CLINICAL ARTICLE

Tibiototalcalcaneal Arthrodesis Using a Retrograde Intramedullary Nail with a Valgus Curve

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Objective: Many different techniques have been described for performing tibiototalcalcaneal arthrodesis (TTCA) in patients with severe hindfoot disorders such as failed ankle arthroplasty and failed ankle joint arthrodesis with subsequent subtalar arthritis. The use of straight retrograde intramedullary nails is extremely limited because they may interfere with normal heel valgus position and risk damaging the lateral plantar neurovascular structures. Curved retrograde intramedullary nails have been designed to overcome these shortcomings. The purpose of this single surgeon series was to investigate the outcomes of TTCA using a curved retrograde intramedullary nail.

Methods: From June 2009 to January 2012, 22 patients underwent TTCA using intramedullary nails with a valgus curve by the same senior surgeon. All patients were available for analysis, the mean follow-up being 22.3 months (range, 6.8–38 months). The main outcome measurements included EQ-5D functional scores, the American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot scale, radiologic assessment and clinical examination.

Results: Bony union and a plantigrade foot were achieved in 100% of subjects, the mean time to union being 3.9 months (range, 2.4 to 6.2 months). Structural bone graft was used in all patients. Postoperative radiologic results showed a good hindfoot alignment in all patients. The only complication was one case of delayed wound healing without deep infection. The mean postoperative EQ-5D functional and AOFAS ankle-hindfoot scores were 69.33 (range, 20 to 90) and 69.9 (range, 45 to 85) points, respectively. No revision surgery was necessary in our cohort.

Conclusion: The results of the present study indicate that TTCA using a short, retrograde, curved intramedullary nail is an acceptable technique for obtaining solid fusion and good hindfoot alignment in patients with severe hindfoot disorders.

Key words: Intramedullary nail; Tibiototalcalcaneal arthrodesis; Union

Introduction

Tibiototalcalcaneal arthrodesis (TTCA) is indicated in patients with complex hindfoot deformity, failed ankle arthroplasty and failed ankle joint arthrodesis with subsequent subtalar arthritis^{1–4}. It has been shown to be an effective treatment option for pain relief and correction of hindfoot malalignment in such subjects^{2,5}. Many alternative fixations

such as crossed cancellous screws⁶, angle bladed plates⁷, external frames⁸, and intramedullary nails combined with bone graft have been reported for performing TTCA^{1,2,4,9,10}. External fixations, compression screws and plates are usually associated with longer periods of non- or partial weight-bearing postoperatively and low bony fusion rates^{7,11}. Intramedullary nail have become more popular than other forms of fixations because of

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Disclosure: The research was carried out in the Department of Orthopaedics of Hannover Medical School, Germany. The manuscript submitted does not contain information about medical device(s)/drug(s). No funds were received in support of this work. No relevant financial activities outside the submitted work.

Received 17 January 2015; accepted 1 March 2015

TABLE 1 Indications for TTCA in the present study

Disorder	Underlying diagnosis	Number of patients
Arthritis	Primary osteoarthritis	3
	Post-traumatic osteoarthritis	9
	Severe talar avascular necrosis	1
Failed ankle arthroplasty	Failed ankle arthroplasty with progressive subtalar arthritis	3
Failed ankle arthrodesis with progressive subtalar arthritis	Failed ankle arthrodesis with screws	4
	Failed TTCA with a nail	1
Deformity	Idiopathic cavovarus with secondary osteoarthritis	1

the stability and compression they achieve; they are capable of generating compression and thereby increasing fusion rates, especially in patients with poor bone quality^{11–13}.

Historically, straight retrograde intramedullary nails have been associated with many complications, such as plantar neurovascular damage, poor hindfoot alignment and stress reactions, especially in the region of the tibial isthmus^{5,11–14}. Those complications have severely limited the clinical use of straight retrograde nails for performing TTCA. Recently, both cadaveric and clinical studies have reported that curved retrograde nails avoid these complications by lateralizing the entry point, thus potentially reducing the risk of damage to the lateral plantar nerve. Additionally, the valgus curve of these nails contributes to maintaining physiological hindfoot valgus^{1,4,9,11}.

