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ANKLE

# Tibiotalocalcaneal arthrodesis using an intramedullary nail: a systematic review

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**Abstract**
*Purpose* Tibiotalocalcaneal arthrodesis is aimed to block the ankle joint motion in cases of severe osteoarthritis, avascular necrosis of the talus and/or failure of arthroplasty operations. This systematic review was carried out to evaluate the clinical outcome after tibiotalocalcaneal arthrodesis using intramedullary nail either open and arthroscopically assisted. Focus was on the success rate of the procedure in terms of union and complications and on the comparison between the techniques.
*Methods* The databases PubMed (Medline), EMBASE and Cochrane Library were searched in order to retrieve relevant studies. All therapeutic level 1–4 studies involving humans with intramedullary nail fixation technique were included. Only studies written in English, Italian, French, Spanish and German were included. Data related to the type of surgery, complications and clinical outcomes were extracted and analysed.
*Results* A total of 83 studies were identified, of which 32 studies were eligible for inclusion; 31 case series and one randomized controlled trial. The main reported outcome score was the American Orthopaedic Foot and Ankle Society scale. Almost, all the included studies reported higher than 50 % union rates and a significant improvement in terms of the clinical and mechanical ankle function after treatment.
*Conclusions* Results suggest that satisfactory outcomes can be achieved by tibiotalocalcaneal arthrodesis using intramedullary nailing. Low complication rates contribute to make this a safe procedure. No comparison can be done between arthroscopic and open technique, due to the lack of scientific works on the first one.
*Level of evidence* IV.

**Keywords** Tibiotalocalcaneal arthrodesis · Intramedullary nailing · Rheumatoid arthritis · Ankle arthrodesis · Ankle osteoarthritis

## Introduction

First reported in 1970s [17], tibiotalocalcaneal arthrodesis (TTCA) is a surgical procedure aimed to achieve a functional block of the tibiotalocalcaneal joint motion. A possible arthroscopic aid to the procedure in 1983 was firstly reported [47], which soon became a common technique, thanks to the significative lower invasiveness and to the minor periarticular soft tissue damage [37]. Furthermore, as well as in every microinvasive technique, the complication rate was significantly reduced, especially in terms of post-operative pain and swelling. Several clinical conditions are managed with TTC arthrodesis; the most important indications include severe osteoarthritis, avascular necrosis (AVN) of the talus and previous failed total ankle arthroplasty. Severe rheumatoid arthritis, osteoarthritis of tibiocalcaneal and talocalcaneal joints, Charcot arthropathy, neuromuscular disease, and trauma, severe deformity of clubfoot, congenital deformities or pseudarthrosis [5, 11, 31, 44] can be treated by TTCA. The main benefit of this procedure is the relief of pain. Furthermore, in case

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of AVN of the talus, it prevents from loss of bone tissue and joint collapse [16]. The most important complications include local deep infection, perioperative fracture and subsidence of the components, neurologic affection, delayed union or a complete non-union. To cope with these events, the clinical management includes antibiotic therapy, hardware removal and in some cases below-the-knee amputation. Different techniques have been described to perform arthrodesis, especially in terms of fixation. Internal fixation with screws (which is the preferred hardware for arthroscopic procedures [37]) and plates or retrograde intramedullary nailing, external fixation alone or combination of both internal and external fixation [17] are the most commonly used. Of these, screw fixation has been shown to yield a low union rate [36], and so has using external fixation alone. External fixation is also correlated with a high risk of infection [30]. Good outcomes have been reported using a 95° angled plate [2, 27].

The aim of this systematic review is to review and analyse the intramedullary nail fixation techniques (both open and arthroscopic), which have evolved over the last few years [7]. Studies related to this procedure were examined, especially focusing on the clinical outcomes, in order to evaluate the success of this procedure, i.e. fusion rate and complications. Moreover, a comparison between the procedure was intended to be proposed. The hypothesis is that intramedullary nailing is a safe and successful procedure and is better performed with arthroscopic assistance.

## Materials and methods

This systematic review was conducted in accordance with the PRISMA guidelines (Preferred reporting items of systematic reviews) [35]. The PRISMA guidelines are made up of a 27-items checklist regarding review contents and a four-phase flow diagram reporting the study selection process.

### Eligibility criteria

Studies in English, Italian, French, Spanish and German were included. Only peer-reviewed randomized controlled trials (RCTs), prospective and retrospective comparative studies and case series were included. Furthermore, eligible studies were all related to adult patients managed by ankle arthrodesis, using an intramedullary nail, with either open or arthroscopic technique. In vitro studies and animal-model studies were excluded.

