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UP-TO DATE REVIEW AND CASE REPORT

Retrograde intramedullary nail entry point for tibio-talo-calcaneal arthrodesis: a review of anatomical studies

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Abstract

Purpose Tibio-talo-calcaneal arthrodesis (TTCA) is considered a safe and valuable option for end-stage tibiotalar and subtalar arthritis, and usually is performed with a retrograde intramedullary nail. Although the good results reported, potential complications may be related to retrograde nail entry point. Aim of this systematic review is to analyze in cadaveric studies the risk of iatrogenic injuries related to different entry points and different retrograde intramedullary nail design when performing TTCA.

Methods According to PRISMA, a systematic review of the literature was performed on PubMed, EMBASE and SCOPUS databases. A subgroup analysis comparing different entry point location (anatomical or fluoroscopic guided) and different nail design (straight vs. valgus curved nails) was performed.

Results Five studies were included, for a total of 40 specimens. Superiority of anatomical landmark-guided entry points was observed. Different nail designs did not seem to influence nor iatrogenic injuries neither hindfoot alignment.

Conclusion Retrograde intramedullary nail entry point should be placed in the lateral half of the hindfoot in order to minimize the risk of iatrogenic injuries.

Keywords Tibio-talo-calcaneal arthrodesis · Entry point · Iatrogenic injuries · Cadaveric studies · Surgical tips

Introduction

Despite the increasing popularity of total ankle arthroplasty (TAA), literature indicates that ankle arthrodesis (AA) still remains the most common surgical treatment for end-stage ankle arthritis [1, 2].

Several operative techniques have been reported for AA, including arthroscopic or open approaches, and using both external and internal fixation systems. Devices used for internal fixation include screws, plates and retrograde intramedullary nails (RIN).

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RIN are typically reserved for arthrodesis of both ankle and subtalar joint, also known as tibio-talo-calcaneal arthrodesis (TTCA).

Indications for TTCA include post-traumatic ankle arthritis with concomitant subtalar arthritis [3], severe ankle deformity on the frontal plane, talar avascular necrosis, failed TAA [4], associated ankle and hindfoot deformities in rheumatoid arthritis and Charcot arthropathy [5].

TTCA is considered an effective procedure, thanks to several advantages: it can be performed with a minimally invasive surgical approach and theoretically provides minimal periosteal aggression and vascular damage [2, 6].

From a biomechanical perspective, TTCA represents a stable internal fixation structure, stiff during all bending and torsional stresses; RIN promotes compression and maintains the hindfoot alignment during the union process, thus increasing fusion rate [7–9].

These features allow for early recovery, mobilization and weight bearing, particularly important in elderly patients with comorbidities [10].

TTCA usually requires a retrograde approach, which was first performed using a variety of straight devices such as Steinmann pins[11], femoral retrograde supracondylar nails [10, 12] and long femoral nail [13]. These devices reported satisfactory outcomes but were applied to a small series of patients.

Although the encouraging results, a few complications were associated with straight RIN, such as tibial stress reaction, especially in the region of the tibial isthmus, hindfoot malalignment, and neurovascular (NV) injuries [4, 14–17].

In particular, several radiographical and anatomical studies have shown the critical location of the nail related to the bony surfaces and the close proximity of the TTC nail entry point to the tendinous and NV structures [18–20].

This led to the development of valgus curved RIN, with the aim to obtain better hindfoot alignment and to minimize the risk of NV injuries, but with controversial results [21].

Although the popularity of curved nail design has raised since then, to our knowledge, no data systematically reporting complications related to RIN entry point, either with straight or curved nails, were published.

Aim of this systematic review was to analyze in cadaveric studies the risk of iatrogenic injuries related to different entry points and different RIN design when performing TTCA.

Materials and methods

This systematic review has been conducted according to the Preferred Reported Items of Systematic Reviews and Meta-analyses (PRISMA) guidelines. PubMed, EMBASE and SCOPUS databases have been searched for the following keywords: (((anatomic) OR (NV) OR (cadaveric)) AND ((structures) OR (considerations) OR (study))) AND (((tibiotalocalcaneal) OR (TTC) OR (ankle) OR (hindfoot) OR (tibiotalar)) AND ((fusion) OR (arthrodesis))).

The period of time investigated was from 1990 up to September 2022.

The inclusion criteria were: cadaveric studies; TTCA performed with retrograde intramedullary devices; NV damage assessed by anatomical dissection and not by radiographic imaging only.

The exclusion criteria were: clinical studies; NV damage assessed by radiographic or 3DCT image only; TTCA performed with 3D reconstruction of the RIN.

After screening by title, abstract and full-text examination, the included studies were examined to extract:

- Number of specimens
- RIN characteristics (diameter, length, straight or valgus curved design)
- Entry point and reaming technique
- RIN distance to the anatomical structures, related lesions and criteria of measurement
- Relationship between RIN and bone structures

Entry point description was collected and classified as anatomical or under fluoroscopic guidance.

All the reported RIN distances from NV and tendinous structures were collected as well as the references from which the measurement was made.