The current study was performed to explore the clinical advantages of performing TTCA using curved retrograde intramedullary nails. We here present the results of TTCAs in 22 patients.

Material and Methods

Study Design

Between June 2009 and January 2012, twenty-two TTCAs in 22 consecutive eligible patients were performed by the same senior surgeon in our foot and ankle department. The study protocol was approved by the Ethics Committee of our institute and all patients consented to the use of their data for research purposes.

The average age of the cohort was 62.2 years (range, 46–79 years), with a male: female ratio of 10:12. The mean follow-up time was 22.3 months (range, 6.8–38 months).

The indications for TTCA using a curved nail were arthritis affecting the ankle and subtalar joint, severe talar avascular necrosis, failed ankle arthroplasty and arthrodesis associated with secondary subtalar joint arthritis, and hindfoot deformities that were refractory to other treatments (Table 1).

TTCA Nail Design

Retrograde, curved, interlocking nails made of titanium (Stryker, Duisburg, Germany) were used in the present study (Fig. 1). This design provides one angle stable lateral screw, one angle stable posterior-to-anterior calcaneal screw and a con-

ventional talar screw for distal fixation. TTCA nails can be adjusted during the operative procedure under the following conditions: internal or external compression or without compression. Talocalcaneal joint compression is provided by an external compression device that is fixed on the target arm. Tibiotalar joint compression and angle stability is achieved by a dynamic compression screw in the nail. Angle stability is attributed to an end cap locked onto the distal posterior to anterior calcaneal screw¹⁰. This nail has a 5° valgus curve to accommodate physiological hindfoot valgus. In terms of the nail axis, external torsion of the calcaneal longitudinal axis is reflected by 10° external rotation provided the posterior-to-anterior calcaneal screw is correctly inserted from a posteromedial to anterolateral direction¹⁰.

Fig. 1 Photograph of a curved retrograde intramedullary nail for TTCA.

Fig. 2 Intraoperative photographs showing the procedure of TTCA in a 71-year-old woman with failed ankle arthroplasty and progressive subtalar arthritis. (A) The post-lateral approach. (B) Removal of the ankle prosthesis. (C) Thorough resection of the articular surfaces of the ankle and subtalar joints (arrows). (D) Bone defect. (E) Under fluoroscopic guidance, a cannulated reamer is employed to increase the size of the canal passing through the subtalar and ankle joints to 1 mm more than the diameter of the nail. (F) Bony defects are filled with the autologous bone graft obtained from the resected distal fibula.

Surgical Technique

Three patients of the 22 patients had failed ankle arthroplasty; their surgeries were performed in the supine position with a sandbag under ipsilateral buttock. The other 19 patients were placed in a prone position. Tourniquet hemostasis at the thigh was used in all operations. A posterolateral approach was used to facilitate access to the ankle and subtalar joints (Fig. 2). The distal fibular was resected at the level of the syndesmosis with an oscillating saw. The articular surfaces of the ankle and subtalar joints were thoroughly resected to ensure contact between viable bleeding bones. Autologous bone graft obtained from the resected distal fibula was performed to fill bony defects. In the failed ankle arthrodesis cases, iliac-crest bone graft was required because the distal fibula had been resected in the primary surgery. Percutaneous Achilles tendon lengthening was performed if needed. A 1.5 cm longitudinal incision was made in the heel pad lateral to the midline¹⁰ and a hemostat used to bluntly dissect down to the calcaneus. The ideal entry point for the calcaneus is at the junction of the lateral one-third and medial two-thirds, which corresponds to the mid-point of the medullary canal of the

tibia (Fig. 3)¹. Under fluoroscopic guidance and with an assistant maintaining a neutral position for arthrodesis, a guide wire was placed in the calcaneus with a physiological 5° valgus curve and passed through the subtalar joint. The direction is supposed to change to straight after the guide wire enters the talus. With an assistant maintaining an optimal position, a cannulated reamer was employed to increase the size of the canal passing through the subtalar and ankle joints to 1 mm greater than the diameter of the nail. In this procedure, the main concerns are to avoid anterior and posterior subluxation, which can be achieved by placing the talus correctly in the ankle joint. External rotation was adjusted to match that of the contralateral foot (ranging from 5° to 10°). The nail was inserted under fluoroscopic guidance. The goal of alignment is a plantigrade foot without pronation or supination of the forefoot. First, one transverse locking screw was placed in the talus, after which two proximal locking screws were inserted into the tibia under fluoroscopic guidance and positioned at the superior end of the nail from medial to lateral with the target device. A shaft screw was then inserted into the oblong hole at the distal end of the nail for compression. When the