### Information sources and search

Studies eligible for this systematic review have been identified by two reviewers (E.F. and F.F.), through an electronic systematic search of CINAHL, EMBASE, PubMed and the Cochrane Central Registry of Controlled Trials, until 25 of February 2014. The search string utilized was as follows: ((ankle arthrodesis [MeSH Terms]) OR tibiotalocalcaneal arthrodesis [MeSH Terms]) AND intramedullary nail, ((ankle arthrodesis [MeSH Terms]) AND arthroscopic [MeSH Terms]) AND intramedullary nail, ((ankle arthrodesis [MeSH Terms]) OR tibiotalocalcaneal arthrodesis [MeSH Terms]) AND outcomes, ((ankle arthrodesis[MeSH Terms]) OR TTC arthrodesis[MeSH Terms]) AND intramedullary nail, (TTC arthrodesis[MeSH Terms]) AND intramedullary nail.

### Study selection

Articles that were considered relevant by electronic search were retrieved in full-text, and a hand-search of their bibliography was performed, in order to find further related articles. Reviews and meta-analysis were also analysed, in order to broaden the search for studies that might have been missed through the electronic search. All duplicates were removed, and all the articles retrieved have been analysed by two reviewers (E.F. and G.T.). After the first screening, records not meeting eligibility criteria were excluded. Reviewers were not blinded to the authors, year and journal of publication. Remnant studies were categorized by study type, according with the Oxford Centre for Evidence-Based Medicine. Following categories were utilized: case reports, RCTs and case series (CS). Case reports, reporting data of four or less patients, were excluded due to low scientific impact. Furthermore, CSs were divided in prospective and retrospective series. The study selection process is depicted in Fig. 1.

### Data collection process

All the included studies were analysed and data related to the type of surgery; complications and clinical scores were extracted and summarized in tables using Microsoft Excel (2010 version, Microsoft Corporation, Redmond, WA, USA). Type of study, level of evidence, year of publication, and number and type of procedures were extracted first. Data in terms of clinical features and outcomes were extracted and discussed in triplicate (F.F., E.F., G.T.), and then these data were reported in text. Studies were divided by topic (type of hardware, specific pathologies evaluated, etc.,) and reported in paragraphs in results section. Where reported, accurate measures or scores were extracted and inserted in text and tables. All complications were summarized (Table 3).