The neurovascular structures which were considered in this review are the lateral plantar artery (LPA), lateral plantar nerve (LPN), medial plantar artery (MPA), medial plantar nerve (MPN) and nerve to abductor digiti minimi or Baxter nerve (BN).

If not otherwise specified, distance of the LPA and LPN was considered the same and equated to the lateral NV bundle.

If not otherwise specified, distance of the MPA and MPN was considered the same and equated to the medial NV bundle.

Flexor hallucis longus (FHL) and flexor digitorum longus (FDL) tendons were the only tendinous structures considered, since they were indicated as the closest to the RIN by Pochatko et al. [18].

Anatomical structures were considered damaged or potentially damaged when appeared visually injured or in direct contact with the device ($<= 1$ mm) during the anatomical dissection.

The results were analyzed by a statistics calculator (MedCalc Statistical Software) applying a Chi-squared test as recommended by Campbell [22] and Richardson [23]. The confidence interval was calculated according to the recommended method given by Altman et al.[24].

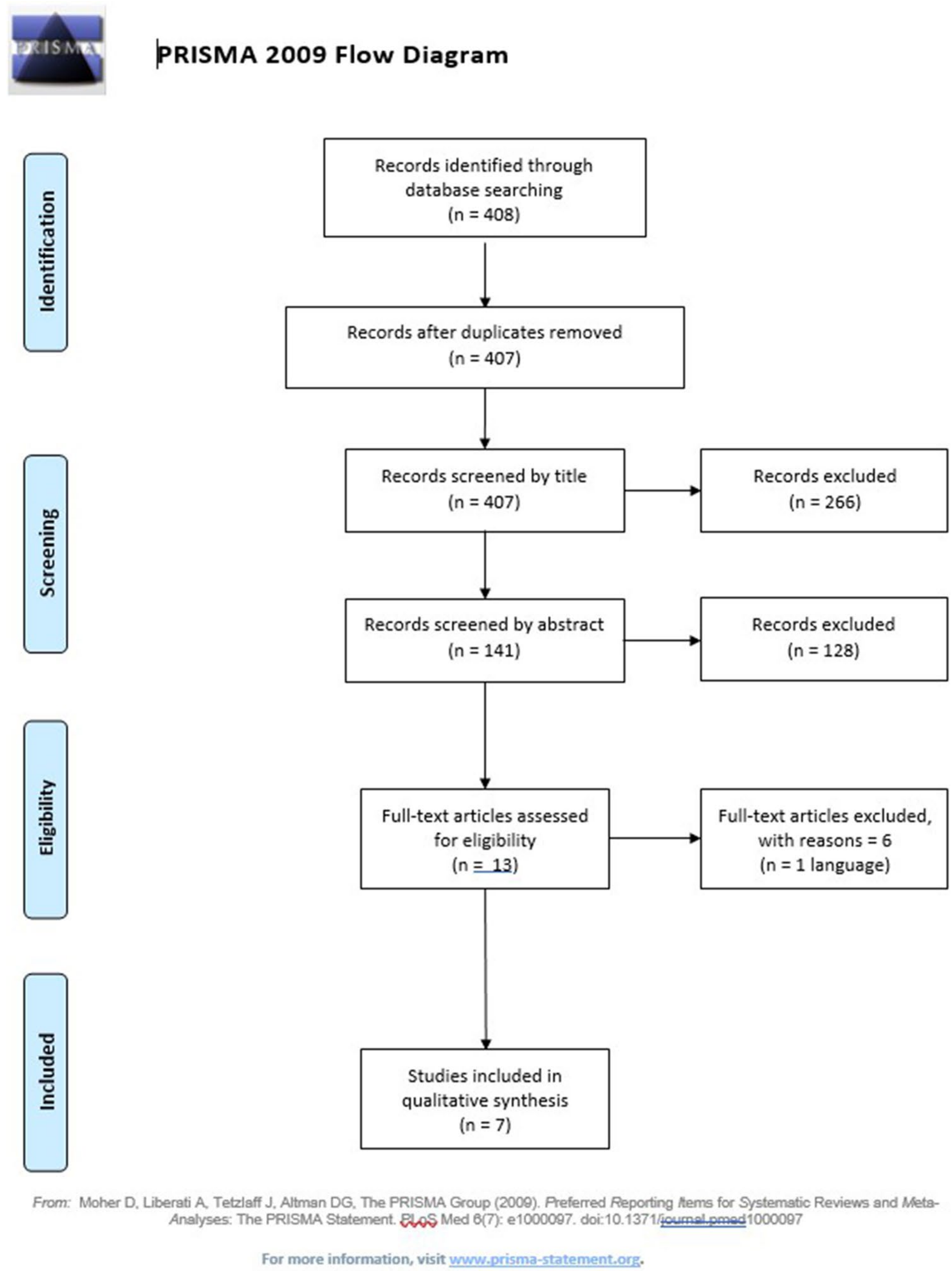
Results

Four hundred and eight studies were identified through the database search. One of the records was removed after searching for duplicates. Records were screened by title, and 266 of them were excluded. After screening the remaining 141 studies, thirteen full-text articles were assessed for eligibility. Five records were included for the systematic review (Fig. 1).

