Foot and Ankle Surgery 25 (2019) 804–811

Contents lists available at ScienceDirect

Foot and Ankle Surgery

journal homepage: www.elsevier.com/locate/fas

Comparison of arthroscopic to open tibiotalocalcaneal arthrodesis in high-risk patients

Sebastian Felix Baumbach[a], Felix Kurt Massen[a], Severin Hörterer[b], Mareen Braunstein[a], Hazibullah Waizy[c], Wolfgang Böcker[a], Hans Polzer[a,*]

[a] Department of General, Trauma and Reconstructive Surgery, Munich University Hospital LMU, Munich, Germany
[b] Department of Trauma and Orthopaedic Surgery, Hospital München-Schwabing, Kölnerplatz 1, 80804 Munich, Germany
[c] Hessing Foundation, Clinic for Foot and Ankle Surgery, Hessingstr. 17, 86159 Augsburg, Germany

ARTICLE INFO

Article history:
Received 30 May 2018
Received in revised form 9 September 2018
Accepted 16 October 2018

Keywords:
Tibiotalocalcaneal arthrodesis
Hindfoot arthrodesis
Arthroscopic
Open
Intramedullary nail
Surgical side infections
Non-union

ABSTRACT

Background: Open tibiotalocalcaneal arthrodesis (TTCA) is associated to high complication rates, which led to the development of arthroscopic techniques. Aim was to compare complication rates of open to arthroscopic TTCA in high-risk patients.
Methods: Single-center, retrospective case-control study. Patients were selected from the authors' TTCA database. Eligible were high-risk patients receiving arthroscopic-, or open TTCA retrospectively suitable for arthroscopic TTCA. Primary outcome were major complications.
Results: Eight open and 15 arthroscopic TTCAs were included. Three open and 4 arthroscopic TTCAs presented preoperative plantar ulceration. Fusion rates were similar (75% vs. 67%; $p = 0.679$). Major complications occurred in 63% of open (80% surgical-site-infections (SSI)) and 33% of arthroscopic (100% non-unions) TTCA. Preoperative plantar ulceration did not affect major SSI in open TTCA (67% vs. 60%) but resulted in a significant increase of non-union rates for arthroscopic TTCA (75% vs. 18%; $p = 0.039$). In patients without plantar ulceration the union-rate was 80% for both, open and arthroscopic TTCA.
Conclusion: Arthroscopic TTCA drastically reduced major SSI. Patients without preexisting ulceration had excellent union-rates for open and arthroscopic TTCA.

1. Introduction

Various pathologies, such as combined hindfoot osteoarthritis, Charcot neuro-osteoarthropathy, rheumatoid arthritis, or non-union in ankle fractures might necessitate tibiotalocalcaneal arthrodesis (TTCA) [1]. It aims at restoring hindfoot alignment, eliminating pain, and preserving ambulation [2]. TTCA can be performed using various implants and operative approaches. Lately, curved intramedullary nails have becoming increasingly popular [3]. Up to now, the vast majority of these procedures is performed by open operative techniques.

Open TTCA often is considered a safe procedure [4]. Yet, several studies observed a considerable number of complications. Larger case series evaluating open TTCA using a retrograde intramedullary nail reported non-union rates from 0% to 45%, major complications in 5% to 38%, and minor complications in 1% to 56% [5–12]. Consequently, one has to conclude that open TTCA using an intramedullary nail is associated with a considerable number of non-unions and a high-risk for complications [1]. Most of these complications were surgical site infections (SSI). This might be attributable to the extensive operative approaches needed for open TTCA. As many patients undergoing TTCA suffer from co-morbidities such as diabetes mellitus and peripheral arterial occlusive disease, these might additionally increase the risk for complications [13–15]. Consequently, new operative TTCA techniques had to be developed to reduce the number of wound related complications while reliably achieving bony fusion.

One way to reduce the procedure's invasiveness could be arthroscopic TTCA. Various studies have reported favorable results for isolated arthroscopic compared to open arthrodesis of the ankle or subtalar joint only [16–21]. A recent systematic review demonstrated superior union-rates rates for arthroscopic ankle arthrodesis (94%; range: 70%–100%) when compared to open arthrodesis (89%; range: 64%–100%) [22]. Furthermore, the

* Corresponding author at: Munich University Hospital LMU, Department of General, Trauma and Reconstructive Surgery, Foot and Ankle Surgery, Nussbaumstr. 20, 80336 Munich, Germany.
E-mail addresses: sebastian.baumbach@med.uni-muenchen.de (S.F. Baumbach), felix.massen@med.uni-muenchen.de (F.K. Massen), severin.hoerterer@gmail.com (S. Hörterer), mareen.braunstein@med.uni-muenchen.de (M. Braunstein), hwaizy@yahoo.com (H. Waizy), wolfgang.boecker@med.uni-muenchen.de (W. Böcker), hans.polzer@med.uni-muenchen.de (H. Polzer).

https://doi.org/10.1016/j.fas.2018.10.006
1268-7731/

arthroscopic procedure seems to feature a comparable potential to correct deformities [19]. Therefore, Eric Giza concluded, that arthroscopic ankle arthrodesis is to become the new gold standard procedure for ankle arthrodesis [23].

Consequently, arthroscopic TTCA could be a promising strategy to reduce the number of complications. Currently, only 6 case series on arthroscopic TTCA are available, reporting the results of 23 patients in total [24–29]. Despite promising results, these studies are limited to a small number of patients, did not focus on high-risk patients, and are missing a control group.

As a result of the considerable number of major SSI following open TTCA, the study group started to utilize arthroscopic TTCA for high-risk patients in 07/2013 at their institute. Prior to this date, open TTCA was performed through an extensive lateral approach. The authors' hypothesis was, that arthroscopic TTCA would reduce major complications compared to open TTCA in a high-risk population. Therefore, the aim of this study was to compare the results of open to arthroscopic TTCA in high-risk patients.

2. Materials and methods

Single-center, retrospective case-control study comparing open to arthroscopic TTCA using a curved intramedullary nail in a comparable high-risk patient sample. The local ethics committee approved the study (#520-15).

