTC nailing and ORIF ($RR = 1.11$, 95% CI: 0.69 to 1.78; $p = 0.67$). Heterogeneity was absent ($I^2 = 0\%$, $p = 0.86$) (Figure 7). Mortality was numerically higher with primary TTC nailing, but the difference was not statistically significant.

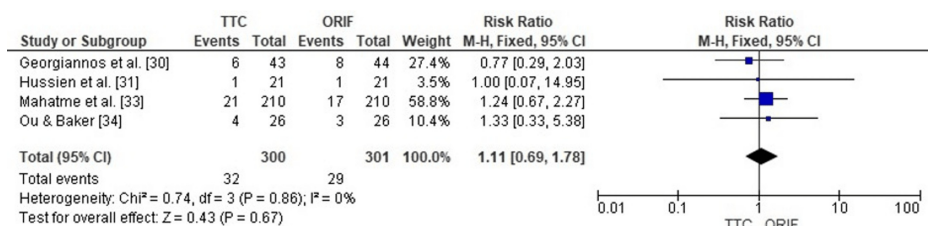


FIGURE 7: Forest plot comparing mortality between primary TTC nailing and ORIF for unstable ankle fractures in older and high-risk adults.

CI: confidence interval; TTC: tibiototalcanal; ORIF: open reduction and internal fixation; M-H, Mantel-Haenszel.

Discussion

This systematic review and meta-analysis compared primary TTC nailing or TTCA with ORIF for unstable ankle fractures in older and high-risk adults. Overall, the pooled findings did not show a statistically significant difference between TTC nailing/TTCA and ORIF for LOS, postoperative infection, implant-related complications, nonunion, reoperation, or mortality. These findings suggest that TTC fixation may provide comparable safety outcomes to ORIF in selected patients, although interpretation should remain cautious because TTC was often selected for frailer, older, or medically complex patients [27].

The main advantage of TTC nailing was earlier postoperative weight-bearing. Georgiannos et al. reported immediate full weight-bearing after TTC, with shorter LOS of 5.2 ± 3.1 versus 8.4 ± 5.2 days and fewer postoperative complications of 8.1% versus 33.3%. Hussien et al. [31] found earlier weight-bearing after TTC (1.6 versus 9.8 weeks), without an increase in early complications. Ou and Baker also reported earlier weight-bearing after hindfoot nailing (22 versus 59 days), although return to theatre was higher (7 versus 2 cases). Therefore, TTC fixation may be useful when early mobilization is important or when non-weight-bearing compliance is unlikely.

Despite this advantage, hospital stay was not consistently improved. Georgiannos et al. reported shorter hospitalization after TTC, whereas Balziano et al. [27] and Ou and Baker [34] reported no significant difference in LOS between groups. This suggests that length of stay may depend not only on fixation method but also on frailty, comorbidities, discharge destination, rehabilitation protocols, and institutional practice [29].

Postoperative infection outcomes were generally comparable between TTC nailing/TTCA and ORIF. Superficial infection was lower with TTC in the pooled analysis, possibly because TTC requires less soft-tissue dissection than plate-and-screw fixation. However, infection risk varied by population. DeMedal et al. [29] reported high infection and wound problem rates in neuropathic patients, with infection of 42.1% versus 26.9% and wound problems of 47.4% versus 42.3%. This indicates that diabetes, neuropathy, vascular disease, and soft-tissue condition may be more important determinants of infection than implant choice alone [30].

Implant-related complications and nonunion were also not significantly different in the pooled analyses. However, individual studies showed different patterns. Dawar et al. [28] reported higher any-complication rates after TTCA (35% versus 13%), with higher nonunion (10% versus 2%), and malunion (13% versus 1%). In contrast, Large et al. [32] reported comparable reoperation, infection, and union outcomes, with reoperation of 21.4% versus 17.0%, infection of 14.3% versus 12.8%, and union of 85.7% versus 76.6%. These differences likely reflect variation in patient selection, fracture severity, surgical technique, joint preparation, and follow-up duration [31].

Reoperation remains an important concern. Mahatme et al. [33] reported higher secondary surgery after TTCA, with rates of 28.1% versus 17.1% at one year and 31.4% versus 21.0% at two years. Ou and Baker also reported more returns to theatre after TTC (7 versus 2 cases). In contrast, Balziano et al. [27] and Georgiannos et al. [30] reported fewer revision or reoperation events after TTC, with revision rates of 11.1% versus 28.6% and reoperation events of 1 versus 5, respectively. Therefore, TTC nailing should not be considered uniformly superior or inferior to ORIF; its value depends on careful patient selection and treatment goals [32].