Number of specimens

A total of 40 specimens were analyzed overall in the five studies, which consisted of case series ranging from five to ten specimen. Moorjani et al.[25] used the same six specimens for three different entry points.

Fig. 1 PRISMA flow diagram



RIN characteristics

Different devices were used to perform the retrograde intramedullary nailing. Three of them were straight, while three were valgus curved.

Only two of the straight devices were commercial retrograde nails: Biomet Ankle Arthrodesis Nail, Biomet, Berlin, Germany, 180-mm-long, 11-mm-diameter nail; and OrthoFix Ankle Compression Nailing System, OrthoFix, 150-mm-long, 10-mm-diameter straight nail. The third straight device, used by Moorjani [25], was a 5-mm Steinman pin of unspecified length.

The three valgus curved devices were all commercial RIN: AAN Ankle Arthrodesis Nail, Stryker, Sch¨onkirchen, Germany, FDA approved, 200-mm-long, 11-mm-diameter nail; Hindfoot arthrodesis nail (HAN) DuPuy Synthes (Johnson & Johnson, West Chester, PA) or its 13-mm-diameter reamer; and T2™ Ankle Arthrodesis Nail, Stryker, Sch¨onkirchen, Germany, 200-mm-long, 11-mm-diameter nail.

Muckley et al. [26] were the only authors to compare two different nails, a straight one (Biomet Ankle Arthrodesis Nail, Biomet, Berlin, Germany), and a curved one

(AAN Ankle Arthrodesis Nail, Stryker, Sch¨onkirchen, Germany, FDA approved).

In the study by Knight et al. [27], since some surgeons chose not to advance a nail, a 13-mm-diameter reamer was placed in situ for measurement (Table 1).

Entry point and reaming technique

Different techniques were described to identify the correct insertion point, based on anatomical or fluoroscopic guided landmarks.

Three studies described an anatomical landmark-guided entry point.

Moorjani et al. [25] performed the incision along a bisecting line drawn across the malleoli. The position in the coronal plane was at 2, 3 and 4 cm from the lateral border of the foot. In a larger foot, with a fat pad of 28 mm instead of 9 mm, the three different position in the coronal plane were shifted to 3, 4 and 5 cm from the lateral border. The reported heel width was 6 cm in 4 feet, 5.4 cm in one foot and 7.5 cm in the 28-mm-thick fat pad foot (average thickness of the fat pad was found to be 9 mm [range 3–12 mm].). The applied intramedullary device was a 5-mm Steinman pin, and the specimen dissection was performed for each entry point.

Muckley et al. [26] employed a 3-cm longitudinal plantar skin incision at the intersection of a sagittal line drawn from the tip of the second toe to the center of the heel and a coronal line drawn at the junction of the anterior and middle thirds of the heel pad. The same entry point was exploited for both the straight and the valgus curved intramedullary nail.

Knight et al. [27] located the entry point at the intersection of a line drawn along the tibial canal and a line drawn at the center of the lateral column, with the incision in line with the longitudinal axis of the foot.

Two studies described a fluoroscopic guided entry point.

De Cesar Netto et al. [21] determined the starting point for the skin incision under fluoroscopic imaging guidance by the intersection of 2 lines: the axis of the calcaneus in the Harris heel view and the axis of the tibia in a lateral view of the ankle joint.

Callahan et al. [28], after a 3-cm midline incision, used a guidewire to palpate the medial, lateral, and plantar-most portions of the calcaneus, confirmed by an anterior–posterior, lateral, and Harris heel views. Although this technique can be considered "hybrid," we defined it as fluoroscopic guided since it is mainly based on X-rays imaging.

As regard reaming technique, Knight et al. [27] and De Cesar Netto et al. [21] used soft tissue protection for the 13-mm and a 12-mm reamer, respectively. Callahan et al. [28] and Muckley et al. [26] performed the reaming (11 mm and 12.5 mm, respectively) without specifying the use of soft tissue protection. Moorjani et al. [25] did not ream before inserting the intramedullary device (Table 2).

RIN distance to the anatomical structures, related lesions and criteria of measurement

All the authors reported the distance of the anatomical structures from the edge of the RIN, except Moorjani et al. [25] who calculated the distance from the center of the inserted pin. Since most of the commercial RIN available have a 10- to 13-mm diameter, an anatomical structure at a distance less than 5 mm from the center of the pin (equals to a 10 mm diameter) was considered damaged.

LPA distance was reported by all authors, although Knight et al. [27] did not consider the individual NV structures, but the whole lateral NV bundle (LPA and LPN).

Only in one case out of 52, the RIN was placed medially respect to the LPA, which is reported to be the most lateral NV structure by all the authors.

LPA was reported injured in a total of 12 out of 40 specimens: 3/6 by Moorjani et al. [25], 7/10 by De Cesar Netto et al. [21] and 3/5 by Callahan et al. [28]. No injury was reported by other authors.

