The Role of Cadaveric Simulation in Talus Fracture Research: A Scoping Review

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Abstract

Background: Talus fractures are rare (<1% of all fractures), and their rarity limits the number of studies available to guide management. In instances such as this, cadaveric studies can play an important role. The purpose of this scoping review was to identify and describe the current body of literature on cadaveric studies of fractures of the talus.

Methods: Through multiple electronic database searches (Medline, Embase, Scopus) we identified a broad body of cadaveric research into talus fractures, and these were classified into 4 main themes. Study characteristics were summarised along with any descriptive results and conclusions.

Results: The search yielded 484 articles of which 19 met the inclusion criteria. They provide valuable insights into benefits and drawbacks of surgical approaches to the talus, particularly with regard to direct visualisation of anatomic reduction, and risks of neurovascular or tendon compromise. For talar neck fractures it is clear that cannulated screws offer superior fixation over plates, however, are inferior when considering anatomic reduction of the fracture. Direct visualisation of fracture reduction is far superior to intraoperative radiographic assessment, and mal-reduction leads to reduced subtalar joint range of motion, midfoot deformity, and increased joint contact pressures.

Conclusions: This study provides a summary of the existing literature surrounding the use of cadaver studies in fractures of the talus. We have identified gaps in the literature, particularly surrounding strength of fixation of new locking plate fixation techniques.

Keywords

Talus; fracture; cadaver; fixation; approach; avascular necrosis

1. Introduction

Cadaveric research plays an important part in determining optimal treatment in lower-limb fracture care. To date, there has not been a formally conducted scoping review into what types of cadaveric research and techniques are most helpful.

Scoping reviews are now becoming an increasingly accepted means to achieve evidence-based conclusions; and the methods can help surgeons to make informed decisions on operative interventions. Cadaver studies provide a powerful method for providing information in the treatment of talus fractures that other study modalities may not define.

The management, approach and fixation options of talus fractures has been evolving and to date there has been no publication that qualitatively assesses the use of cadaver research with respect to the talus.

The objective of this study is to review the current evidence base with regards to the use of cadaveric studies in guiding management of injuries of the talus, and that this may help to guide further research

2. Methods

The literature search strategy was developed using medical subject headings (MeSH) and text words related to Cadaver and talus fracture (see search strategy in Appendix 1). Two reviewers independently identify studies by searching Medline, (OVID interface), Embase (OVID interface) and Scopus. The search was conducted on 23rd October 2020. A hand search of the reference lists from all preliminarily identified papers was also carried out.

Eligibility criteria for inclusion into this scoping review were studies on talus fractures involving the themes of:

1. Anatomy of safe approaches
2. Stability of fracture fixation
3. Improving the imaging of the hind foot, and
4. Better predicting the outcome/prognosis of talar neck fractures.

Exclusion criteria were as follows:

1. No cadaveric element to the research
2. No English translation available
3. No human subjects
4. Studies using surrogate only for cadaver, e.g. plastic bones
5. Studies using only finite element analysis (or equivalent) for simulation

6. Studies that were radiographic only, or
7. Studies where only the abstract was available

Three reviewers (MY, KK, AH) independently screened the titles and abstracts identified by the literature search for inclusion using the screening form (level 1 screening). To increase the reliability of screening of paper title and abstracts by the reviewers, a test of the level 1 screening, based on the eligibility criteria was performed on a random sample of 288 articles. The κ statistic was calculated to determine the inter-rater agreement for study inclusion and found to be 0.14, suggesting a low level of agreement. Where there was disagreement between level 1 reviewers, a fourth reviewer (AN), who was most knowledgeable in the research area, was called upon to resolve discrepancies.

The full text of potentially relevant articles was then obtained and screened to determine final inclusion (level 2 screening).

3. Results

Our search strategy yielded 162 studies from Medline, 225 from Embase, and 97 from Scopus. After duplicates were removed there were a total of 299 records included for level 1 screening. 208 studies did not meet the inclusion criteria and so were excluded. An additional 12 studies were excluded on the basis of the full text being unavailable. After level 2 screening, 19 papers remained (Figure 1).