Mortality was not significantly different between TTC nailing/TTCA and ORIF. Georgiannos et al. reported one-year mortality of 13.9% versus 18.1%, while Ou and Baker reported mortality of 4/26 versus 3/26. Survival in this population is likely influenced more by age, frailty, comorbidities, baseline mobility, and injury severity than by the fixation method alone. Overall, ORIF remains suitable for patients with acceptable bone quality, soft tissues, and functional demand, whereas TTC nailing/TTCA may be more appropriate for frail, low-demand, neuropathic, or medically complex patients in whom early weight-bearing is prioritized [33].

Limitations

This review is limited by the small number of eligible studies, predominance of retrospective cohorts, heterogeneous patient selection, variable fracture patterns, different operative techniques, and inconsistent follow-up durations. Selection bias was important because TTC was often used in frailer or medically complex patients. Some outcomes were also based on database coding, which may lack detailed radiographic and clinical information [34].

Conclusions

Primary TTC nailing or TTCA may provide a clinically useful alternative to ORIF for unstable ankle fractures in selected older and medically high-risk adults, particularly when early postoperative weight-bearing, poor soft-tissue condition, frailty, or limited ability to tolerate prolonged non-weight-bearing are major concerns. In this review, pooled outcomes showed no clear statistically significant difference between TTC fixation and ORIF for LOS, overall postoperative infection, implant-related complications, nonunion, reoperation, or mortality, although superficial infection appeared lower after TTC fixation. However, TTC was frequently used in frailer and more medically complex patients, and some studies reported higher readmission, malunion/nonunion, or secondary surgery after TTCA. Therefore, TTC fixation should not be considered universally superior to ORIF, but rather a selective strategy for patients in whom conventional fixation is biologically or mechanically unfavourable. Further adequately powered prospective comparative studies are required to define optimal patient selection, surgical technique, rehabilitation protocols, and long-term functional outcomes.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Ahmed Elnewishy, Pir Zarak Khan, Sean M. Garcia, Styliani Zachari, Shajee Ud Din, Yazan Shalan, Harris Mangal, Hagar Teama, Rami Ali Abowali

Acquisition, analysis, or interpretation of data: Ahmed Elnewishy, Pir Zarak Khan, Sean M. Garcia, Styliani Zachari, Shajee Ud Din, Yazan Shalan, Harris Mangal, Hagar Teama, Rami Ali Abowali

Drafting of the manuscript: Ahmed Elnewishy, Pir Zarak Khan, Sean M. Garcia, Styliani Zachari, Shajee

Ud Din, Yazan Shalan, Harris Mangal, Hagar Teama, Rami Ali Abowali

Critical review of the manuscript for important intellectual content: Ahmed Elnewishy, Pir Zarak Khan, Sean M. Garcia, Styliani Zachari, Shajee Ud Din, Yazan Shalan, Harris Mangal, Hagar Teama, Rami Ali Abowali

Supervision: Ahmed Elnewishy, Pir Zarak Khan

Disclosures

Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Acknowledgements

Ahmed Elnewishy and Pir Zarak Khan contributed equally to the work and should be considered co-first authors.