Fig. 3 The plantar facet of the calcaneus showing the ideal entry point (the slim arrow) for a curved retrograde nail with regard to the tibial medullary canal (the bold arrow) and the adjacent lateral nerve vascular bundle (yellow line).

compression screw is inserted axially into the distal end of the nail, it pushes against the shaft screw to generate compression between the resected bone surfaces. The distal screw of the calcaneus was placed from lateral to medial with the target device after completion of the compression procedure. Finally, the posterior-to-anterior calcaneal screw was inserted from posteromedial to anterolateral. Wound closure was performed in a standard manner (Video S1).

Immobilization was achieved with a below-knee orthotic for a minimum of 6 weeks (non-weight-bearing for 2 weeks, partial weight-bearing with 10 kg for 4 weeks). The screws were not removed for dynamization purposes. Findings on X-ray films and medical co-morbidities were recorded at each follow-up visit: at 6 weeks, 3 months, 6 months, and 1 year after surgery.

Ankle and hindfoot radiographs, including weight-bearing lateral and antero-posterior ankle views as well as calcaneal axis view, were performed preoperatively and postoperatively (Fig. 4). Hindfoot alignment was assessed in terms of the calcaneal axis with regard to the distal tibial axis on calcaneal axis views (Saltzman).¹¹ Measurements were based on digitized radiographs using Ortho-Tool Cedara 1 Report 5.2 P14 software (Cedara Software, Milwaukee, WI, USA). Radiographic union was defined as bone trabeculae crossing the joint with joint line obliteration and consolidation¹⁴. Delayed union was defined as absence of radiographic evidence of bony consolidation at the 3-month follow-up visit. Clinical union was defined as pain-free passive and active movement at the subtalar and ankle joints^{5,15}.

Patients were asked about their satisfaction with their outcomes and treatment procedures and completed the EQ-5D-3L questionnaire to assess health-related quality of life at the latest follow-up. This questionnaire comprises the following five dimensions: mobility, self-care, usual activities, pain/discomfort and anxiety/depression). Each dimension has three levels: no problems, some problems and extreme problems^{16,17}. Other variables recorded included the duration of orthotic support and requirement for analgesics during follow-up.

Statistical analysis was performed using SPSS 17.0 (SPSS, Chicago, IL, USA). Student's *t*-test was performed to compare the data. Significance was set at $P < 0.05$.

Results

The mean operation time was 128 minutes (range, 72 to 214 minutes).

Union

Radiographic and clinical union was achieved in 100% (22/22) of patients, the mean time to union being 3.9 months (range, 2.4–6.2 months). Two patients had delayed radiographic union at ankle joint (union at 5 and 6.2 months, respectively).

Correction of Deformity

Preoperatively, 15 patients had a mean $15.29^\circ \pm 14.21^\circ$ of varus hindfoot deformity and five a mean of $11.16^\circ \pm 9.61^\circ$ of valgus hindfoot deformity. Postoperatively, 100% patients in our cohort achieved a plantigrade foot. Satisfactory hindfoot with varus and valgus of less than 5° was achieved in all patients (Fig. 5).

Functional Score

Due to lack of sagittal motion (flexion plus extension) and coronal motion (inversion plus eversion) of the hindfoot, the highest American Orthopaedic Foot and Ankle Society (AOFAS) ankle-hindfoot score after TTCA was 86. Functional scores were evaluated in seventeen patients. The mean postoperative EQ-5D functional score was 69.33 (range, 20–90) and the mean postoperative AOFAS ankle-hindfoot score 69.9 (range, 45–85) points at the latest follow-up. Two patients required a walking aid (elbow crutch or cane). Eight patients had slight or severe difficulty on uneven terrain, stairs, inclines and ladders. Six patients had obvious or marked gait abnormality. On questioning, five patients reported mild pain, no patients reported severe pain. The remaining patients were pain-free. Twenty-one of 22 (95%) patients stated that they would undergo the operation again.