2.1. Patient selection

Patient selection was based on the authors' hindfoot-arthrodesis database. In total 43 patients had a primary TTCA using a curved intramedullary nail. Arthroscopic hindfoot arthrodesis was introduced in 07/2013. From this database, all arthroscopic TTCAs were identified first (n = 15). Second, the database was screened for patients (up to 07/2013) who underwent open TTCA (n = 29). Only patients retrospectively suitable for arthroscopic TTCA were included. Suitability was defined based on the degree of deformity and similar co-morbidities (high-risk population). Further, a minimum follow-up of one year was required.

15 patients met the inclusion criteria for arthroscopic TTCA. Out of 29 patients undergoing open TTCA, 8 were excluded because of gross hindfoot deformity, 6 for large talar bone defects, 2 because they were not considered high-risk patients, 4 because a straight hindfoot nail was used and 1 patient missed sufficient follow-up. Consequently, the final analysis was based on 15 arthroscopic and 8 open TTCAs.

2.2. Treatment strategy

In cases of preoperative, refractory plantar ulceration within the operative field, osteomyelitis was ruled out. Then preconditioning interventions were conducted. Operative debridement and negative pressure wound therapy were performed until repetitive wound swabs showed no bacterial growth. Open and arthroscopic TTCAs were conducted in a similar standardized technique. Only the operative approaches differed (Fig. 1). The entire procedure was conducted in supine position. First, a percutaneous Achilles tendon tenotomy was performed. In open TTCA, an extended lateral approach (Fig. 1A) was performed. Then the distal fibula was resected two centimeters above the tibiotalar joint line. For arthroscopic TTCA anteromedial and –lateral portals (Fig. 1B1) were used to approach the ankle and antero- and posterolateral portals (Fig. 1B2) for the subtalar joint. In this case the distal fibula was not resected. For both procedures, the articular surfaces were debrided until the subchondral bone was exposed, preserving the normal contours of the bones. Once a proper hindfoot alignment and surface fit were insured, the subchondral bone marrow was perforated. Then, the hindfoot was aligned and temporary fixed using 2.0 K-wires. Two different curved intramedullary nails were used: Expert HAN (Depuy/Synthes, Oberdorf, CH) and the AFN (Tornier, Montbonnot Sant Martin, France). Nail insertion was conducted as recommended by the manufacturer. For both, open and arthroscopic TTCA a guide wire was placed from the centro-lateral calcaneus to the center of the tibio-talar joint. To determine the entry point lateral fluoroscopy views were obtained and the guide wire was placed in line with the tibial canal. In the coronal plane the guide wire was positioned at the lateral column of the calcaneus. Then the guide wire was inserted through the center of the lateral column of the calcaneus up to the center of the talar dome just penetrating the tibia. Correct placement of the guide wire was evaluated in both AP and lateral fluoroscopy views. Then, drilling was performed to a depth of 1 cm beyond the tibial articular surface. Afterwards the 2.0 K-wires were removed, the hindfoot was placed in varus and a reaming rod was inserted. Reaming of the distal tibia was performed until the reamer demonstrated good bony contact. The diameter of the nail was determined according to the reaming. Then, the nail was inserted and locked using the targeting jig. Fig. 2 illustrates a clinical and radiographic course of a case for each group.

The postoperative treatment was standardized for both groups, consisting of non-weightbearing and immobilization in a cast for 8 weeks. Radiographic follow-up using CT-scans was conducted 8 weeks postoperatively and every 6 weeks thereafter until bony fusion was detected. Custom-made orthopedic shoes were recommended following bony fusion.

2.3. Outcome parameters

The data collection was conducted at one-year follow-up. Occurrence of complications was the primary outcome parameter. Major complications were defined as complications necessitating surgery or bony non-union. Minor complications included non-operatively treated SSI, implant failure (with bony union) or fractures. Secondary outcome parameters were radiographic evaluation, healing of preexisting ulceration, time to bony fusion and the time of the in-house stay.

Fig. 1. Illustrations of the two operative approaches.
(A) Open TTCA: extended lateral approach; (B) arthroscopic TTCA; (B1) anteromedial and –lateral portals; (B2) antero- and posterolateral portals.

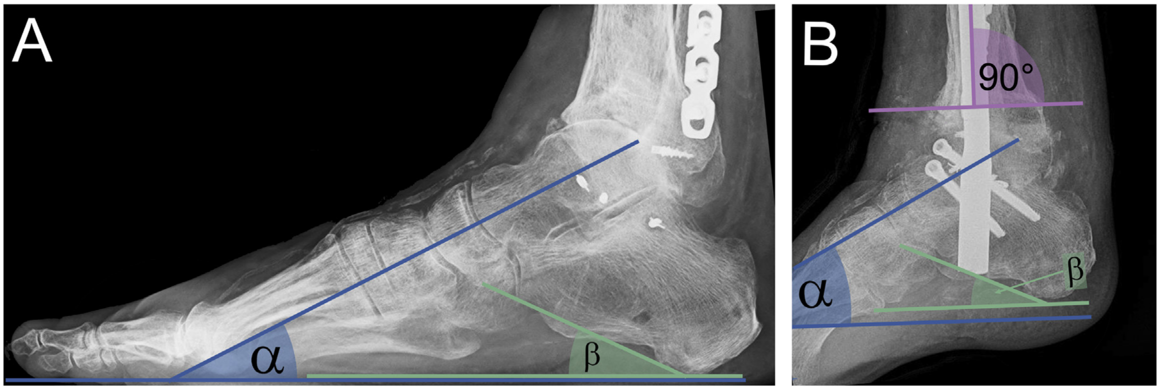

Fig. 2. Clinical-radiographic illustration of one patient for each group.
TTCA: tibiotalocalcaneal arthrodesis; ASC: arthroscopic; Pre-OP: before the operation; Peri-OP: intra-/postoperative; fusion: bony fusion verified on CT-scans; (A) clinical weightbearing images of the ap-foot; (B) lateral weightbearing radiographs; (C) surgical approach; (D) postoperative lateral radiographs; (E) arthroscopic views following complete removal of the cartilage; (F/G) fully fused ankle and subtalar joint on sagittal (F) and coronal (G) CT-scans.