LPN distance was reported by each author. It was reported injured in a total of seven out of 40 specimens: 2/6 by Moorjani et al. [25], 2/10 by De Cesar Netto et al. [21] and 3/5 by Callahan et al. [28]. No injury was reported by other authors.

MPN distance was reported by De Cesar Netto et al. [21], Moorjani et al. [25] and Muckley et al. [26], while MPA was only reported by the two latter authors. No damage to any MPN or MPA was reported.

BN was only investigated by Muckley et al. [26] and by de Cesar Netto et al. [21]; the latter reported injuries in two of the ten specimen, while no damage was reported by Muckley et al. [26] or any other authors.

FHL and FDL were only investigated by Muckley et al. [26]. They reported no damage in the 12 specimens, although the FHL distance from the straight RIN compared to the distance of the curved RIN was statistically significant shorter ($P = 0.041$) (Table 3).

Relationship between RIN and bone structures

RIN location relative to bone structures was clearly reported only by Knight et al. [27], as they explicitly stated that "the nail was correctly placed in the calcaneal body." No reference as regard the talar location was found.

Muckley et al. [26] performed a radiographic analysis which did not show any significant preoperative to postoperative changes in the hindfoot axis in relation to the nail design. The volumetric portion of the nail completely

Table 1 Characteristics of the cadaveric studies

References	Article title	Specimens number	Device features	Reaming technique	Criteria of measurement
Moorjani et al. [25]	Optimal insertion site for intramedullary nails during combined ankle and subtalar arthrodesis	6-Medial	Straight 5-mm Steinman pin	Reaming was not performed	From the center of the pin If closer than 5 mm, a structure was considered damaged (for a theoretical diameter of the RIN equals to 10 mm)
		6-Intermediate			
		6-Lateral			
Mückley et al. [26]	Comparison of two intramedullary nails for tibio-talo-calcaneal fusion: anatomic and radiographic considerations	6	Straight (Biomet Ankle Arthrodesis Nail, Biomet, Berlin, Germany) 180-mm-long, 11-mm-diameter straight nail	12.5-mm flexible reamer. Soft tissue protection was not specified	From the edge of the inserted RIN
		6	Curved AAN Ankle Arthrodesis Nail, Stryker, Sch¨onkirchen, Germany, FDA approved, 200-mm-long, 11-mm-diameter nail with a 5° valgus curve in the hindfoot	Same technique as the straight nail	From the edge of the inserted RIN
Knight et al. [27]	Anatomic structures at risk: curved hindfoot arthrodesis nail—a cadaveric approach	7	Curved HAN (Depuy-Synthes)—A 13-mm protection sleeve was used with the 13-mm cannulated reamer	A 13-mm protection sleeve was used with the 13-mm cannulated reamer	From the edge of the inserted RIN
De Cesar Netto et al. [21]	Neurovascular structures at risk with curved retrograde TTC fusion nails	10	Curved T2™ Ankle Arthrodesis Nail, Stryker, Sch¨onkirchen, Germany, 200-mm-long, 11-mm-diameter	A 12-mm-wide reamer, with soft tissue protection sleeve	From the edge of the inserted RIN
Callahan et al. [28]	Avoiding pitfalls of tibio-talo-calcaneal nail malposition with internal rotation axial heel view	5	Straight 11 mm and a 10 mm × 150 mm straight nail (OrthoFix Ankle Compression Nailing System, OrthoFix, Verona, Italy)	11-mm reamer, tissue protection not specified	From the edge of the inserted RIN

Table 2 Entry point description

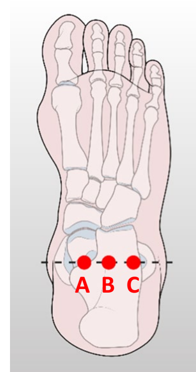
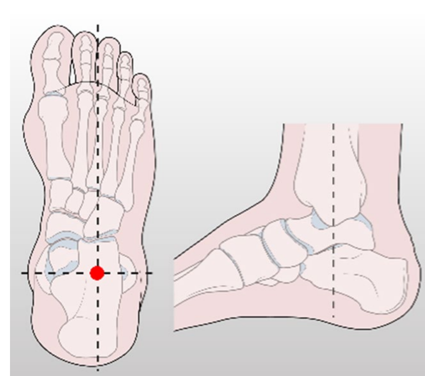
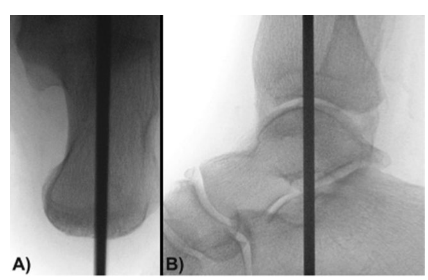
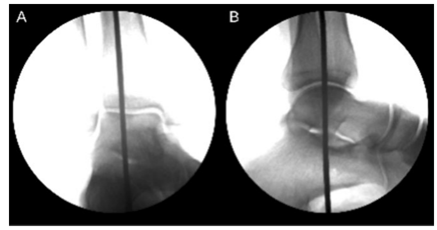
References	Entry point	Graphic entry point
Moorjani et al. [25]	Anatomical guided-along a bisecting line drown across the malleoli	
	Medial entry point—4 cm from the lateral border (5 cm in one larger foot with a fat pad = 28 mm instead of 9 mm)	
	Intermediate entry point—3 cm from the lateral border (4 cm in one larger foot with a fat pad = 28 mm instead of 9 mm)	
	Lateral entry point—2 cm from the lateral border (3 cm in one larger foot with a fat pad = 28 mm instead of 9 mm)	
Mückley et al. [26]	Anatomical-guided: A 3-cm longitudinal plantar skin incision at the intersection of a sagittal line drawn from the tip of the second toe to the center of the heel and a coronal line drawn at the junction of the anterior and middle thirds of the heel pad (for both straight and curved nail)	
Knight et al. [27]	Anatomical-guided: The entry point is located at the intersection of a line drawn along the tibial canal and a line drawn at the center of the lateral column. The incision should be in line with the longitudinal axis of the foot	
De Cesar Netto et al. [21]	Fluoroscopic-guided by the intersection of two lines: (A) axis of the calcaneus in the axial heel Harris view and (B) axis of the tibia in the lateral view of the ankle joint	