Complications

At the latest follow-up, 90.9% (20/22) patients were satisfied with their outcome and treatment procedures. The one dissatisfied patient had superficial delayed wound healing without evidence of infection. One patient experienced soft tissue irritation resulting from the screw in the calcaneus. She recovered immediately and was satisfied with the result of removal of the

Fig. 4 (A) AP and (B) lateral radiographs of ankle showing ankle arthritis in a 48-year-old man. (C) Postoperative 48 months' AP and (D) lateral radiographs and (E) postoperative MRI after removal of the screws showing bone nonunion and subtalar joint destruction caused by the screw after the ankle arthrodesis. Three months postoperative (F) lateral and (G) AP radiographs after the third operation showing bony union of both subtalar and ankle joints and good alignment of the hindfoot after a TTCA using a curved retrograde intramedullary nail.

Fig. 5 Comparisons of radiologically assessed valgus and varus deformity (hindfoot alignment).

TABLE 2 Published reports concerning TTCA (more than 20 patients) using retrograde nails including curved and straight nails

Authors	Number of TTCA's	Type of retrograde nail	Union rate (%)	Complication rate (%)	Postoperative AOFAS hindfoot-ankle score	Satisfactory rate (%)
Chou <i>et al.</i> ⁵	45	Curved	89	21	69.76	78
Mückley <i>et al.</i> ¹⁰	55	Curved	96	25	66.8	93
Goebel <i>et al.</i> ¹⁴	29	Straight	90	21	71	79
Anderson <i>et al.</i> ¹³	26	Five retrograde nails*	96	23	64	92
Hammett <i>et al.</i> ¹⁹	49	Humeral nails	87	20	63	82
Boer <i>et al.</i> ²	50	Curved	96	4	70	92

*, Five different designs of the nail were used, including the flanged Thornton nail (originally designed for hip fractures), the revision nail (Smith and Nephew, Memphis, TN, USA), the Biomet ankle arthrodesis nail (Biomet Orthopedics, Warsaw, IN, USA), the AIM nail (DePuy Orthopedic, Warsaw, IN, USA), and the humeral nail (Synthes, Obersdorf, Switzerland).

screw. There were no cases with non-union of ankle or subtalar joints. Additionally, by the time of the latest follow-up, no evidence of cortical stress reactions, including complete fracture around the proximal locking screws and the proximal tip of the nail, was observed.

Discussion

The aim of this study was to evaluate the effects of the TTCA using a curved, retrograde intramedullary nail. In this single surgeon series, 100% bony fusion rate with a 9.1% overall complications rate was achieved in 22 patients who had undergone TTCA using a curved, retrograde intramedullary nail.

The ideal position for the hindfoot after TTCA is a neutral position for dorsal/plantar flexion, 5° valgus and 5° to 10° external rotation^{14,18,19}. Straight retrograde intramedullary nails can interfere with normal heel valgus position and fail to maintain the physiological valgus angle, resulting in further dysfunction of adjacent joints^{5,14,19,20}. In the current study, satisfactory postoperative hindfoot alignment with physiological valgus was achieved despite significant preoperative varus and valgus deformity. We attribute our achievement of good radiographic alignment to the distal anatomical curve of the nail. The distal curve in the nail permits a satisfactory position in the tibial medullary canal without hindfoot varus; this is likely crucial to achieving good hindfoot alignment¹. A point to emphasize is that maintaining correct position of the ankle joint while the operator is drilling the Kirschner wire is the crucial factor that determines the postoperative position after the procedure of TTCA.

The overall complication rate of using a nail in TTCA reportedly ranges from 4%^{2,13} to 59%¹⁹ (Table 2); complications include complications of wound healing, superficial and deep infection, pseudoarthrosis, neurovascular damage, malalignment, stress reactions, fracture and persistent pain. Additionally, lateral plantar neurovascular damage resulting in a permanent but tolerable sensory loss on the plantar aspect of the foot has been reported with a straight nail¹². This type of damage associated with straight retrograde nails is attributable to the proximity of the lateral plantar nerve and its branches to