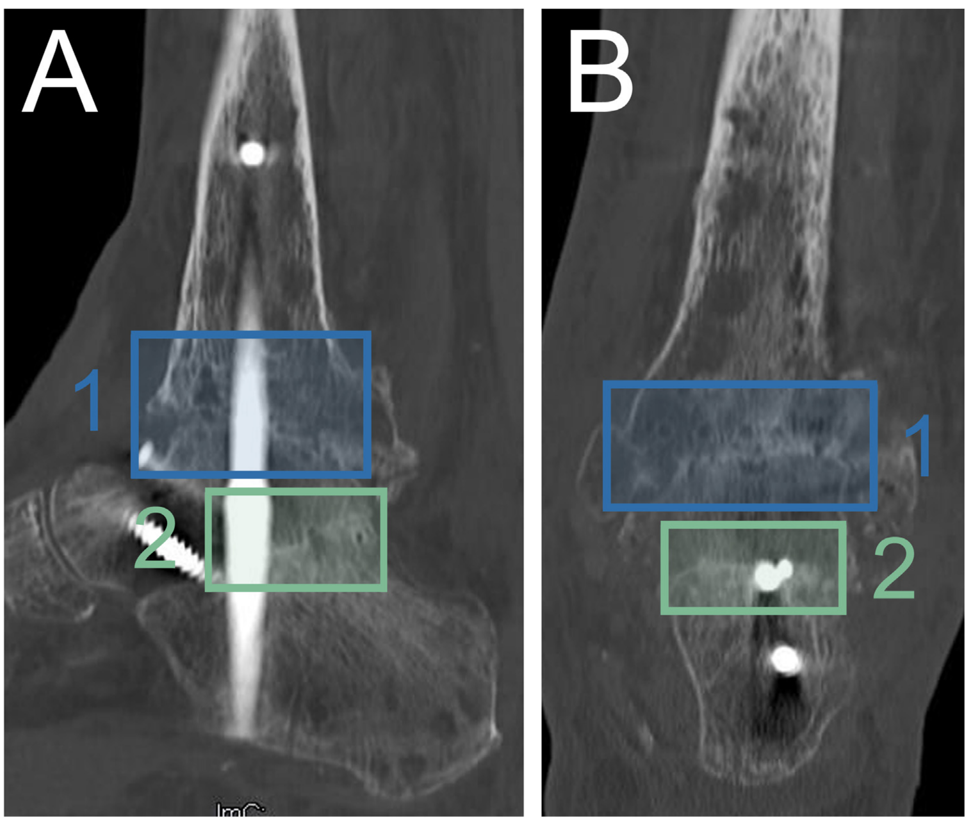

Fig. 3. Pre- and postoperative alignment assessed on lateral radiographs.
(A) Lateral weightbearing radiograph; ∠α: talar declination angle (plantar plane and long axis of the talus); ∠β: calcaneal inclination angle (plantar plane and tangent to the inferior portion of the calcaneus).
(B) Lateral non-weightbearing radiographs, plantar plane was defined as the plane perpendicular to the axis of the arthrodesis nail: ∠α: talar declination angle (plantar plane and long axis of the talus); ∠β: calcaneal inclination angle (plantar plane and tangent on the inferior portion of the calcaneus).

Radiographic evaluation was conducted pre- and postoperatively. The talar declination angle (∠a, Fig. 3) and the calcaneal inclination angle (∠β, Fig. 3) were assessed on weightbearing lateral radiographs preoperatively (Fig. 3A). With no postoperative weightbearing measurements available, the plantar plane was defined as the plane perpendicular to the axis of the arthrodesis nail (Fig. 3B).

Bony fusion was assessed on CT scans (Fig. 4). CT scans were conducted using identical scan and reconstruction parameters (i.e. identical scan protocol, bone kernel reconstructions, 1.25 mm axial slice thickness; Discovery HD 750, GE Healthcare, Waukesha IL/USA). Scans were performed immediately postoperative, 8 weeks after the procedure and thereafter every 6 weeks until bony fusion was detected. The tibiotalar joint (Fig. 4.1) and the talocalcaneal joint (Fig. 4.2) were assessed on frontal (Fig. 4A) and sagittal (Fig. 4B) reconstructions separately. Bony fusion was defined as bone trabeculae crossing more than 50% of the joint with joint line obliteration [3,12,30,31].