An extraction sheet containing data from the full text articles, included publication year, primary and secondary aims of the study, number of cadavers used, male to female ratio of cadavers, information on jigs used for testing, key results and conclusions can be seen in Table 1.

Studies were published between 1992 and 2021 (median 2007).

Papers generally fell into 6 categories:

1. Importance of anatomical reduction (n=2)
2. Approaches for talus fixation (n=4)
3. Imaging of the hindfoot (n=3)
4. Stability of fixation (n=5)
5. Avascular necrosis and talus implants (n=1)
6. Lateral process fractures of the talus (n=4)

All studies were observational/descriptive in nature. None were blinded, no papers specified how specimens were allocated to various groups in each study. No authors declared any conflicts of interest.

3.1. Importance of anatomical reduction

Sangeorzan [1] has shown in cadaveric studies that small 2mm displacements significantly impact subtalar joint contact characteristics. Measurements show no significant changes in overall contact area or high-pressure area in the posterior facet. However, four out of seven specimens demonstrated increased localisation of the contact area. The combined antero-middle facet was significantly unloaded in all malunions with medial displacement of the talar neck.

Daniels [2] showed that the effect of varus displacement of the talus affects the structure and the function of the midfoot. In vitro studies on 12 cadaver feet were used to see if varus decreased subtalar motion. A talar neck osteotomy was performed, and specimens studied with and without removal of a medially based wedge of bone. Removal of the wedge produced an average varus malalignment of the talar neck of 17.1 degrees. In the coronal plane, the average arc of motion of the subtalar joint decreased from 17.2 degrees before the osteotomy to 11.7 degrees after the osteotomy and removal of the wedge. In the transverse plane, it decreased from 17.5 to 11.9 degrees after wedge removal. In the sagittal plane, it decreased from 8.9 degrees to 6.8 degrees. The decrease in subtalar motion was characterized by an inability to evert the foot. Inversion was not impaired. The malalignment produced an average of 4.8 degrees of varus deformity and 8.7 degrees of internal rotation of the hindfoot and an average of 5.5 degrees of varus deformity and 11.5 degrees of adduction of the forefoot.

3.2. Approaches for talus fixation

To achieve an anatomic reduction of the talus, adequate visualisation of the talar articular surface is required. To explore this further, using a cadaveric model Mullen et al [3] evaluated the area of talus exposed for the fixation of talar neck fractures comparing different surgical approaches. The mean area of the talus visible using the anterior approach was 1166mm^2. They did however acknowledge the potential disruption to the superior blood supply with the

anterior approach. For the anterolateral approach a mean of 570mm^2 was visible. Via the anteromedial approach a mean of 395mm^2 and 474mm^2 was visible before and after a medial malleolar osteotomy respectively. They found this to be statistically significant difference. A combined anteromedial and anterolateral approach gives 964mm^2 exposure and the medial malleolar osteotomy with lateral approach gives 1043 mm^2.

Because of the large area of the talus visible and because the approach is familiar (commonly used in the fixation of distal tibial fracture fixation or ankle arthroplasty), the anterior approach to the talus for fracture fixation is often preferred. This approach allows screw placement along the long axis of the talus, perpendicular to the fracture axis (for talar neck fractures) in an antero-posterior direction. Anteroposterior (AP) or Posteroanterior (PA) screws exceed the theoretical load to failure. [4] The main drawback is the lack of direct visualisation of all surfaces with only a part of the superior surface showing. Reduction of other elements of the fracture relies of fluoroscopic assessment, which is inferior to direct visualisation.

The Anterior approach carries risk to the anterior tibial/dorsalis pedis artery and their branches. This artery can be directly visualised through this approach and lateral retraction is preferred as it protects damage to its contribution to the sinus tarsi anastomosis. The area of greatest risk to the blood supply in the anterior approach is at the level of the superior talar neck.