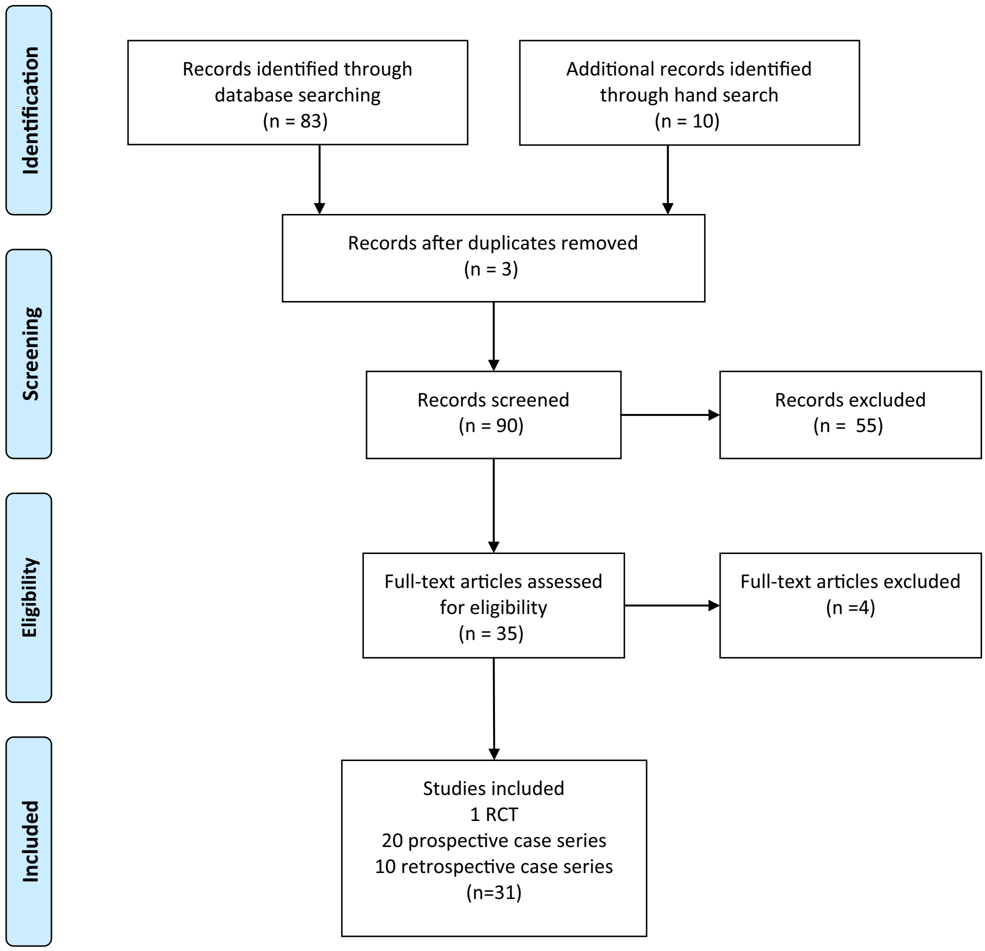


**Fig. 1** PRISMA flow diagram and the selection of studies

## Results

### Selection of the studies

A total of 83 studies were found through the electronic searching engines, and 10 studies were identified as relevant through manual search. A total of 32 studies [3, 4, 7–10, 12–16, 19, 21–26, 28, 29, 32–34, 38, 40–43, 47–50] were included in this systematic review. Of the included studies, 21 were prospective case series, ten were retrospective case series and one was a RCT. A total of 865 patients undergoing TTCA with intramedullary nail were described. The study selection process is shown in Fig. 1. Study details are summarized in Table 1.

### Type of surgery

Thirty-one articles reported outcomes of open TTCA and only one study [47] reported on arthroscopic technique. Since different kind of hardware (nail and screws) was utilized, to simplify the description of devices utilized, the simple straight nail fixed by two screws was termed "classic hardware", and any variation from this standard tool was termed "special hardware", e.g. bone allograft added or curved nails. The study by Thordarson et al. [50] reported the addition of a posterior mouldable bone graft.

### Outcome measures and complications

The most important scores used in the studies were the American Orthopaedic Foot and Ankle Society (AOFAS) ankle/hindfoot scale, which evaluates patients pre- and post-operative condition, in terms of pain, function (walking and motion) and alignment; foot and ankle outcome score (FAOS) questionnaire, that is composed of a five-parts functional evaluation by the patient him/herself; visual analogue scale (VAS) for evaluation of pain. Main scores are summarized in Table 2. Complications of the surgery were reported in all but one study [49]. Complications are reported in Table 3.

**Table 1** Study details

| Study | Level of evidence | Type of study | Year of publication | Procedure | No. of patients (ankles) |
|---|---|---|---|---|---|
| Anderson et al. | IV | CS | 2005 | TTC arthrodesis with intramedullary nail | 25 |
| Anderson et al. | IV | CS | 2005 | TTC arthrodesis with intramedullary nail after failed ankle replacement | 16 |
| Boer et al. | IV | CS | 2007 | TTC arthrodesis with intramedullary nail with or without subtalar debridement | 50 |
| Brodsky et al. | IV | CS | 2014 | TTC arthrodesis with intramedullary nail | 30 |
| Budnar et al. | IV | CS | 2010 | TTC arthrodesis with curve intramedullary nail | 42 (45) |
| Caravaggi et al. | IV | CS | 2006 | TTC arthrodesis with intramedullary nail | 14 |
| Chettiar et al. | IV | CS | 2010 | TTC arthrodesis with intramedullary nail | 30 (31) |
| Dalla Paola et al. | IV | CS | 2007 | TTC arthrodesis with intramedullary nail | 18 |
| De Smet et al. | IV | CS | 2003 | TTC arthrodesis with intramedullary nail | 7 |
| Devries et al. | IV | CS | 2010 | TTC arthrodesis with intramedullary nail | 14 |
| De Vries et al. | IV | CS | 2012 | TTC arthrodesis with intramedullary nail and direct or external bone stimulation | 154 |
| Fazal et al. | IV | CS | 2006 | TTC arthrodesis with intramedullary nail and bone grafting | 40 (43) |
| Fujimori et al. | IV | CS | 1999 | TTC arthrodesis with intramedullary nail and fins | 15 |
| Gavaskar et al. | IV | CS | 2009 | TTC arthrodesis with intramedullary nail | 7 |
| Goebel et al. | IV | CS | 2006 | TTC arthrodesis with intramedullary nail | 29 |
| Gross et al. | IV | CS | 2013 | TTC arthrodesis with intramedullary nail | 30 |
| Haaker et al. | IV | CS | 2010 | TTC arthrodesis with intramedullary nail | 11 (13) |
| Hammett et al. | IV | CS | 2005 | TTC arthrodesis with intramedullary nail | 49 (52) |
| Kamath et al. | IV | CS | 2005 | TTC arthrodesis with intramedullary nail | 24 (27) |
| Kile et al. | IV | CS | 1994 | TTC arthrodesis with intramedullary nail | 30 |
| Mader et al. | IV | CS | 2007 | TTC arthrodesis with intramedullary nail | 10 |
| Mendicino et al. | I | RCT | 2004 | TTC arthrodesis with intramedullary nail | 19 (20) |
| Millett et al. | IV | CS | 2002 | TTC arthrodesis with intramedullary nail | 15 |
| Niinimaki et al. | IV | CS | 2007 | TTC arthrodesis with intramedullary nail | 34 |
| Pelton et al. | IV | CS | 2006 | TTC arthrodesis with intramedullary nail | 33 |
| Pinzur et al. | IV | CS | 1997 | TTC arthrodesis with intramedullary nail | 20 (21) |
| Pinzur et al. | IV | CS | 2005 | TTC arthrodesis with intramedullary nail | 9 |
| Rammelt et al. | IV | CS | 2013 | TTC arthrodesis with intramedullary nail | 38 |
| Sekyia et al. | IV | CS | 2011 | Arthroscopic TTC arthrodesis with intramedullary nail | 8 (9) |
| Tavakkolizadeh et al. | IV | CS | 2005 | TTC arthrodesis with intramedullary nail | 26 |
| Thomason et al. | IV | CS | 2008 | TTC arthrodesis after ankle replacement | 3 |
| Thordarson et al. | IV | CS | 1999 | TTC arthrodesis with intramedullary nail with posterior mouldable bone grafting | 12 |