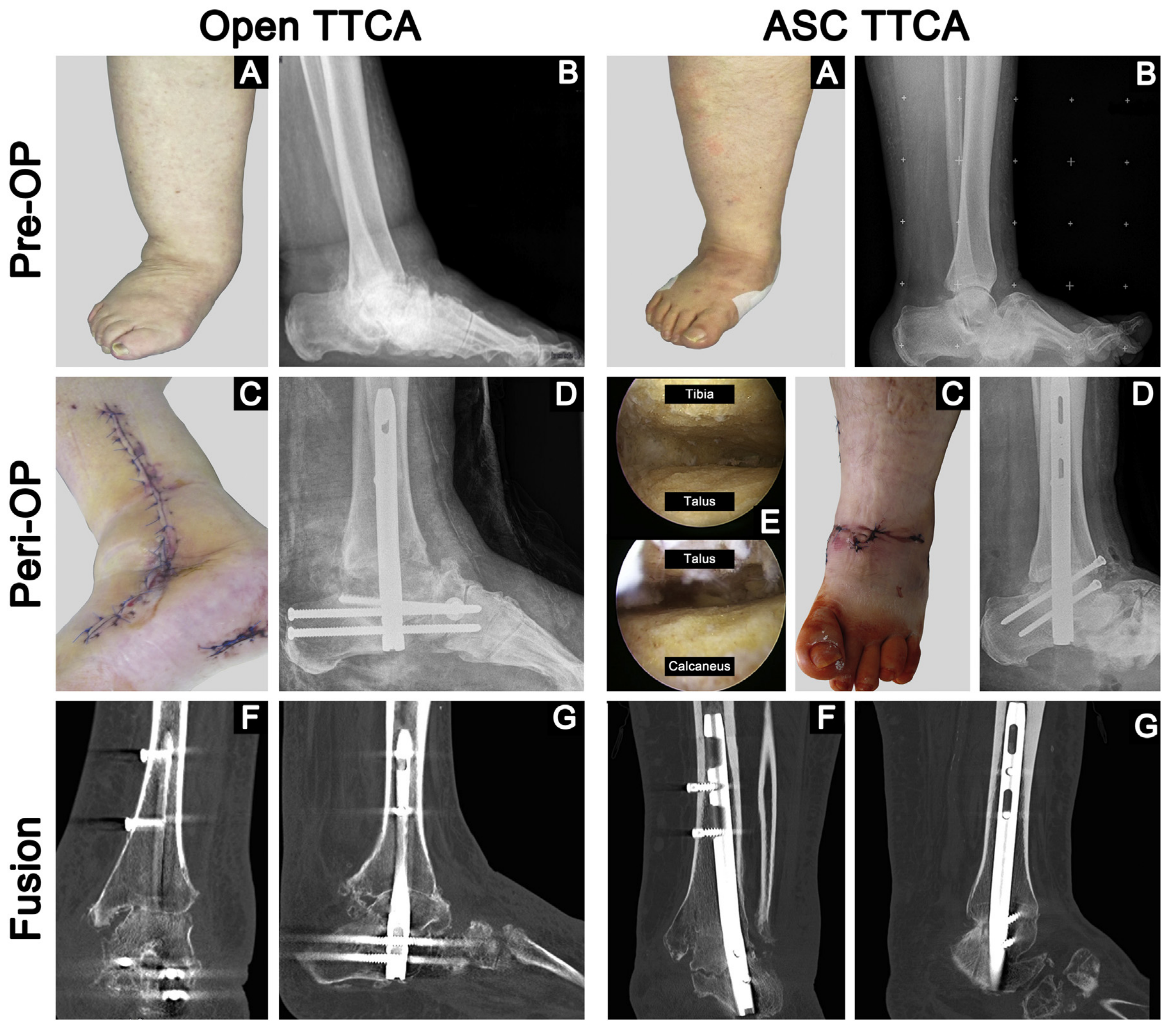

Fig. 4. Evaluation of bony fusion.
(A) Frontal CT image; (B) sagital CT image; (1) tibiotalar joint (2) talocalcaneal joint; bony fusion was defined as bone trabeculae crossing more than 50% of the joint with joint line obliteration.

2.4. Statistical analysis

The Shapiro Wilks test revealed normal distribution. Consequently, data were given as mean ± standard deviation, if not stated differently. Next to descriptive statistics, parametric tests (paired and independent sample t-test, Chi-Square Tests) were applied where necessary. The level of significance was set to $p < 0.05$. No sample size calculation could be conducted due to the limited data available on arthroscopic TTCA. Statistics were calculated using SPSS 20.0.0 (SPSS Inc. Chicago, Illinois 60606).

3. Results

In total 23 patients, 8 receiving open and 15 arthroscopic TTCA were included. The mean age was 59 ± 10 years, 91% were male. Patient's demographics, indications for TTCA, pre-existing medical conditions and previous operative interventions are summarized in Table 1. All patients were considered high-risk patients with no significant group differences.

3.1. Intra- and postoperative period

The Expert Hindfoot Arthrodesis Nail (HAN, Depuy/Synthes, Oberdorf, CH) was used in all open TTCAs and in 4 (29%) cases of arthroscopic TTCAs. The remaining 11 arthroscopic TTCAs were performed using the Ankle Fusion Nail (AFN, Tornier, Montbonnot Sant Martin, France). Additional procedures were performed in 5 cases of each group (62% vs. 33%; $p = 0.221$). The in-house stay for patients undergoing open TTCA was 43 ± 36 days and 19 ± 11 days ($p = 0.103$) for arthroscopic TTCA.

3.2. Radiographic outcomes

Overall, significant improvements for both, the talar declination angle (43° ± 8° vs. 30° ± 8°, $p < 0.001$) and the calcaneal inclination angle (6° ± 10° vs. 18° ± 6°, $p < 0.001$) were observed between pre- to post-operative imaging. The talar declination angle improved by 18° ± 8°/11.8° ± 7° in the open/arthroscopic group ($p = 0.183$). The calcaneal inclination angel improved by 16° ± 10°/11° ± 8° for open/arthroscopic TTCA ($p = 0.393$). Overall, a significant improvement of the hindfoot alignment was seen for both groups, with no significant differences of the correction (delta) between the two groups.

3.3. Bony fusion

Following open TTCA bony fusion occurred in 75% (6 patients) after 15 ± 7 weeks. For arthroscopic TTCA bony fusion was achieved

Table 1
Patient's demographics, indications for TTCA, pre-existing medical conditions and previous operative interventions.

	Open (n = 8)	Arthroscopic (n = 15)
Demographics		
Age	63 ± 11	56 ± 10
Sex (male)	7 (88%)	14 (93%)
Side (left)	2 (25%)	8 (53%)
BMI (kg/m^2)	29 ± 5	29 ± 7
ASA classification	2.7 ± 0.5	2.5 ± 0.5
Indications for TTCA		
Charcot neuro-ostoarthopathy	2 (25%)	8 (53%)
Combined posttraumatic osteoarthritis	0 (0%)	4 (27%)
Neurogenic equinus	1 (12%)	1 (7%)
Equinus following chopart amputation	5 (62%)	2 (13%)
Pre-existing medical conditions		
Smoker	4 (50%)	7 (47%)
Alcohol misuse	3 (38%)	3 (20%)
DM type II	8 (100%)	9 (64%)
Peripheral polyneuropathy	6 (75%)	11 (85%)
Peripheral arterial occlusive disease	6 (75%)	6 (43%)
Arterial hypertension	7 (88%)	10 (71%)
Coronary heart disease	0 (0%)	4 (29%)
Atrioventricular block	1 (13%)	1 (7%)
Atrial fibrillation	1 (13%)	2 (17%)
Congestive heart failure	0 (0%)	1 (7%)
COPD	0 (0%)	1 (7%)
Chronic kidney insufficiency	3 (38%)	2 (14%)
Cirrhosis liver	1 (13%)	0 (0%)
Previous operative interventions		
Previous operative interventions	8 (100%)	11 (73%)
Chopart amputation for plantar ulceration prior TTCA	4 (50%)	0 (%)
Operative preconditioning of plantar ulceration	3 (37%)	4 (29%)
Number of preconditioning interventions	2.3 ± 2.3	3 ± 1.8
Time Preconditioning to TTCA [days]	23 ± 18	30 ± 10

n: Number of patients; BMI: Body Mass Index; ASA: American Society of Anesthesiologists; DM: diabetes mellitus; COPD: chronic obstructive pulmonary disease.