Ebraheim [5] evaluated the use of an open posterolateral approach for placing posterior screws in 12 cadavers. They found that the boney window was small and consideration had to take place for posterior screw insertion. The bony window was medially bounded by the lateral tubercle of the posterior process, laterally by the fibular facet, superiorly by the trochlear articular surface, and inferiorly by the posterior calcaneal facet. The saphenous vein and the sural nerve were found to be very close to the achilles tendon. The calcaneal branch of the peroneal artery was deep to the lateral border of the flexor hallucis longus. The medial K-wire did enter on the lateral tubercle of the posterior process and the medial K-wire did transfix the posterior talofibular ligament. There was recognition that there was potential to jeopardize the blood supply through this surgical approach. This posterior approach also has the disadvantage of being unable to see quality of reduction of the talus. Visualisation of the subtalar joint is also limited.

Roberts [6] evaluated the placement of percutaneous posterior screws for talar neck and body fractures directed posterior to anterior that have been found to be biomechanical and anatomically superior. Percutaneous guidewire and screw placement poses anatomic risks for posterolateral neurovascular and tendinous structures and their objective was to determine the

injury rate to local neurovascular and tendinous structures using this technique in a cadaveric model and the number of attempts at passing the guidewires required to achieve acceptable placement of 2 parallel screws. Eleven fresh frozen cadaver limbs were used with two 2.0-mm guidewires placed under fluoroscopic guidance posterior to anterior centered within the talus. The Number of attempts required and the shortest distance between the closest guidewire and the soft tissue structures was measured. The mean attempts to obtain optimal placement of 2 parallel screws was 2.9 ± 0.7. Direct contact between the guidewire and the sural nerve was seen in 100% of the specimens, with the nerve impaled by the guidewire in 3 of 11 (27.2%) cases. The peroneal tendons were impaled in 1 of 11 (9%) specimens and the Achilles tendon was in contact with the guidewire in 8 of the 11 (72.7%) specimens and impaled at its most lateral border with the guidewire in 2 specimens (18.2%). Given the sural nerve was injured in 100% of the cases they recommended a formal posterolateral incision to visualise and retract anatomic structures at risk.

Wang [7] evaluated the posterolateral approach and dimensions of the posterolateral bony window for screw insertion defining optimal position for posterolateral screw insertion in fifteen adult ankle cadavers in a neutral ankle position. The height and width of the window was measured. The distance from the centre of the window to the lateral malleolus tip (LMT), horizontal distance from the center of the window to the lateral of the Achilles tendon (LAT), and to the sural nerve (SN) were measured. The posterolateral window was bounded medially by the lateral tubercle of the posterior talus process, laterally by the posterior border of lateral malleolar, superiorly by the trochlear articular surface (TAS), and inferiorly by the posterior calcaneal facet. The height and width of the posterolateral window was 1.89±0.04 cm and 0.91±0.01cm respectively. LMT was 0.40±0.01 cm, LAT was 0.19±0.02 cm, and SN was 0.62±0.04 cm. They felt that using the posterolateral window had no negative effect on surrounding tissues such as the flexor hallucis longus and posterior talofibular ligament tissues when the ankle joint was positioned in neutral.

3.3. Imaging of hind foot

Chan [8] evaluated the clinical accuracy of imaging talar neck malunion in 8 cadavers that were osteotomized at the talar neck. The talus was reduced and fixed with 3.5 mm cortical screws. The fragments were then displaced and rotated to create a varus and supination deformity and screw fixation was repeated in non-anatomic alignment. Plain films and radio-isometric analysis (RSA)

films, and CT were used to determine angulation, translation and rotation. K-wires were inserted into the fragments to guide rotational and translational measurements before and after displacement which was assessed by calipers. Both plain radiographs and RSA underestimated the displacement by 5-6 mm. The most accurate method of assessing talus displacement was by CT scan which was accurate to 2.4 mm.