## Open procedures

### TTCA using classic hardware

The study by Boer et al. [7] compared TTCA procedure with or without debridement of the subtalar joint. Fifty patients were retrospectively reviewed, and all of them achieved fusion, except two in which a subtalar joint non-union occurred. Average fusion time was 20 weeks.

Two recent case series by Goebel et al. [23] and Brodsky et al. [8] reported a high union rate of 96.6 % [8] and a fusion rate of 90 % [23]. The fusion rate evaluated radiologically in the study by Budnar et al. [9] was 89 %. In this study, significant improvement in pain was reported by 82 % of patients and 73 % reported an improved ankle joint function.

Gavaskar et al. [22] evaluated seven patients who had undergone TTCA using a shortened supracondylar femoral nail. All the patients were affected by tuberculosis arthritis of the ankle. FAOS score was assessed before and after surgery, for pain and quality of life, showing a significant increase in pain and quality of life.

**Table 2** Main scores

| Study | Mean follow-up | Duration of surgery | Fusion time | AOFAS | | FAOS | | VAS | | AAOS-FAO | | Mazur score | | HAQ | | JOA | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | PRE | POST | PRE | POST | PRE | POST | PRE | POST | PRE | POST | PRE | POST | PRE | POST |
| Anderson et al. | 36 m | nr | nr | – | 66/86 | – | – | – | – | – | – | – | 64/90 | – | 1.8 | – | – |
| Anderson et al. | 34 m | nr | nr | – | 58/86 | – | – | – | – | – | – | – | – | – | – | – | – |
| Boer et al. | 51 m | nr | 20.4w | – | 70/86 | – | – | – | – | – | – | – | – | – | – | – | – |
| Brodsky et al. | 26 m | nr | nr | 29.7 | 74.3/86 | – | – | 6.5 | 1.3 | – | – | – | – | – | – | – | – |
| Budnar et al. | 48 m | nr | nr | 34/86 | 76/86 | – | – | – | – | – | – | – | – | – | – | – | – |
| Caravaggi et al. | 18 m | nr | nr | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Dalla Paola et al. | 14 m | nr | nr | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| De Smet et al. | 48 m | nr | nr | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| De Vries et al. [16] | nr | nr | nr | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| De Vries et al. [15] | nr | nr | nr | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Fazal et al. | 34 m | nr | 30w | – | 58 | – | – | – | – | – | – | – | – | – | – | – | – |
| Fujimori et al. | 35 m | nr | 11w | – | – | – | – | – | – | – | – | – | – | – | – | 36 | 69.6 |
| Gavascar et al. | 12 m | 65 min | 13w | – | – | 26 | 85 | – | – | – | – | – | – | – | – | – | – |
| Goebel et al. | 25 m | nr | nr | 46 | 71 | – | – | – | – | – | – | – | – | – | – | – | – |
| Gross et al. | 25 m | nr | nr | 37 | 59 | – | – | – | – | – | – | – | – | – | – | – | – |
| Haaker et al. | 8 m | nr | 3 m | 16/100 | 54/78 | – | – | – | – | – | – | – | – | – | – | – | – |
| Hammett et al. | 34 m | 117 min | 4 m | – | 63 | – | – | – | – | – | – | – | – | – | – | – | – |
| Kamath et al. | 38 m | nr | nr | – | MAOFAS = 74.6 | – | – | – | – | – | – | – | – | – | – | – | – |
| Kile et al. | 15 m | nr | nr | – | – | – | – | 8.3 | 1.7 | – | – | – | – | – | – | – | – |
| Chettiar et al. | 23 m | nr | 3 m | 22.8 | 65.8 | – | – | – | – | – | – | – | – | – | – | – | – |
| Mader et al. | 48 m | 52.5 min | 16w | – | 69.7 | – | – | – | – | – | – | – | – | – | – | – | – |
| Mendicino et al. | 20 m | nr | 4.1 m | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Millett et al. | 24 m | nr | 16.5w | – | 35.6 | – | – | – | – | – | – | – | – | – | – | – | – |
| Niinimaki et al. | 24 m | nr | 16w | – | – | – | – | 66 | 19 | – | – | – | – | – | – | – | – |
| Pelton et al. | 14 m | nr | 3.7 m | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Pinzur et al. | 22 m | nr | 20 m | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Pinzur et al. 2005 | 32 m | nr | 10.5w | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Rammelt et al. | 24 m | 168 min | nr | – | – | – | – | – | 2.2 | – | 38 | – | – | – | – | – | – |
| Sekyia et al. | 41 m | nr | nr | 47 | 82 | – | – | – | – | – | – | – | – | – | – | – | – |
| Tavakkolizadeh et al. | 26 m | nr | 15w | – | 66 | – | – | – | – | – | – | – | – | – | – | – | – |
| Thomason et al. | 32 m | nr | 3 m | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Thordarson et al. | 20 m | nr | nr | – | – | – | – | – | – | – | – | – | – | – | – | – | – |