References

- Gundtoft PH, Pedersen AB, Viberg B: Incidence, treatment, and mortality of ankle fractures: a Danish population-based cohort study. *Acta Orthop*. 2025, 96:203-8. [10.2340/17453674.2025.43006](https://doi.org/10.2340/17453674.2025.43006)
- Rydberg EM, Wennergren D, Stigevall C, Ekelund J, Möller M: Epidemiology of more than 50,000 ankle fractures in the Swedish Fracture Register during a period of 10 years. *J Orthop Surg Res*. 2023, 18:79. [10.1186/s13018-023-03558-2](https://doi.org/10.1186/s13018-023-03558-2)
- Liu G, Sun Z, Yang M, Wu X, Giannoudis PV: An overview on the management of ankle fractures in elderly patients aged 65 and over: a scoping review. *Eur J Orthop Surg Traumatol*. 2025, 35:396. [10.1007/s00590-025-04512-0](https://doi.org/10.1007/s00590-025-04512-0)
- Ziegler P, Bahrs C, Konrads C, Hemmann P, Ahrend MD: Ankle fractures of the geriatric patient: a narrative review. *EFORT Open Rev*. 2023, 8:1-10. [10.1530/EOR-22-0082](https://doi.org/10.1530/EOR-22-0082)
- Pearce O, Al-Hourani K, Kelly M: Ankle fractures in the elderly: current concepts. *Injury*. 2020, 51:2740-7. [10.1016/j.injury.2020.10.093](https://doi.org/10.1016/j.injury.2020.10.093)
- Raschke MJ, Ochman S, Milstrey A: Ankle fractures in the elderly: Do we have new concepts? . *EFORT Open Rev*. 2023, 8:223-30. [10.1530/EOR-23-0052](https://doi.org/10.1530/EOR-23-0052)
- Mason L, Orji C, Szatkowski J: Management of geriatric ankle fractures. *Curr Osteoporos Rep*. 2025, 23:48. [10.1007/s11914-025-00940-3](https://doi.org/10.1007/s11914-025-00940-3)
- Dhillon MS, Rajnish RK, Patel S, Chouhan DK, Bansal T: Osteoporotic ankle fractures: a narrative review of management options. *J Clin Orthop Trauma*. 2020, 11:380-7. [10.1016/j.jcot.2019.10.010](https://doi.org/10.1016/j.jcot.2019.10.010)
- Spek RWA, Smeeing DPJ, van den Heuvel L, et al.: Complications after surgical treatment of geriatric ankle fractures. *J Foot Ankle Surg*. 2021, 60:712-7. [10.1053/j.jfas.2019.12.012](https://doi.org/10.1053/j.jfas.2019.12.012)
- Simske NM, Benedick A, Audet MA, Vallier HA: Ankle fractures in patients over age 55 years: predictors of functional outcome. *OTA Int*. 2020, 3:e080. [10.1097/O19.0000000000000080](https://doi.org/10.1097/O19.0000000000000080)
- So E, Rushing CJ, Simon JE, Goss DA Jr, Prissel MA, Berlet GC: Association between bone mineral density and elderly ankle fractures: a systematic review and meta-analysis. *J Foot Ankle Surg*. 2020, 59:1049-57. [10.1053/j.jfas.2020.03.012](https://doi.org/10.1053/j.jfas.2020.03.012)
- Kadakia RJ, Ahearn BM, Schwartz AM, Tenenbaum S, Bariteau JT: Ankle fractures in the elderly: risks and management challenges. *Orthop Res Rev*. 2017, 9:45-50. [10.2147/ORR.S112684](https://doi.org/10.2147/ORR.S112684)
- Wijendra A, Alwe R, Lamymann M, Grammatopoulos GA, Kambouroglou G: Low energy open ankle fractures in the elderly: outcome and treatment algorithm. *Injury*. 2017, 48:763-9. [10.1016/j.injury.2016.11.014](https://doi.org/10.1016/j.injury.2016.11.014)
- Larsen P, Rathleff MS, Elsoe R: Surgical versus conservative treatment for ankle fractures in adults - a systematic review and meta-analysis of the benefits and harms. *Foot Ankle Surg*. 2019, 25:409-17. [10.1016/j.fas.2018.02.009](https://doi.org/10.1016/j.fas.2018.02.009)
- Hoogervorst P, Van Bergen CJA, Van den Bekerom MPJ: Management of osteoporotic and neuropathic ankle fractures in the elderly. *Curr Geriatr Rep*. 2017, 6:9-14. [10.1007/s13670-017-0196-y](https://doi.org/10.1007/s13670-017-0196-y)
- Tarkin IS, Fourman MS: Retrograde hindfoot nailing for acute trauma. *Curr Rev Musculoskelet Med*. 2018, 11:439-44. [10.1007/s12178-018-9507-y](https://doi.org/10.1007/s12178-018-9507-y)
- Dimitroulias A: Ankle tibiototalcalcaneal nailing in elderly ankle fractures as an alternative to open reduction internal fixation: technique and literature review. *OTA Int*. 2022, 5:e183. [10.1097/O19.0000000000000183](https://doi.org/10.1097/O19.0000000000000183)
- Persigant M, Colin F, Noailles T, Pietu G, Gouin F: Functional assessment of transplatar nailing for ankle fracture in the elderly: 48 weeks' prospective follow-up of 14 patients. *Orthop Traumatol Surg Res*. 2018, 104:507-10. [10.1016/j.otsr.2018.03.008](https://doi.org/10.1016/j.otsr.2018.03.008)
- Elmajee M, Gabr A, Aljawadi A, et al.: Treatment of fragility ankle fractures using hindfoot nail, systemic review. *J Orthop*. 2020, 22:559-64. [10.1016/j.jor.2020.11.006](https://doi.org/10.1016/j.jor.2020.11.006)
- Ebaugh MP, Umbel B, Goss D, Taylor BC: Outcomes of primary tibiototalcalcaneal nailing for complicated diabetic ankle fractures. *Foot Ankle Int*. 2019, 40:1382-7. [10.1177/1071100719869639](https://doi.org/10.1177/1071100719869639)
- Kulakli-Inceleme E, Tas DB, Smeeing DPJ, et al.: Tibiototalcalcaneal intramedullary nailing for unstable geriatric ankle fractures. *Geriatr Orthop Surg Rehabil*. 2021, 12:21514593211020705.