In addition to conventional radiographs and computed tomography scans, the Canale view has proven beneficial, when evaluating varus displacement [9]. Evaluating the Canale view could be modified for improved evaluation for varus displacement. Simulated talar neck fractures were created in 6 cadaveric specimens. These were placed into varying amounts of varus displacement; the Canale view was performed with progressive degrees of eversion, from 0^{o} to 25^{o}, resulting in 108 total views. Blinded evaluation was performed, and a ranking system was used to determine the most beneficial degree of eversion for evaluating varus malalignment. Multiple statistical analyses were performed. A significant difference was seen between the high and low range of values of eversion. A significantly lower ranking was achieved with 10^{o} of eversion. As opposed to a single view taken at 15^{o} of eversion, a range of angles may be most beneficial in evaluating varus displacement in talar neck fractures.

Twelve cadaver feet were used for a radiographic assessment of the talonavicular joint after simulated screw fixation of talus fractures.[10] A 4.0- to 6.5-mm screw was inserted through the posterior tubercle of the talus, directed anteriorly into four quadrants of the talar head causing a deliberate screw tip violation of 1mm. Lateral, dorsoplantar, lateral oblique, and medial oblique radiographic views were obtained for each specimen, to assess the position of the screw tip in relation to the talonavicular joint. The lateral view consistently demonstrated the screw tip violation when the screw was directed through the center of the talar head, but it failed when screws were passed into the medial or lateral quadrants of the talar head. The dorsoplantar view consistently demonstrated a screw tip violation of the superior two quadrants of the talar head when other views failed. Each screw tip violation of the inferior quadrants (medial and lateral) required a different view. A screw tip violation of the inferior medial quadrant required the lateral oblique view, whereas the inferior lateral quadrant required the medial oblique view for full

appreciation. Here again, other views failed to demonstrate minor screw tip violations consistently. Using these views to assess screw placement could decrease the risk of developing traumatic arthritis caused by screw tip violation of the talonavicular joint.

3.4. Stability of fixation in talar fractures

Swanson [4] looked at anatomical reduction and rigid internal fixation of fractures of the talar neck to allow early mobilization of the ankle and subtalar joints. Forty fresh tali from cadavers were fractured across the talar neck and were internally fixed with one of four methods. The specimens were loaded to failure, and mean yield loads, yield deformations, stiffness and energy absorbed were compared. The two configurations of screws that were inserted posterior to anterior provided yield loads superior to those of screws inserted anterior to posterior. All combinations of screws were stronger than Kirschner wires. Comparisons of yield deformations, stiffness, and energy absorbed corroborated these results. The calculated theoretical maximum shear force across the talar neck during active motion was 1129 newtons. This exceeded the strength that was provided by Kirschner wires and anteriorly inserted screws but not that provided by screws that were placed posteriorly.

Attiah [11] looked at 3 different fixation techniques to treat talus fractures in 2007 by comparing groups in cadaver feet that were osteotomised at the talar neck. A wedge was removed from the medial aspect to simulate a degree of instability at the talar neck. The first group was fixed with 3 anterior-to-posterior screws partially threaded cancellous screws. The second group was fixed with 2 cannulated screws inserted from posterior to anterior. The third group was fixed with 1 screw from anterior to posterior and a medially applied blade plate. Radiographs confirmed screw position. Specimens were embedded in acrylic cement and mounted on an Instron mechanical testing machine. Load was applied in the dorsal-medial direction to failure. The mean yield point to create 3mm of deformation for each of the fixation techniques tested exceeded 1.4 kN with no statistically significant difference between the groups. Authors conclude that fixation with an anterior plate provides equivalent stability to posterior screw fixation.

Capelle [12] evaluated the use of 2 anterior cannulated variable-pitch headless screws in talar fractures and compared this to standard cannulated headed-screw fixation. They found that talar head fixation could be performed adequately with either two cannulated headless or two 4.0 cannulated headed screws. Headless variable-pitch screw fixation had statistically lower failure displacement than the conventional screw fixation and their mode of failure was by pull out at the talar body as well as the bone failure at the talar head. Statistically, no significant differences were found in failure load, failure energy, or stiffness between the conventional screw and headless variable-pitch screw fixations. Differences in stiffness ($p=.058$) and energy absorption ($p=.065$) between screw types were approaching statistical significance. The headless design of the variable pitch screw can be fully buried beneath the surface and they compress throughout the screw length. Limitations include small sample size and failure to evaluate screw difference in other configurations of use such as posterior screw placement.