Table 2 (continued)

References	Entry point	Graphic entry point
Callahan et al. [28]	Fluoroscopic-guided anterior–posterior (A), lateral (B), and axial Harris heel views were used to confirm the starting point of the guidewire	

surrounded by bone within the calcaneus did not differ significantly between the two devices.

Callahan et al. [28] affirmed that "placing the wire 1 cm lateral to the perceived starting point offered greater purchase in the calcaneus […] but offered less than ideal positioning within the tibial canal." In addition, four of the five specimens, after the dissection, had the medial aspect of the nail placed in the sustentaculum tali.

No study mentioned RIN positioning relative to the tibial shaft (Table 3).

Statistical analysis

For statistical purpose, the results of the three different entry points performed in the same specimen by Moorjani et al. were independently considered.

An independent sample Chi-squared test was performed between the two subgroups of anatomic-guided and fluoroscopic-guided entry point. The anatomical-guided subgroup reported three injured NV structures, in particular three LPA, in the 37 dissected specimens, while the fluoroscopic-guided subgroup reported ten out of 15 specimens with injured NV structures (five isolated LPA, three associated LPA and LPN and two associated LPA, LPN and BN). A statistically significative difference was found, with less risk of injury in the anatomical-guided entry point compared to the fluoroscopic-guided ($P < 0.0001$) (Table 4).

An independent sample Chi-squared test was also performed between the two subgroups of straight and valgus curved intramedullary devices. The straight subgroup accounted for six specimens with injured LPA, three of which had associated LPN lesions. The valgus curved subgroup accounted for seven out of 23 specimens with injured LPA, two of which had associated LPN and BN lesions.

No statistically significant difference was found between the two subgroups ($P = 0.4268$) (Table 4).

Discussion

Aim of this systematic review was to analyze in cadaveric studies the risk of iatrogenic injuries related to different entry points and different RIN design when performing TTCA.

As a matter of fact, iatrogenic injuries related to TTCA are not uncommon and may be underestimated: NV lesions are described in 2.5% [29] up to 27% [20]. Bony-related complications such as fractures and postoperative foot deformities are reported to be 2.7% and 3%, respectively [29].

Nail design

Our study included different nail designs.

Valgus curved intramedullary nails have had major success in the last years, encouraged by Moorjani et al. who suggested that a more lateral placed entry point allows for a major distance from the NV structures [25].

Despite that to our knowledge none up to date has ever shown the superiority of a specific nail in terms of NV complication rate.

Muckley et al. [26] were the only authors to compare different nail designs with equal entry point, with no statistical significative difference reported in terms of NV or tendon lesions.

Our statistical analysis did not observe any significative difference in potential NV lesions between straight and valgus curved nails. Nevertheless, considering all the papers included in the review process, the reported average distance to NV and tendon structures measured with the same entry point is larger in case of curved nail. This finding can theoretically support the greater safety of curved nails.

Entry point

As concerned the entry point, studies were divided in two subgroups: anatomical and fluoroscopic guided landmark.

The first authors to account the clinical importance of a proper RIN insertion point were Stephenson et al. [20], who