**Table 3** Complications

| Study | No. of patients | Infections | Non-unions | Delayed unions | DVT | Fractures | Neurologic | Pain | Flex. deformity | Amputation | Hardware removal | Total | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Anderson et al. | 25 | 4 | – | – | – | – | 7 | 7 | 7 | – | 2 | 25 | 108 |
| Anderson et al. | 16 | 2 | 3 | 2 | – | – | – | – | 7 | – | 1 | 14 | 87.5 |
| Boer et al. | 50 | – | 2 | – | – | – | 1 | 1 | – | – | – | 4 | 8 |
| Brodsky et al. | 30 | 3 | 1 | – | – | – | 3 | – | 7 | – | 1 | 14 | 50 |
| Budnar et al. | 42 | 1 | 5 | 3 | 4 | 2 | – | – | – | – | – | 15 | 34.7 |
| Caravaggi et al. | 14 | 3 | – | 4 | – | – | – | – | – | 1 | 4 | 8 | 85.7 |
| Chettiar et al. | 30 | 2 | – | – | – | 1 | – | 1 | – | – | 2 | 4 | 20 |
| Dalla Paola et al. | 18 | – | – | – | – | – | – | – | – | – | 3 | 0 | 16.7 |
| De Smet et al. | 7 | – | 3 | – | – | – | 1 | 1 | – | – | 1 | 5 | 85.7 |
| De Vries et al. [16] | 14 | 2 | 1 | – | – | 2 | – | – | – | – | – | 5 | 35.7 |
| De Vries et al. [15] | 154 | 43 | – | – | 2 | 8 | – | – | – | 19 | 33 | 72 | 68.2 |
| Fazal et al. | 40 | 7 | 3 | 7 | – | 2 | 1 | – | – | – | 5 | 25 | 62.5 |
| Fujimori et al. | 15 | – | 2 | – | – | – | – | – | – | – | – | 2 | 18.2 |
| Gavascar et al. | 7 | 2 | – | – | – | – | – | – | – | – | – | 2 | 28.6 |
| Goebel et al. | 29 | 2 | 3 | 7 | – | – | – | 4 | 1 | – | – | 17 | 58.6 |
| Gross et al. | 30 | 3 | 7 | 5 | 1 | 1 | 2 | – | – | 1 | 5 | 20 | 83.3 |
| Haaker et al. | 11 | 4 | – | – | – | – | – | – | – | – | – | 4 | 36.4 |
| Hammett et al. | 52 | 2 | 6 | 10 | 1 | 3 | – | – | – | 2 | 1 | 24 | 48.1 |
| Kamath et al. | 24 | – | 4 | – | – | – | – | – | – | – | – | 4 | 16.7 |
| Kile et al. | 30 | 2 | 2 | – | – | – | – | – | – | 2 | 1 | 6 | 23.3 |
| Mader et al. | 10 | – | – | – | – | – | – | – | 1 | – | – | 1 | 10 |
| Mendicino et al. | 19 | 2 | 1 | – | – | – | – | – | – | 1 | – | 4 | 21.1 |
| Millett et al. | 15 | 2 | 2 | – | – | – | – | 6 | – | – | 2 | 10 | 80 |
| Niinimaki et al. | 34 | 4 | 3 | – | 1 | – | – | – | – | – | – | 8 | 23.5 |
| Pelton et al. | 33 | 1 | 4 | 1 | – | – | 1 | 3 | – | – | 4 | 10 | 42.4 |
| Pinzur et al. | 20 | 6 | – | – | – | – | – | – | – | – | 3 | 6 | 45 |
| Pinzur et al. | 9 | 1 | – | – | – | – | – | – | – | – | – | 1 | 11.1 |
| Rammelt et al. | 38 | 3 | 6 | – | – | 2 | – | – | 3 | – | 1 | 14 | 39.5 |
| Sekyia et al. | 9 | – | 1 | – | – | – | – | 7 | – | – | – | 8 | 93 |
| Tavakkolizadeh et al. | 26 | 1 | 6 | – | – | – | – | – | – | 2 | 5 | 14 | 53.8 |
| Thomason et al. | 3 | – | – | – | – | – | – | – | – | – | – | 0 | 0 |
| Thordarson et al. | 12 | – | – | – | – | 2 | – | – | – | – | 3 | 2 | 41.5 |
| Vilà y Rico et al. | 2 | – | – | – | – | – | – | – | – | – | – | 0 | 0 |