With the advent of small contoured plates, fixation models were compared with 2 posterior screws vs a lateral plate vs an anterior screw using nine matched pairs of fresh frozen talar specimens stripped of soft tissue and mounted in a cylindrical jig.[13] The talar neck was fractured and dorsal comminution was simulated by removing a 2-mm section of bone. One specimen from each pair was fixed with either two solid 4.0-mm partially threaded cancellous screws posterior-to-anterior just lateral to the posterior process of the talus or with a four-hole 2.0-mm mini fragment plate contoured to the lateral surface of the talar neck and secured with 2.7-mm screws. A 2.7-mm fully threaded cortical screw was placed medially using a lag technique. The specimens were then loaded to failure with a dorsal force. Failure was defined as 2 mm of displacement. PA screw fixation had a statistically significant higher load to failure than plate fixation (120.7 ± 68.5 N vs 89.7 ± 46.6 N, $p<0.05$). Authors conclude that plate fixation offers substantial advantages in controlling anatomic alignment of comminuted talar neck fractures, but does not provide biomechanical advantages compared with axial screw fixation.

Karakasli [14] evaluated the effects of locking plates in the treatment of talar neck fractures. The use of a locking plate theoretically may confer greater pull-out strength compared to PA screw fixation. The biomechanical fixation strength of cannulated headless variable-pitch screw fixation

and locking plate fixation in 14 fresh cadaver talar necks were compared. A shearing force was applied until the talar head was separate from the body. No statistical significance was found between fixation stiffness and yield stiffness. Cannulated locking screws resulted in better failure displacement compared to locking plate fixation models. This may be because the screws are perpendicular to the fracture site and therefore obtain strong compression. Disadvantages of this study and where plates may benefit in modem techniques are in comminuted fractures where plates can maintain axial length in the presence of comminution, they do however require a more significant dissection.

3.5. Avascular Necrosis and Talar Implants

Trovato [15] looked into the treatment for talar avascular necrosis and the feasibility of a generic talar implant using cadaveric assessment. Ten cadaver ankles had CT-scans to determine talar implant size. The opposite ankles were CT-scanned with the biological talus and then with the implant in position. 3D ankle geometry was reconstructed and implant position was compared to the biological talus position. Seventy percent of talar dome deviations between the biological talus and implant were within an acceptable range, the authors conclude that this yields promising results to support a generic talus bone prosthetic.

3.6. Lateral process talar fractures

Funk [16] notes there has been an increased incidence of lateral process fractures as a result of snowboarding injuries. Fractures of the lateral process of the talus are unusual and have an association with snowboarding. Its diagnosis can be confused with lateral ankle sprain. A misdiagnosis as anterolateral sprain can lead to long-term morbidity in a young and active population, with ensuing osteoarthritis and severe subtalar degeneration. Knowing the mechanism of injury may aid in diagnosis. Funk looked to see if eversion of dorsiflexed ankle was more likely to fracture the lateral process of the talus than inversion of a dorsiflexed ankle. Ten cadaveric specimens were subjected to dynamic inversion or eversion of an axially loaded dorsiflexed ankle. Inversion produced no fractures in three injured specimens. However, all six specimens subjected to eversion sustained a fracture of the lateral process of the talus.

Boon [17] further evaluated the effect of external rotation on lateral talus process fractures. Lateral talus process fractures were evaluated with axial loading with and without external rotation. External rotation was thought to be a key component of the mechanism of injury. Ten cadaver ankles were mounted on a materials testing machine in a position of fixed dorsiflexion and inversion. All ankles were loaded to failure axially, with or without combined external rotation. No fractures occurred after axial loading in dorsiflexion and inversion, but six of eight specimens sustained fractures of the lateral process of the talus when similarly loaded with external rotation added. This study demonstrates that external rotation with axial loading is responsible for the lateral process fractures.