Table 3 Reported anatomical injuries

References	Specimen number	RIN design	Lateral plantar artery	Lateral plantar nerve	Medial plantar artery	Medial plantar nerve	Baxter nerve	Flexor hallucis longus tendon	Flexor digitorum longus	Bony location
Moorjani et al.[25]	6 Medial	Straight	Damaged = 3 AV.D. = 9.5 (− 1/7)	Damaged = 3 AV.D. = 9 mm (− 5/15)	Damaged = 0 AV.D. = 21 mm (13/30)	Damaged = 0 AV.D. = 9 mm (− 5/15)	\	\	\	Not specified
	6 Intermediate	Straight	Damaged = 0 AV.D. = 13 mm (9–16)	Damaged = 0 AV.D. = 19 mm (14–23)	Damaged = 0 AV.D. = 25 mm (23/36)	Damaged = 0 AV.D. = 41 mm (31/52)	\	\	\	Not specified
	6 Lateral	Straight	Damaged = 0 AV.D. = 23.5 (18–30)	Damaged = 0 AV.D. = 30 mm (14–23)	Damaged = 0 AV.D. = 25 mm (23/36)	Damaged = 0 AV.D. = 41 mm (31–52)	\	\	\	Not specified
Mückley et al. [26]	6	Straight	Damaged = 0 AV.D. = 2.3 mm (0–5)	Damaged = 0 AV.D. = 5.2 mm (2–8)	Damaged = 0 AV.D. = 13.8 mm (9–17)	Damaged = 0 AV.D. = 15.2 mm (10–19)	Damaged = 0 AV.D. = 7.2 mm (5–10)	Damaged = 0 AV.D. = 10.7 mm (8–15)	Damaged = 0 AV.D. = 18.2 mm (13–21)	Not specified
	6	Curved	Damaged = 0 AV.D. = 6 mm (0–10)	Damaged = 0 AV.D. = 9 mm (5–12)	Damaged = 0 AV.D. = 18.3 mm (12–21)	Damaged = 0 AV.D. = 19.3 mm (14–25)	Damaged = 0 AV.D. = 9.5 mm (4–14)	Damaged = 0 AV.D. = 16.3 mm (10–24)	Damaged = 0 AV.D. = 21.2 mm (10–25)	Not specified
Knight et al. [27]	7	CURVED	Damaged = 0 AV.D. = 6.5 mm (3.5—8)	Damaged = 0 AV.D. = 6.5 mm (3.5—8)	Damaged = 0 Distance: always > 10 mm	Damaged = 0 Distance: always > 10 mm	\	\	\	Nail correctly placed in the calcaneal body
De Cesar Netto et al. [21]	10	Curved	Damaged = 7 AV.D. = 1 mm (0–8)	Damaged = 2 AV.D. = 4.7 mm (0–11)	Damaged = 0	Damaged = 0 AV.D. = 21.5 mm (16–31)	Damaged = 2 AV.D. = 6.6 mm (2.2–11.0)	\	\	Not specified
Callahan et al. [28]	5	Straight	Damaged = 3 Distance < 5 mm = 4/5	Damaged = 3 Distance < 5 mm = 4/5	\	\	\	\	\	In 4/5, the RIN was placed in the sustentaculum tali

Table 4 Subgroup statistical analysis

	Number of injured NV structures	Sample size (specimens)	Proportion	Statistical analysis
Anatomical-guided entry point	3	37	8.1%	$P < 0.0001$ (Chi-squared = 19.11)
Fluoroscopic-guided entry point	10	15	66.6%	
Straight IMN	6	29	20.7%	$P = 0.4268$ (Chi-squared = 0.631)
Curved IMN	7	23	30.4%	

described an anatomical landmark applied to a series of 22 patients. However, the reported complication rate was not negligible, accounting for 18% of NV deficit.

In a recent systematic review by Franceschi et al. [29], the reported NV complication accounted for 1.8%, although not systematically reported in the 21 included studies. Moreover, a vast group of the population was affected by diabetes or Charcot neuropathy, well-known confounding factors to perform a valuable postoperative neurologic examination.

Regarding reaming technique, only two authors applied soft tissue protection. The highest rate of potential NV lesions was reported by De Cesar Netto et al. [21], despite applying a soft tissue protection sleeve. This suggests that a protection device does not prevent injuries during the reaming procedure if the guide wire is placed in an inaccurate position.

When considering cadaveric studies, Moorjani et al. [25] were the only authors who reported potential NV injuries exploiting an anatomical guided entry point. Both specimens were in the medial entry point series, with a remarkable injury rate of 33%. According to the entry point description, this was the only specimen cohort in which the insertion point was located in the medial half of the plantar aspect of the hindfoot. On the contrary, no potential NV injuries were reported when the entry point was located along the plantar midline or centered in the lateral half.

In light of this evidence, we may state that an entry point located in the lateral half of the hindfoot plantar aspect could minimize the risk of potential NV injuries.

Our analysis has shown that the incidence of potential NV injuries was statistically significant higher in the fluoroscopic guided group. We may suppose that in the first subgroup the main focus was on the correct nail placement toward the bony surfaces, giving less importance to the soft tissues overall, thus causing a higher incidence of potential NV lesion.

Tendon injuries

Tendon injuries were investigated only by Muckley et al. [26]; although no damage to tendinous structures was reported, the straight nail was significantly nearer to the FHL and FDL than the valgus curved one ($P = 0.041$). In the literature, McGarvey et al.[30] reported a high incidence of FHL injured or in direct contact to the RIN (6/8 specimens). Pochatko et al. [18] also noticed that FHL was within 5 to 10 mm in five out of six specimens. It should be noted that these two cadaveric studies, not included in this review, applied an antegrade insertion technique of the intramedullary device, thus not comparable to the normal clinical practice. Considering the close distance of the FHL to the RIN entry point, a careful inspection of the first metatarsophalangeal passive dorsiflexion before and after placing the guide wire should always be performed, in order to preserve this important anatomical structure.