Mader et al. [32] reported ten patients operated on using intramedullary nail TTCA with minimally invasive approach, after failed fusion. Fusion was achieved at a mean time of 16 weeks. Post-operatively, mean overall satisfaction was 9.5 on a 10-point scale, and the AOFAS score averaged 69.7 points.

TTCA with special hardware

Fujimori et al. [21] evaluated intramedullary nail with fins in 12 consecutive TTCAs. Clinical evaluation was performed using the Japan Orthopaedic Association (JOA) score, which improved from a mean of 36–69.6 points at the last follow-up. Walking was improved in all patients except one and daily activity ability improved in 11 patients.

The study by De Smet et al. [14] reported on a retrospective assessment of seven patients who underwent TTCA using the Marchetti-Vincenzi nailing. Only three patients achieved total fusion, and in the other four, consolidation was observed only after replacement of the Marchetti-Vincenzi nail, by another type of intramedullary nail. A total of nine re-operations were necessary, with one below-the-knee amputation.

Kile et al. [29] reported on the outcomes in 30 patients treated with TTCA using a technique [44] that adds autogenous bone graft harvested from the iliac crest in addition to the intramedullary nail. Complete patient satisfaction was reported in 20 patients (67 %). Pain was assessed on a 10-grade scale before and after surgery, with a mean improvement of 6.6 points (mean pre-operative value was 8.3 and post-operative 1.7 points).

Thomason and Eyres [49] reported three cases of TTCA with intramedullary nailing and femoral head allograft to restore the talar height. At 12 weeks, clinical and functional outcomes were good, the patients were fully weight-bearing and no significant complication occurred. Mean time for bony union was 3 months.

Use of bone stimulation in TTCA

In the study by De Vries et al. [15], the outcomes after internal and external electrical bone stimulation with nail TTCA in 154 patients were compared. Patients treated with direct current internal bone stimulation ($n = 91$) did not show different outcomes compared with patients treated with external stimulation ($n = 63$), in terms of clinical scores and union rate. Overall procedure success was 81.3 and 82.5 % in the two groups, respectively (n.s.).

TTCA in patients with rheumatoid arthritis

Anderson et al. [3, 4] carried out two studies on patients with rheumatoid arthritis, both in 2005. One of these is a retrospective study where 25 patients undergoing arthrodesis were reviewed. Mean post-operative AOFAS score was of 66 out of 86 points and the Mazur score averaged 64 out of 90 points. A Health Assessment Questionnaire was used to evaluate rheumatic disease activity and correlated negatively with AOFAS and Mazur score ($r = -0.74$ and $-0.70$, respectively). The second study evaluated TTCA as a salvage procedure with complete healing and pain relief in 13 out of 16 subjects, with a mean AOFAS (for the healed ankles) of 56.2. Kamath et al. [28] assessed 24 rheumatoid arthritis-affected patients after TTCA using an intramedullary nail. The mean Fries score [20] (for the assessment of rheumatoid disease) was 2.3; 16 patients had severe arthritis (Fries >2.0). Radiological union was achieved in 52 % of the patients. Mean rheumatoid ankle grading system was of 77 and the modified AOFAS [1] score averaged 74.6 out of 95.