in 67% (10 patients; p = 0.679) patients after 11 ± 4 weeks (p = 0.285). Following open TTCA, 2 patients suffered a symptomatic septic non-union, 1 of the ankle and 1 of the subtalar joint. Following arthroscopic TTCA, 1 non-symptomatic and 1 symptomatic non-septic subtalar non-union as well as 3 symptomatic septic ankle non-unions were observed.

3.4. Complications

Open TTCA resulted in 63% (5 patients) in one or more major complications. 4 out of 5 patients suffered a SSI with multiple revision surgeries. In one of those patients the SSI resulted in a septic non-union of the subtalar joint, secondary osteomyelitis of the hindfoot and subsequent below-the-knee amputation. In 25% (2 patients) minor complications occurred.

Arthroscopic TTCA resulted in 33% (5 patients) in a major complication, all of which were non-unions (1 non-symptomatic and 4 symptomatic non-unions). No major SSI were observed. Minor complications occurred in 29% (4 patients). All complications are outlined in Table 2.

In order to identify possible predisposing factors for major complications, a subgroup analysis was conducted (Table 3). None of the assessed parameters, i.E. age, BMI, Diabetes mellitus, number of complications, and preoperative plantar ulceration, differed significantly between patients suffering a major complication and those who did not.

With preexisting plantar ulceration being a known risk factor for complications [32] patients with plantar ulceration were compared per procedure to those without (Table 4). Plantar ulceration did not affect the primary major complication in open TTCA, i.E. SSI (60% vs. 67%). But for arthroscopic TTCA, non-union rates were significantly lower in patients without- compared to those with preexisting plantar ulceration (18% vs. 75%; p = 0.039). Three out of 4 patients suffering from a plantar ulceration preoperatively did not achieve bony union following arthroscopic TTCA, while 9 out of 11 patients without ulceration achieved bony union.

Table 2
Complications following open and arthroscopic TTCA.

Complications		Open TTCA (n = 8)	Arthroscopic TTCA (n = 15)
Major	Asymptomatic non-union	0%	7%[a]
	Symptomatic non-union	25%[b]	27%[c]
	SSI requiring reoperation	50%	0%
	Major amputation	13%	0%
Minor	SSI non-operatively	13%	20%
	Screw-loosening	0%	7%
	Fracture	13%	0%

n = Number; SSI: surgical site infection.
[a] non-septic subtalar.
[b] 1x septic ankle and 1x septic subtalar.
[c] 3x septic ankle and 1x non-sept. ankle.

Table 3
Subgroup analysis for patients suffering major complications.

Procedure	Complications	Age	BMI	DM	Co-morbidities	Ulcus
All (n = 23)	None (n = 13)	57 ± 11	29 ± 7	9 (69%)	4 ± 2	2 (15%)
	Major (n = 10)	62 ± 9	29 ± 4	8 (80%)	4 ± 1	5 (50%)
	Sig	0.246	0.720	0.560	0.966	0.184
Open (n = 8)	None (n = 3)	58 ± 17	30 ± 6	3 (100%)	5 ± 1	1 (33%)
	Major (n = 5)	66 ± 6	28 ± 4	5 (100%)	5 ± 2	2 (40%)
	Sig	0.393	0.517	na	1.000	0.850
Arthroscopic (n = 15)	None (n = 10)	56 ±10	29 ± 8	6 (60%)	4 ± 2	1 (10%)
	Major (n = 5)	57 ±9	29 ± 5	3 (60%)	4 ± 1	3 (60%)
	Sig	0.867	0.989	0.803	0.568	0.052

n: Number; Co-morbidities: the number of co-morbidities per patient; Complications: the number of patients suffering one or more complications; BMI: Body Mass Index; DM: diabetes mellitus.

Table 4
Analysis of major complications for patients with a preoperative plantar ulceration.

	Open		ASK	
	No ulceration (n = 5)	Ulceration (n = 3)	No ulceration (n = 11)	Ulceration (n = 4)
% of patients with major comp	60%	67%	18%	75%
% of non-unions	20%	33%	18%	75%
% of major SSI	60%	67%	0%	0%

4. Discussion

Open TTCA is considered a safe but technically demanding procedure. Nevertheless, when analyzing studies in detail fusion-rates range from 55 to 100% and complications rates between 1% to 56% [5–12]. Moreover, amputation rates of up to 12% have been reported following open TTCA [14]. This variability is most likely attributed to patient specific risk factors which, in most studies, are not clearly stated. Only few studies have focused on patient specific risk factors. Wukich et al. [10] (117 open TTCAs) found Diabetes mellitus (DM) to increase the likelihood of SSI by a factor of 8. In a cohort of 179 patient, open TTCAs resulted in a major amputation in 12% [14]. DM again was the highest risk factor for amputation (odds ratio 7), followed by revision surgery (odds ratio 6) and preoperative ulceration (odds ratio 3). Mendicino et al. [33] compared complication rates following open TTCA in patients with DM to non-DM patients (10 vs. 10). Patients with DM had an overall complication rate of 80% and a major complication rate of 50%, compared to 60% overall and 0% major complications for non-DM patients. Taken together, DM seems to be a major patient specific risk factor for major complications following extensive surgeries to the foot and ankle such as a TTCA.