Relationship between RIN and bone structures

Regarding RIN location relative to bone structures, Callahan et al. [28] affirmed that it should be a compromise among a good purchase in the tibial, talar and calcaneal bones; a more lateral entry point in the calcaneus often leads to suboptimum purchase in talus and tibia and vice versa. Knight et al. [27] explicitly stated the nail was correctly placed in the calcaneal bone, but did not mention RIN location toward the tibia. Furthermore, no radiographic examination was performed by the authors to confirm the correct location of the nail inside the calcaneal bone. Muckley et al. [26] were the only authors to perform a radiographic analysis of the RIN; although no statistically significative difference was found in the two different nails, curved ones had a slight trend to increase hindfoot valgus. RIN purchase toward the calcaneus was evaluated by determining the volumetrically portion of the nail completely surrounded by bone within the calcaneus, but the quality and the thickness of the bony structures surrounding the nail were not taken into account.

Pochatko et al. [18] and McGarvey et al. [30], with an antegrade insertion of the intramedullary nail, referred that the exit point was either at the junction of the medial wall of the calcaneus with the sustentaculum tali, or directly through the sustentaculum itself. This placement could potentially cause a failure of the calcaneal bone and lack of bony support when placing the calcaneal interlocking screw.

A better placement in the calcaneal bone could be potentially achieved by a more lateral entry point. However, a nail inserted through the body of the calcaneus may result in poor bony contact and hindfoot deformity, since the narrow tibial isthmus forces the nail into varus position. As suggested by McGarvey et al. [30], a short, slightly valgus-placed nail could be the solution, at the cost of a suboptimal placement relative to the tibial axis.

To better assess the exact placement of the RIN inside the calcaneal bone, Callahan et al. [28] suggested a modification of the Harris heel view, obtaining good results with a 30° internally rotated leg.

Limitations

This review presents some limitations. It was conducted on a small sample group, and anatomical variations were not taken into consideration. The included studies did not perform the TTCA on a pool of specimens with arthritic degenerative changes and, when specified, the specimens were in generally good condition [27], thus far distant from the typical clinical patient undergoing TTCA.

Moreover, when specified [21, 26], the joint surfaces were left unprepared, although this is not the accepted method in the clinical practice.

However, cadaveric studies allowed visual inspection of the anatomical structures at risk, with greater accuracy in identifying NV or tendon injuries compared to clinical examination.

Conclusion

Although the potential risk of iatrogenic injuries enlightened in different cadaveric studies, TTCA is still considered a safe and valuable option for end-stage concomitant ankle and subtalar arthritis.

Different nail designs did not seem to influence iatrogenic injuries neither hindfoot alignment.

Our study suggests a superiority of anatomical landmark-guided entry points.

It should be recommended to place the RIN entry point in the lateral half of the plantar hindfoot in order to minimize the risk of iatrogenic injuries.

Care must be taken to obtain a good bony support during RIN and interlocking screw placement.

Despite these findings, further clinical studies are requested to better detect and reduce iatrogenic injuries linked to TTCA with RIN.

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Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

References

1. Milstrey A, Domnick C, Garcia P et al (2021) Trends in arthrodeses and total joint replacements in foot and ankle surgery in Germany during the past decade-Back to the fusion? Foot Ankle Surg 27:301–304. https://doi.org/10.1016/J.FAS.2020.05.008
2. Yasui Y, Hannon CP, Seow D, Kennedy JG (2016) Ankle arthrodesis: a systematic approach and review of the literature. World J Orthop 7:700–708. https://doi.org/10.5312/wjo.v7.i11.700
3. Moore TJ, Smith JW, Prince R et al (1995) Retrograde intramedullary nailing for ankle arthrodesis. Foot ankle Int 16:433–436. https://doi.org/10.1177/107110079501600710
4. Anderson T, Linder L, Rydholm U et al (2005) Tibio-talocalcaneal arthrodesis as a primary procedure using a retrograde intramedullary nail: a retrospective study of 26 patients with rheumatoid arthritis. Acta Orthop 76:580–587. https://doi.org/10.1080/17453670510041592
5. Rammelt S, Pyrc J, Agren P-H et al (2013) Tibiotalocalcaneal fusion using the hindfoot arthrodesis nail: a multicenter study. Foot ankle Int 34:1245–1255. https://doi.org/10.1177/1071100713487526
6. Burns PR, Dunse A (2017) Tibiotalocalcaneal arthrodesis for foot and ankle deformities. Clin Podiatr Med Surg 34:357–380. https://doi.org/10.1016/j.cpm.2017.02.007
7. Berend ME, Glisson RR, Nunley JA (1997) A biomechanical comparison of intramedullary nail and crossed lag screw fixation for tibiotalocalcaneal arthrodesis. Foot ankle Int 18:639–643. https://doi.org/10.1177/107110079701801007
8. Muckley T, Eichorn S, Hoffmeier K et al (2007) Biomechanical evaluation of primary stiffness of tibiotalocalcaneal fusion with intramedullary nails. Foot ankle Int 28:224–231. https://doi.org/10.3113/FAI.2007.0224
9. Goebel M, Gerdesmeyer L, Mückley T et al (2006) Retrograde intramedullary nailing in tibiotalocalcaneal arthrodesis: a short-term, prospective study. J Foot Ankle Surg 45:98–106. https://doi.org/10.1053/j.jfas.2005.12.001
10. Johl C, Kircher J, Pohlmannn K, Jansson V (2006) Management of failed total ankle replacement with a retrograde short femoral nail: a case report. J Orthop Trauma 20:60–65. https://doi.org/10.1097/01.bot.0000171880.03581.4a
11. Carrier DA, Harris CM (1991) Ankle arthrodesis with vertical Steinmann's pins in rheumatoid arthritis. Clin Orthop Relat Res 268:10–14
12. Pant R, Ilyas I, Younge DA (2003) The supracondylar femoral nail in tibia. Int Orthop 27:352–354. https://doi.org/10.1007/s00264-003-0508-z
13. Stone KH, Helal B (1991) A method of ankle stabilization. Clin Orthop Relat Res 268:102–106
14. Chou LB, Mann RA, Yaszay B et al (2000) Tibiotalocalcaneal arthrodesis Foot ankle Int 21:804–808. https://doi.org/10.1177/107110070002101002
15. Thordarson DB, Chang D (1999) Stress fractures and tibial cortical hypertrophy after tibiotalocalcaneal arthrodesis with an intramedullary nail. Foot ankle Int 20:497–500. https://doi.org/10.1177/107110079902000806