Treatment of comminuted lateral process fractures is to excise the fragments, this may include a significant portion of the lateral process. Langer [18] evaluated the effects of lateral process excision on the lateral stabilising ligaments. Langar states that removal of 1cm of lateral process results in compromise of the 3 major stabilising ligaments of the talus, approximately 100% of the lateral talocalcaneal ligament, 11% of the anterior talofibular ligament and 14% of the posterior talofibular ligament was excised upon removal of the lateral process. These are major lateral stabilising ligaments, and so he concluded that excision of the lateral process fragments could lead to instability. However, later cadaveric testing by the same author, [19] concludes that although there were statistically significant increases in anterior tibiotalar translation, talar tilt, medial talocalcaneal motion, and talocalcaneal tilt seen in the cadaveric feet after simulated lateral talar process fracture fragment excision, these changes were small and not substantial enough to constitute instability.

4. Discussion

This study maps the body of cadaveric research to date pertaining to talus fractures and gives insights into fracture etiology, and gives recommendations for management.

Fractures of the talar neck comprise almost 50% of talar fractures and may result in significant long-term morbidity. Anatomic reduction of talar neck fractures, particularly any articular surface displacement, is critical to minimise the risk of nonunion, malunion, and future post-traumatic

osteoarthritis. Included studies have demonstrated the potential benefits of different surgical approaches with regards to articular cartilage visualisation and at risk structures, and suggest that combined approaches give optimal results.

When considering fixation of these fractures, there is a large body of evidence looking at the strength of fixation with K-Wires, anteriorly and posteriorly inserted screws, and locking plates. It is clear that K-Wire fixation is inadequate, and that while posterior to anterior screw fixation appears to have a higher pull out strength, this method lacks the ability to control axial length of the fracture and so is suboptimal for the management of comminuted talar neck fractures, and that plate fixation would be advantageous for these. The main disadvantage of these studies lay in the more historic nature of fixation methods used. Modern plates now have smaller footprints with variable angle locking constructs and are pre-contoured to the lateral side of the talus to allow better fixation, without the need for such extensive dissections. This is one area where further studies should focus.

AVN is an unfortunate complication of talus fractures due to it's unique blood supply, and can occur despite treatment with robust fixation.[20] There was only one study looking at options for treatment with regards to generic talus implants, and authors felt it showed promising results. Since recent advances in 3D printing techniques, there are now patient specific total talus replacements available. It has been shown that patient specific total talus replacements do improve patient reported outcomes [21], further cadaveric studies could look at the biomechanics of these implants, particularly with regards to articular contact pressures, to see if it truly is suitable to model a talus replacement based on the contralateral uninjured side.

There were several papers looking specifically at lateral process fractures of the talus, and they convincingly show that these fractures occur due to forced eversion of a dorsiflexed ankle. This is important since it will allow clinicians to have a high index of suspicion, since they are difficult fractures to identify on radiographs. Importantly, studies also appear to show that simple excision of the fracture fragments is unlikely to lead to ankle instability, this is a valuable insight into the management of this rare fracture should it go on to heal with a painful non-union.

5. Conclusions

The most appropriate form of the treatment of talus injuries fractures should be decided based upon evidence. Cadaver studies provide us with useful insight into treatments in talus fracture fixation that would be difficult to ascertain through other modalities of investigation given the rarity of talus fractures.

Whilst the drawback of cadaver based studies are they are not clinical, are not RCT based, and are unblinded, cumulative evidence of this uncommon fracture and its complications takes time to assimilate. Cadaver studies have provided valuable insights into the optimum approach and fixation of the talus, quantified the area of talus exposure, and defined at-risk structures. Cadaver studies have determined fixation strength using screws and plating techniques as well as evaluated the effects of malunion on joint biomechanics, and they have also helped to identify the deforming forces that cause lateral process fractures, and also the recommended management.

Future research using cadavers may be directed to evaluating the biomechanical strength of newer low-profile contoured locking plate fixation techniques. Double pre-contoured plates with variable angle locking screws provide ease of fixation with good strength. Further validation of strength to failure of these plates compared with conventional plates and screw fixation using cadavers would provide valuable in vitro assessment of their biomechanical properties in talus fracture fixation.