TTCA in diabetic patients with Charcot arthropathy

Caravaggi et al. [10] reported the outcomes in 14 diabetic patients with Charcot disease of the ankle, who underwent TTCA using intramedullary nail with compression. This technique is implemented through the insertion of a compressive device, turned onto the distal part of the nail, to ensure the adherence to the surrounding bone. The union rate was 71.4 %. The procedure was performed as a treatment to prevent limb amputation, and overall limb salvage rate was 92.8 %. Limb salvage rate reported by Dalla Paola et al. [13] was 100 % in a series of 18 TTCAs.

Mendicino et al. [33] compared diabetic and non-diabetic patients' outcomes after TTCA using intramedullary nailing. Fusion rate was 95 % at an average time of 4.1 months. Major complications (osteomyelitis, Charcot arthropathy, failure of fixation) occurred in five diabetic patients. Higher complication rates were found in the diabetic group, in terms of both major (50 %) and minor (50 %) complications. Only minor complications occurred in the non-diabetic group (60 % of patients).

Pinzur et al. published two studies in 1997 and 2005 [41, 42]. In the first, 20 Charcot neuropathy-affected patients (19 diabetic) were evaluated after TTCA using intramedullary nail. Bony fusion was achieved in 19 patients, with a time range of 12–31 months. In the second study (nine patients), the efforts were focused on to assess whether it is possible to avoid stress fracture by insertion of a longer nail [39]. All patients achieved union at an average time of 10.5 weeks, and no stress fracture was noted.

## Arthroscopic procedures

TTCA using classic hardware

The case series by Sekyia et al. [47] reported about nine arthrodesis in eight patients with an average age of 52

(22–72), followed up for an average of 41 months. In 1 week after surgery, below-the-knee cast or brace was required in seven cases, in order to reduce pain, and the immobilization lasted mainly 5 weeks (2–11). All but one patient achieved full fusion within 6 months. The average AOFAS score was 47 pre-operatively and improved to 82 after surgery.

## Discussion

Union rate reported for open tibiotalocalcaneal arthrodesis has often been reported to be above 80 % for open [8, 9, 23] and arthroscopic procedure. This, in a certain manner, can be considered the guarantee of the success of a challenging procedure as TTCA. Furthermore, in almost all the studies included, the scores used to evaluate the clinical features of the patients increased after surgery as well as the fusion rate, meaning that the clinical benefit of this surgery can be considered as high. The main aim of this systematic review was to evaluate whether the TTCA is considered a successful procedure and to evaluate the possible complications. The second goal of this review of the literature was to compare outcomes of arthroscopic and open TTCA, but we did not succeed in this, since the literature is lacking of studies about arthroscopically assisted intramedullary nailing. Two case reports [46, 51] were described, and several technical notes describing the procedure [6] were developed, but no study met the inclusion criteria of the present work, except for that one included, by Sekyia et al. [47]. Arthroscopical nailing is technically demanding, and this is one of the main issues which this procedure is not performed daily for. Arthroscopic TTCA can be otherwise carried out using cannulated screws [37], which are inserted through the superior aspect of the malleoli, with less impediment than the sub-plantar nail. From a further analysis of the report present in literature, it is clear that minor complications are brought by the mini-invasive approach, such arthroscopy is, although a few data (small number of patients) are reported, thus no statistical comparison can be performed achieving significance. In the report by Vilà y Rico [51], two cases were presented, reporting no intra- or post-operative complication, except for the removal of the proximal locking screw after 4 months, for complaining of the patient. The AOFAS improved meanly of 54.5 points, which is slightly higher compared with the trend of AOFAS improvement for the open technique. Similar results were reported by Sekyia et al. [46] in a report published in 2006. A 100 % fusion rate is reported in both studies. The studies concerning open arthrodesis included in this systematic review all reported clinical and/or radiological outcomes of TTCA procedures with intramedullary nail in adult patients. The aim was to collect the outcomes and to evaluate the effectiveness of this procedure. In almost all studies, the AOFAS scoring system (Ankle and Hindfoot Scale, AHS) was utilized as the main functional outcome score to assess the pre-operative and post-operative functional outcome, in terms of function, pain and flexion deformities. Regrettably, the studies are not comparable in terms of cohort size, surgical details and outcome measures, and 16 of the included studies cohorts were composed of 20 or less patient. The overall bony fusion rate ranged between 52 % [28] and 96.6 % [8] evaluated clinically or by radiological assessment of trabecular bone formation at the site of the fusion. No study reported unsuccessful case series; therefore, the procedure could be considered a valid option, which usually provides satisfying results. Only in the study by De Smet et al. [14], the Marchetti-Vincenzi nailing system is presented as an inferior option for the treatment of posttraumatic pseudoarthrosis of the ankle. In that study, only three out of seven patients achieved solid fusion, one of them after hardware removal. Of the remaining patients, one ankle was fused only after Marchetti-Vincenzi nail replacement with another type of nail and one developed further pseudoarthrosis. Although the union rate was always higher than 50 %, several cases of non-union or delayed union were observed. Several studies reported separately tibiotalar (TT) and subtalar (ST) union rates, because of different consolidation time and the higher rate of ST non-union in comparison with the TT non-union. For instance, Gross et al. [24] reported an 86 % of TT union rate and a 74 % of ST union rate. The explanation of their findings was that they did not perform a ST debridement and the nails they utilized were not suitable for the compression of the subtalar joint. Boer et al. [7] concluded that formal debridement of the subtalar joint is not necessary for the success of the fusion, although consolidation time rose to a mean of 20 weeks. Hammett et al. [26] reported that the inexperience of the surgeon accounted for the ST non-union in four patients in their study. Furthermore, ankle fusion is usually more difficult in patients affected by Charcot neuropathy [42]. In the study by Mendicino et al. [33], diabetic versus non-diabetic patients were evaluated and all major complication were observed in diabetic patients, even if in diabetic patients, a faster fusion was reported. However, limb salvage rate reported by the studies was 90 %; therefore, the procedure can be considered successful.