Consequently, it can be hypothesis, that a less invasive procedure should reduce the number of complications, especially in high-risk patients. One approach to reduce the invasiveness could be arthroscopic TTCA. It significantly reduces the wound surface, minimizes disruption of the extraosseous talar blood supply [34–36] and increases the bony contact surfaces [24,37]. Up to now, only 6 case series on arthroscopic TTCA with 23 patients cumulatively have been published [24–29]. These studies resemble a proof of principle as they are limited to a low number of patients in each study, heterogeneous patient samples, lack information on risk factors and complications. Moreover, the miss a control group. All but two studies [26,29] were case reports with a maximum of 3 patients [24,25,27,28]. The largest case series was published by Sekiya et al. [26]. They reported one subtalar non-union in nine arthroscopic TTCAs with two patients lost to follow-up. Besides the non-union observed no further information on any other complication was supplied. Although the authors stated the diagnosis leading to TTCA (rheumatoid arthritis, osteoarthritis, drop foot), no further information was provided on the patients' medical history. Mencière et al. [29] reported no complications following arthroscopic TTCA in 6 patients (4/6 smokers, 6/6 polyneuropathy, 3/6 venous insufficiency). Taken together, current evidence on arthroscopic TTCA is limited to small case reports/ series lacking detailed information on complications, patient specific risk factors, and a control group. Consequently, their value is limited.

This study is not only the largest cohort of arthroscopic TTCA, but also the first case-control study comparing arthroscopic to open TTCA in a larger high-risk patient sample. At one-year follow-up, 50% of the patients receiving open TTCA had suffered major SSI, necessitating multiple revision surgeries. One patient even went on to below-the-knee amputation. On the contrary, patients undergoing arthroscopic TTCA suffered no major SSI and had a considerably shorter in-house stay. The union-rate for open TTCA was 75% compared to 67% for arthroscopic TTCA. Yet it is important to note, that 3 out of 5 non-unions in the arthroscopic group occurred in patients with a preexisting plantar ulceration (Table 4). For patients without preexisting ulceration 9 out of 11 did achieve bony union, while 3 out of 4 patients with ulceration suffered a non-union in the arthroscopic group. This difference was significant ($p = 0.039$). The high rate of non-unions in patients with ulceration could be the result of chronic low-grade osteomyelitis which may not be suggested by radiography, laboratory and clinical findings. The operative strategy of multiple debridements and negative pressure wound therapy until wound swabs showed no bacterial growth, obviously did not sufficiently reduce the risk for non-union. The influence of preexisting ulcerations on bony-union following TTCA has not been analyzed sufficiently. On the contrary, most studies on TTCA either do not report on the incidence of plantar ulcer [5,7,8,11,12], or do not report on the correlation between plantar ulceration and complications [9,10]. Wukich et al. [32] just recently reported on the influence of foot ulceration on the amputation rate of 280 feet with Charcot neuro-osteoarthropathy. Patients with foot ulceration had an odds ratio of 6.02 (95% CI 2.28–15.91, $P < 0.0001$) to necessity amputation compared to patients without ulceration. These findings are well in line with various other studies [38–40]. They all found the presence of an ulceration to significantly increase complication and amputation rates. The authors are only aware of one study, analysing the interrelation of plantar ulceration and complications following TTCA [41]. Caravaggi et al. [41] performed open TTCA in 14 patients suffering from DM and Charcot neuro-osteoarthropathy. Four patients presented with a plantar ulceration, which prior to surgery healed completely by off-loading and immobilization. Nevertheless, in none of these 4 patients, a complete union was achieved. One patient even went on to below-the-knee amputation. Consequently, treatment strategies for patients suffering of plantar ulceration have to be revisit. One possible approach could be arthroscopic preparation of the arthrodesis and fixation using an external fixateur.

As outlined above, several patients presented with preoperative ulceration and/or suffered from early onset postoperative SSI. Consequently, these patients necessitated multiple additional interventions within their in-house stay. Both aspects explain the relatively long mean in-house stay of 43 ± 36 days in open and 19 ± 11 days in arthroscopic TTCA.

When analyzing patients without preexisting ulceration only, a union-rate of about 80% for both, open and arthroscopic TTCA was observed in the present study. Taken together, in high-risk patients without preexisting ulceration, the rate of revision surgery due to wound complications was zero and the union rate was 82% with arthroscopic TTCA. This seems to be an excellent result, especially when considering the high-risk population. Previous studies have reported major complication rates of 50% in DM-patients [33]. These numbers compare well to the herein observed 63% major complications following open TTCA. When analyzing arthroscopic TTCAs in patients without ulceration, the herein reported fusion rates compare to non-high-risk patients treated by open TTCA, while the wound complications were significantly less [1,5–8,10–12,42,43].

4.1. Limitations

The first limitation might be the limited size of the control group (open TTCA). In order to ensure comparability of the open TTCA group, only patients with deformities retrospectively suitable for arthroscopic TTCA and similar co-morbidities were eligible. Only 8 patients receiving open TTCA met those criteria. Still, these strict eligibility criteria for open TTCA patients ensured the comparability of both groups. Another limitation might be the radiographic work-up. First, preoperative weightbearing Saltzman-views were not available for all patients. Therefore, the pre- and postoperative hindfoot alignment could not be assessed. Second, no weightbearing postoperative radiographs were available. Therefore, the parameters assessed were measured on non-weightbearing radiographs. As postoperatively the hindfoot was fixed, talar- and calcaneal inclination should not be affected by weight-bearing. Further limitations were missing patient reported outcome measurements and the retrospective study design.

4.2. Strengths

Despite the above-mentioned limitations, there are several positive aspects of the study. First, a detailed analysis of 15 patients treated by arthroscopic TTCA is presented, which resembles by far the largest cohort published. Second, a comparison group, although small, treated by open TTCA is presented. Third, in contrast to most other studies, the co-morbidities and risk factors are comprehensible reported. Both cohorts presented reflect a high-risk population. Finally, unlike most other studies bony union was assessed on CT-scans, which allows a more accurate analysis, which might increase the number of diagnosed non-unions.

5. Conclusions

Taken together, arthroscopic TTCA drastically reduced wound related complications necessitating revision surgery when compared to the open procedure in high-risk patients. If no preexisting plantar ulceration was present, an excellent rate of bony unions of 80% was achieved, comparable to open TTCA.

Formatting of funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of interest

No author but Hans Polzer has to disclose any financial or personal relationships with other people or organizations that could inappropriately influence (bias) their work. Hans Polzer does consultancy for Arhtrex.