16. Mückley T, Schütz T, Srivastava S et al (2003) Ankle arthrodesis with intramedullary compression nailing. Unfallchirurg 106:732–740. https://doi.org/10.1007/s00113-003-0638-1
17. Goebel M, Muckley T, Gerdesmeyer L et al (2003) Intramedullary nailing in tibiotalocalcaneal arthrodesis. Unfallchirurg 106:633–641. https://doi.org/10.1007/s00113-003-0626-5
18. Pochatko DJ, Smith JW, Phillips RA et al (1995) Anatomic structures at risk: combined subtalar and ankle arthrodesis with a retrograde intramedullary rod. Foot ankle Int 16:542–547. https://doi.org/10.1177/107110079501600905
19. Flock TJ, Ishikawa S, Hecht PJ, Wapner KL (1997) Heel anatomy for retrograde tibiotalocalcaneal roddings: a roentgenographic and anatomic analysis. Foot ankle Int 18:233–235. https://doi.org/10.1177/107110079701800409
20. Stephenson KA, Kile TA, Graves SC (1996) Estimating the insertion site during retrograde intramedullary tibiotalocalcaneal arthrodesis. Foot ankle Int 17:781–782. https://doi.org/10.1177/107110079601701212
21. de Cesar NC, Johannesmeyer D, Cone B et al (2017) Neurovascular Structures at Risk With Curved Retrograde TTC Fusion Nails. Foot Ankle Int 38:1139–1145. https://doi.org/10.1177/1071100717715909
22. Campbell I (2007) Chi-squared and Fisher-Irwin tests of two-by-two tables with small sample recommendations. Stat Med 26:3661–3675. https://doi.org/10.1002/sim.2832
23. Richardson JTE (2011) The analysis of 2 × 2 contingency tables--yet again. Stat Med 30:890; author reply 891–2
24. Altman DG, Machin D, Bryant TNGM (eds) (2000) Statistics with confidence, 2nd edn. BMJ Books
25. Moorjani N, Buckingham R, Winson I (1998) Optimal insertion site for intramedullary nails during combined ankle and subtalar arthrodesis. Foot Ankle Surg 4:21–26. https://doi.org/10.1046/J.1460-9584.1998.00077.X
26. Mückley T, Ullm S, Petrovitch A et al (2007) Comparison of two intramedullary nails for tibiotalocalcaneal fusion: anatomic and radiographic considerations. Foot ankle Int 28:605–613. https://doi.org/10.3113/FAI.2007.0605
27. Knight T, Rosenfeld P, Jones IT et al (2014) Anatomic structures at risk: curved hindfoot arthrodesis nail–a cadaveric approach. J Foot Ankle Surg 53:687–691. https://doi.org/10.1053/j.jfas.2014.06.005
28. Callahan R, Juliano P, Aydogan U, Clayton J (2018) Avoiding pitfalls of tibiotalocalcaneal nail malposition with internal rotation axial heel view. Foot Ankle Spec. https://doi.org/10.1177/1938640018770255
29. Franceschi F, Franceschetti E, Torre G et al (2016) Tibiotalocalcaneal arthrodesis using an intramedullary nail: a systematic review. Knee Surgery, Sport Traumatol Arthrosc 24:1316–1325. https://doi.org/10.1007/s00167-015-3548-1
30. McGarvey WC, Trevino SG, Baxter DE et al (1998) Tibiotalocalcaneal arthrodesis: anatomic and technical considerations. Foot ankle Int 19:363–369. https://doi.org/10.1177/107110079801900604

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