- 10.1177/21514593211020705
22. Lu V, Tennyson M, Zhou A, Patel R, Fortune MD, Thahir A, Krkovic M: Retrograde tibiototalcalcaneal nailing for the treatment of acute ankle fractures in the elderly: a systematic review and meta-analysis. *EFORT Open Rev.* 2022, 7:628-43. [10.1530/EOR-22-0017](#)
23. Harter C, Cho T, Liu J: Tibiototalcalcaneal nailing as a treatment for ankle fractures in the elderly population: a systematic review. *J Orthop.* 2025, 67:1-6. [10.1016/j.jor.2024.12.047](#)
24. McDonald J, Oravic M, Wardell W, Lee W: Open reduction and internal fixation vs primary tibiototalcalcaneal hindfoot nailing for ankle fractures in elderly patients: a systematic review and meta-analysis. *Foot Ankle Int.* 2025, 46:661-71. [10.1177/10711007251325841](#)
25. Giesche F, Stief F, Groneberg DA, Wilke J: Effects of sport specific unplanned movements on ankle kinetics and kinematics in healthy athletes from systematic review with meta-analysis. *Sci Rep.* 2025, 15:32476. [10.1038/s41598-025-18746-9](#)
26. Review Manager (RevMan), version 5.4. The Cochrane Collaboration, Copenhagen . (2020). Accessed: June 30, 2026: https://training.cochrane.org/system/files/uploads/protected_file/RevMan5.4_user_guide.pdf.
27. Balziano S, Baran I, Prat D: Hindfoot nailing without joint preparation for ankle fractures in extremely elderly patients: comparison of clinical and patient-reported outcomes with standard ORIF. *Foot Ankle Surg.* 2023, 29:588-92. [10.1016/j.fas.2023.07.001](#)
28. Dawar A, Chundi G, Fuller Z, Ahn DB, Chopra AA, Lin SS, Jones T: Tibiototalcalcaneal arthrodesis vs open reduction internal fixation for trimalleolar ankle fractures in high-risk patients: a national database analysis. *Foot Ankle Orthop.* 2025, 10:24730114251375027. [10.1177/24730114251375027](#)
29. DeMedal SC, Dopke K, Queenan K, et al.: Retrospective comparison of complication rates following tibiototalcalcaneal (TTC) nail fusion vs ORIF for neuropathic ankle fractures. *Foot Ankle Orthop.* 2026, 11:24730114261425629. [10.1177/24730114261425629](#)
30. Georgiannos D, Lampridis V, Bisbinas I: Fragility fractures of the ankle in the elderly: open reduction and internal fixation versus tibio-talo-calcaneal nailing: Short-term results of a prospective randomized-controlled study. *Injury.* 2017, 48:519-24. [10.1016/j.injury.2016.11.017](#)
31. Hussien D, Verlinsky L, Wheeler A, Ni A, Hand T, Karia R, Martin C: Tibiototalcalcaneal nailing allows early weightbearing without increased early complication risk in unstable geriatric malleolar ankle fractures. *Eur J Orthop Surg Traumatol.* 2026, 36:207. [10.1007/s00590-026-04769-z](#)
32. Large TM, Kaufman AM, Frisch HM, Bankieris KR: High-risk ankle fractures in high-risk older patients: to fix or nail?. *Arch Orthop Trauma Surg.* 2023, 143:3725-34. [10.1007/s00402-022-04574-3](#)
33. Mahatme RJ, Murphy M, Moore SA, Gangavaram A, Szabo C, Huq A, Laughlin R: Tibiototalcalcaneal arthrodesis versus open reduction and internal fixation in treatment of trimalleolar ankle fractures: a propensity-matched TriNetX database study. *J Clin Orthop Trauma.* 2026, 79:103511. [10.1016/j.jcot.2026.103511](#)
34. Ou C, Baker JF: Hindfoot nailing for displaced ankle fractures in the elderly: a case-control analysis . *Injury.* 2023, 54:110921. [10.1016/j.injury.2023.110921](#)