References

[1] Jehan S., Shakeel M, Bing AJF, Hill SO. The success of tibiotalocalcaneal arthrodesis with intramedullary nailing — a systematic review of the literature. Acta Orthop Belg 2011;77(5):644–51.

[2] Ettinger S, Stukenborg-Colsman C, Plaass C, Yao D, Claassen L, Berger S, et al. Tibiocalcaneal arthrodesis as a limb salvage procedure for complex hindfoot deformities. Arch Orthop Trauma Surg 2016;136(4):457–62, doi:http://dx.doi.org/10.1007/s00402-016-2420-1.

[3] Fang Z, Claaßen L, Windhagen H, Daniilidis K, Stukenborg-Colsman C, Waizy H. Tibiotalocalcaneal arthrodesis using a retrograde intramedullary nail with a valgus curve. Orthop Surg 2015;7(2):125–31, doi:http://dx.doi.org/10.1111/os.12171.

[4] Franceschi F, Franceschetti E, Torre G, Papalia R, Samuelsson K, Karlsson J, et al. Tibiotalocalcaneal arthrodesis using an intramedullary nail: a systematic review. Knee Surg Sports Traumatol Arthrosc 2016;24(4):1316–25, doi:http://dx.doi.org/10.1007/s00167-015-3548-1.

[5] Quill GE. Tibiotalocalcaneal arthrodesis with medullary rod fixation. Tech Foot Ankle Surg 2003;2:135–43.

[6] Hammett R, Hepple S, Forster B, Winson I. Tibiotalocalcaneal (hindfoot) arthrodesis by retrograde intramedullary nailing using a curved locking nail. The results of 52 procedures. Foot Ankle Int 2005;26(10):810–5, doi:http://dx.doi.org/10.1177/107110070502601004.

[7] Boer R, Mader K, Pennig D, Verheyen CCPM. Tibiotalocalcaneal arthrodesis using a reamed retrograde locking nail. Clin Orthop Relat Res 2007;463:151–6.

[8] Mückley T, Klos K, Drechsel T, Beimel C, Gras F, Hofmann GO. Short-term outcome of retrograde tibiotalocalcaneal arthrodesis with a curved intramedullary nail. Foot Ankle Int 2011;32(1):47–56, doi:http://dx.doi.org/10.3113/FAI.2011.0047.

[9] DeVries JG, Berlet GC, Hyer CF. A retrospective comparative analysis of Charcot ankle stabilization using an intramedullary rod with or without application of circular external fixator — utilization of the Retrograde Arthrodesis Intramedullary Nail database. J Foot Ankle Surg 2012;51(4):420–5, doi:http://dx.doi.org/10.1053/j.jfas.2012.03.005.

[10] Wukich DK, Mallory BR, Suder NC, Rosario BL. Tibiotalocalcaneal arthrodesis using retrograde intramedullary nail fixation: comparison of patients with and without diabetes mellitus. J Foot Ankle Surg 2015;54:876–82.

[11] Lucas Y, Hernandez J, Abad J, Remy S, Darcel V, Chauveaux D, et al. Tibiotalocalcaneal arthrodesis using a straight intramedullary nail. Foot Ankle Int 2015;36(5):539–46, doi:http://dx.doi.org/10.1177/1071100714565900.

[12] Richter M, Zech S. Tibiotalocalcaneal arthrodesis with a triple-bend intramedullary nail (A3)-2-year follow-up in 60 patients. Foot Ankle Surg 2016;22(2):131–8, doi:http://dx.doi.org/10.1016/j.fas.2015.06.005.

[13] Pinzur MS, Sostak J. Surgical stabilization of nonplantigrade Charcot arthropathy of the midfoot. Am J Orthop 2007;36(7):361–5.

[14] DeVries JG, Berlet GC, Hyer CF. Predictive risk assessment for major amputation after tibiotalocalcaneal arthrodesis. Foot Ankle Int 2013;34(6):846–50, doi:http://dx.doi.org/10.1177/1071100712472488.

[15] Myers TG, Lowery NJ, Frykberg RG, Wukich DK. Ankle and hindfoot fusions: comparison of outcomes in patients with and without diabetes. Foot Ankle Int 2012;33(1):20–8, doi:http://dx.doi.org/10.3113/FAI.2012.0020.

[16] Myerson MS, Quill G. Ankle arthrodesis. A comparison of an arthroscopic and an open method of treatment. Clin Orthop Relat Res 1991;84–95.