the entry point of a straight nail. Of note, delayed stress reactions and even complete fracture around the proximal nail tip or locking screws are also possibilities with retrograde nails^{11,19}. In the present study, no lateral plantar vascular damage and no fractures around the nail were observed. This may be attributable to the angular curve in the distal part of the curved nail. On one hand, this enables an ideal entry point in the heel lateral to the mid-line, thus preventing damage to the branches of the lateral plantar nerve and vascular bundle¹. On the other side, it helps to achieve a satisfactory position in the tibial medullary canal and a good hindfoot alignment, which may be crucial in preventing abnormal loading and stress in the proximal region of the nail. A point to emphasize is that the relatively short length of the nail, the proximal tip usually of which never exceeds the tibia isthmus, also contributes to preventing such stress fractures¹².

Infection is a common problem with intramedullary nails in TTCA^{10,20,21}. In the current study, one patient had superficial delayed wound healing without infection. However, published reports indicate that intramedullary nails have risks of infection, especially in patients with a history of previous infection^{2,14,21}.

As to the fusion rate in patients treated with TTCA using a nail (Table 2), Budnar *et al.* documented a fusion rate of 89% (40/45) using a short, anatomically curved intramedullary nail¹. Mückley *et al.*¹⁰ and Boer *et al.*² reported a union rate of 96% in a broad spectrum of patients similar to the pattern of our cohort. Mader *et al.* documented achieving a 100% union rate after TTCA using a retrograde nail in 10 patients with failed ankle arthrodesis, which is consistent with our results²². The fusion rate depends on many factors, including the underlying condition of the patient, debridement of the joint facets and the biomechanical characters of implants^{7,8,10,14,19}. Firstly, the union rate is dependent on the following patient factors: whether the patient is a habitual smoker, the presence of avascular bone at the arthrodesis site and the patient's compliance with the postoperative non-weight-bearing protocol¹⁰. Secondly, other factors such as whether the surgeon performs debridement correctly, the degree of compression provided by the fixation

and bone graft between the arthrodesis joint, also play important roles⁷. The main techniques for preparing the articular surfaces in TTCA are described in published reports; they include thorough resection of the articular cartilage of both joints and preservation of the anatomical contours of the joints to minimize postoperative leg length discrepancy^{10,23}. However, Boer *et al.* recommended TTCA with a nail without formal debridement of the subtalar joint and a choice between open or percutaneous debridement of the ankle; they achieved a 100% fusion rate of the ankle joint and 96% fusion rate of the subtalar joint using this procedure². In the current study, we performed thorough debridement and achieved a 100% fusion rate of both ankle and subtalar joints. Thirdly, intramedullary nails provide greater stability than crossed screws and results of a biomechanical study suggested a more favorable fusion rate with the former²⁴. Additionally, Chou *et al.* reported that use of a posterior-anterior (PA) locking plane may make a decisive difference in contributing to greater angle stability⁵. Thus, PA locking and the reaming process may contribute significantly to achieving high union rates²⁵.

This study had several limitations. Firstly, it is a retrospective study with a short-term follow-up. One disadvantage of TTCA is the rigidity of the hindfoot, which may predispose to secondary degenerative arthritis in the adjacent naviculocuneiform and tarsometatarsal joints. These complications had not yet occurred by the latest follow-up in our study. Secondly, the present study lacked a comparison group,

such as patients managed with different implants. We only compared our results with those of relevant published studies. Thirdly, we did not lack evaluate functional scores preoperatively in the current study and therefore could not objectively compare preoperative and postoperative function; however, the patients were subjectively satisfied with their outcomes. We could not exclude dysfunction of the peroneal tendon. Furthermore, we did not identify any long-term forefoot deformities after we had resected the fibula in the procedure of TTCA. However, we emphasize that comparison of radiological findings indicated that improved hindfoot alignment had been achieved. Finally, we had too few cases to establish a direct relationship between functional outcomes and radiographic findings.

The results of the present study suggest that TTCA using a short, retrograde, curved intramedullary nail is an acceptable technique for achieving solid fusion with minimal complications. However, long-term follow-up is necessary to provide definitive information about topics such as adjacent degenerative arthritis.

Supporting Information

Additional Supporting Information may be found in the online version of this article on the publisher's web-site:

Video S1 Tibiotalocalcaneal arthrodesis using a retrograde intramedullary nail.

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