Other major complications included deep and superficial infections, flexion deformities and stress fractures, although they are infrequent.

In terms of infections, it is clear that a poor sterilization technique of the surgical field contributes to an increased risk of superficial wound infection, for example, by *S. epidermidis* or *S. aureus*. In the case of the intramedullary nail being used, the retrograde insertion of a deep hardware may lead to the development of osteomyelitis [33, 48] or other deep infection. Therefore, considering the high invasiveness of this procedure, great care in the surgical field management and sterility of the wound (in terms of post-operative care also) is needed.

The ideal position for consolidation, to avoid deformity, is 5° of valgus (achieved by bony cuts) and 5°–10° of external rotation [48]. Anderson et al. [4] reported 7° of valgus malposition, 6°–15° of varus malposition and four further cases of equinus position between 3° and 10°. However, a second study by Anderson et al. [3] is stated that AOFAS score for pain did not differ significantly between subjects healed in neutral position and those with malalignment. Accordingly, we advise a special focus on the alignment, in order to avoid malposition during the consolidation phase.

Perioperative or post-operative stress fractures were reported in nine studies. Pinzur et al. [42] evaluated if a longer nail—as reported in a biomechanical study by Noonan et al. [39]—which concentrates stress at proximal metaphysis of the tibia could possibly avoid stress fracture in patients affected by Charcot arthropathy, which often correlates with severe osteopenia. Moreover, two cases of stress fractures were reported by Fazal et al. [19], in patients treated with corticosteroids due to rheumatoid arthritis. Further studies with more significant cohort numbers are needed to evaluate whether a proximal tibia locked nail (longer than standard nails) could actually avoid any consequent fracture events.

Although only 77 hardware removals were necessary in a total of 862 surgeries, this additional procedure is sometimes required to achieve complete fusion or pain relief [3, 24, 33]. Furthermore, breakage or loosening of the screws has been observed [10, 19]. Four patients out of 14 developed loosening and breakage of the calcaneal screw during follow-up in the study by Caravaggi et al. [17] in six cases out of 40 subjects in the study by Fazal et al. [22] distal screws (lateral and posterior ones) backed out. The best way to avoid these events is to utilize high-quality devices. The main mistake is probably poor control of the actual fitting of the screws into the nail holes. One limitation of this systematic review is the lack of high-level studies. Most of the papers included are case series. No comparable results are reported in terms of outcome measures, and there are no comparable cohort baseline characteristics. In addition to this, further limitations are as follows: lack of a bias assessment and of a critical appraisal fitted to low level of evidence papers, and the lack of well-reported statistical analysis, including sample size calculations.

A last question, we asked ourselves was whether the arthrodesis might be performed on active adult subjects involved in sport activities. Since the complete block of the joint movement is achieved, it shows clearly that no high-level activity can be longer participated by the patients. Anyway, a few studies [18, 45] evaluating functional outcomes subsequent to the arthrodesis (although not reporting outcomes of nailing arthrodesis) reported that non-contact and non-jumping sport could be undertaken by the patients after the recovery from the surgery [18].

## Conclusions

Though technically demanding, open tibiotalocalcaneal arthrodesis can be considered a safe and successful procedure. Major complications are reported for diabetic patients, even if a safe fusion is achieved. Taking into account of the present literature concerning arthroscopic TTCA, we did not feel confident to state conclusion about this procedure. Some key points for further development are the alignment of the fixation and individual factors that affect bony fusion. More and well-designed studies about arthroscopic technique should be carried out.

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