[17] O'Brien TS, Hart TS, Shereff MJ, Stone J, Johnson J. Open versus arthroscopic ankle arthrodesis: a comparative study. Foot Ankle Int 1999;20(6):368–74, doi:http://dx.doi.org/10.1177/107110079902000605.
[18] Ogilvie-Harris DJ, Lieberman I, Fitsialos D. Arthroscopically assisted arthrodesis for osteoarthrotic ankles. J Bone Joint Surg Am 1993;75(8):1167–74.
[19] Townshend D, Di Silvestro M, Krause F, Penner M, Younger A, Glazebrook M, et al. Arthroscopic versus open ankle arthrodesis: a multicenter comparative case series. J Bone Joint Surg Am 2013;95(2):98–102, doi:http://dx.doi.org/10.2106/JBJS.K.01240.
[20] Lopes R, Andrieu M, Bauer T. Arthroscopic subtalar arthrodesis. Orthop Traumatol Surg Res 2016;102(8S):S311–6, doi:http://dx.doi.org/10.1016/j.otsr.2016.08.002.
[21] Roster B, Kreulen C, Giza E. Subtalar joint arthrodesis: open and arthroscopic indications and surgical techniques. Foot Ankle Clin 2015;20(2):319–34, doi:http://dx.doi.org/10.1016/j.fcl.2015.02.003.
[22] Yasui Y, Hannon CP, Seow D, Kennedy JG. Ankle arthrodesis: a systematic approach and review of the literature. World J Orthop 2016;7(11):700–8, doi:http://dx.doi.org/10.5312/WJO.V7.I11.700.
[23] Giza E. Arthroscopic ankle fusion: a change of the gold standard: Commentary on an article by David Townshend, MBBS, FRCS(Orth), et al.: arthroscopic versus open ankle arthrodesis: a multicenter comparative case series. J Bone Joint Surg Am 2013;95:1––2, doi:http://dx.doi.org/10.2106/JBJS.L.01383 e10.
[24] Sekiya H, Horii T, Kariya Y, Hoshino Y. Arthroscopic-assisted tibiotalocalcaneal arthrodesis using an intramedullary nail with fins: a case report. J Foot Ankle Surg 2006;45(4):266–70, doi:http://dx.doi.org/10.1053/j.jfas.2006.04.003.
[25] Bevernage BD, Deleu PA, Maldague P, Leemrijse T. Technique and early experience with posterior arthroscopic tibiotalocalcaneal arthrodesis. Orthop Traumatol Surg Res 2010;96(4):469–75, doi:http://dx.doi.org/10.1016/j.otsr.2010.03.012.
[26] Sekiya H, Horii T, Sugimoto N, Hoshino Y. Arthroscopic tibiotalocalcaneal arthrodesis with intramedullary nail with fins: a case series. J Foot Ankle Surg 2011;50(5):589–92, doi:http://dx.doi.org/10.1053/j.jfas.2011.04.021.
[27] Vilà y Rico J, Rodriguez-Martin J, Parra-Sanchez G, Marti Lopez-Amor C. Arthroscopic tibiotalocalcaneal arthrodesis with locked retrograde compression nail. Foot Ankle Surg 2013;52(4):523–8, doi:http://dx.doi.org/10.1053/j.jfas.2013.03.015.
[28] Michels F, Burssens A, Putzeys G, Bauwhede JVD, Guillo S. Endoscopic guided tibiotalocalcaneal arthrodesis after failed osteosynthesis of pilon fractures. Clin Res Foot Ankle 2014;2:135, doi:http://dx.doi.org/10.4172/2329-910X.1000135.
[29] Mencière M-L, Ferraz L, Mertl P, Vernois J, Gabrion A. Arthroscopic tibiotalocalcaneal arthrodesis in neurological pathologies: outcomes after at least one year of follow up. Acta Orthop Belg 2016;82(1):106–11.
[30] Daniels TR, Younger ASE, Penner MJ, Wing KJ, Le IL, Russell IS, et al. Prospective randomized controlled trial of hindfoot and ankle fusions treated with rhPDGF-BB in combination with a β-TCP-collagen matrix. Foot Ankle Int 2015;36(7):739–48, doi:http://dx.doi.org/10.1177/1071100715576370.
[31] Goebel M, Mückley T, Gerdesmeyer L, Militz M, Bühren V. Intramedullary nailing in tibiotalocalcaneal arthrodesis. Der Unfallchirurg 2003;106(8):633–41, doi:http://dx.doi.org/10.1007/s00113-003-0626-5.
[32] Wukich DK, Sadoskas D, Vaudreuil NJ, Fourman M. Comparison of diabetic charcot patients with and without foot wounds. Foot Ankle Int 2017;38(2):140–8, doi:http://dx.doi.org/10.1177/1071100716673985.
[33] Mendicino RW, Catanzariti AR, Saltrick KR, Dombek MF, Tullis BL, Statler TK, et al. Tibiotalocalcaneal arthrodesis with retrograde intramedullary nailing. J Foot Ankle Surg 2004;43(2):82–6, doi:http://dx.doi.org/10.1053/j.jfas.2004.01.012.
[34] Mulfinger GL, Trueta J. The blood supply of the talus. J Bone Joint Surg Br 1970;52(1):160–7.
[35] Prasarn ML, Miller AN, Dyke JP, Helfet DL, Lorich DG. Arterial anatomy of the talus: a cadaver and gadolinium-enhanced MRI study. Foot Ankle Int 2010;31(11):987–93, doi:http://dx.doi.org/10.3113/FAI.2010.0987.
[36] Kendal AR, Cooke P, Sharp R. Arthroscopic ankle fusion for avascular necrosis of the talus. Foot Ankle Int 2015;36(5):591–7, doi:http://dx.doi.org/10.1177/1071100714565901.
[37] Chou LB, Mann RA, Yaszay B, Graves SC, McPeake 3rd WT, Dreeben SM, et al. Tibiotalocalcaneal arthrodesis. Foot Ankle Int 2000;21(10):804–8, doi:http://dx.doi.org/10.1177/107110070002101002.
[38] Sohn M-W, Lee TA, Stuck RM, Frykberg RG, Budiman-Mak E. Mortality risk of Charcot arthropathy compared with that of diabetic foot ulcer and diabetes alone. Diabetes Care 2009;32(5):816–21, doi:http://dx.doi.org/10.2337/dc08-1695.
[39] Sohn M-W, Stuck RM, Pinzur M, Lee TA, Budiman-Mak E. Lower-extremity amputation risk after charcot arthropathy and diabetic foot ulcer. Diabetes Care 2010;33(1):98–100, doi:http://dx.doi.org/10.2337/dc09-1497.
[40] Eschler A, Gradl G, Wussow A, Mittlmeier T. Prediction of complications in a high-risk cohort of patients undergoing corrective arthrodesis of late stage Charcot deformity based on the PEDIS score. BMC Musculoskelet Disord 2015;16:349, doi:http://dx.doi.org/10.1186/s12891-015-0809-6.
[41] Caravaggi C, Cimmino M, Caruso S, Dalla Noce S. Intramedullary compressive nail fixation for the treatment of severe Charcot deformity of the ankle and rear foot. J Foot Ankle Surg 2006;45(1):20–4, doi:http://dx.doi.org/10.1053/j.jfas.2005.10.003.
[42] De Vries JG, Berlet GC, Hyer CF. Union rate of tibiotalocalcaneal nails with internal or external bone stimulation. Foot Ankle Int 2012;33:969–78.
[43] Baumbach SF, Braunstein M, Maßen F, Regauer M, Mutschler W, Böcker W, et al. Arthroscopic tibiotalocalcaneal arthrodesis. Unfallchirurg 2016;119(2):86–91, doi:http://dx.doi.org/10.1007/s00113-015-0133-5.