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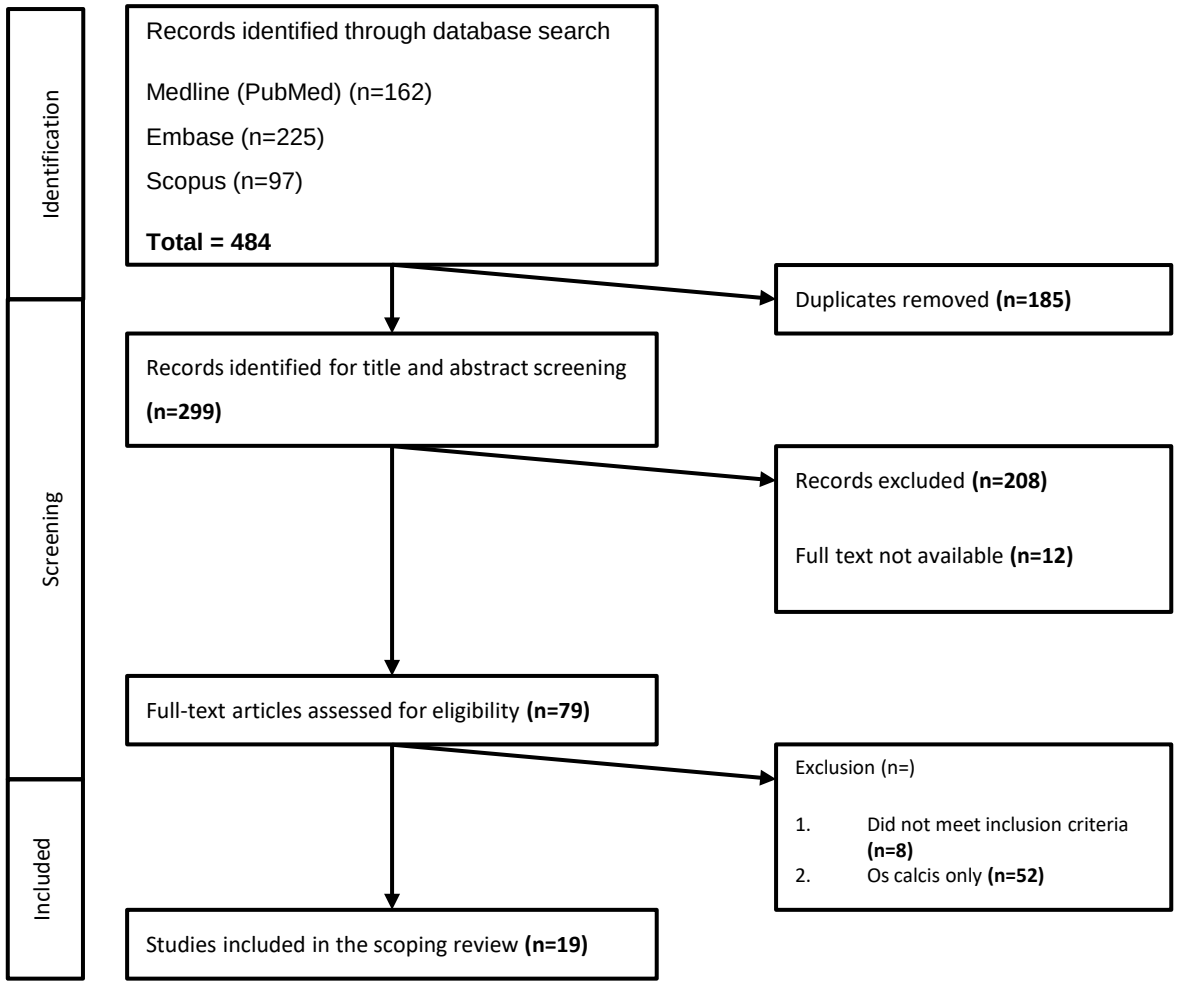
Identification
Screening
Included
Records identified through database search
Medline (PubMed) (n=162)
Embase (n=225)
Scopus (n=97)
Total = 484
Duplicates removed (n=185)
Records identified for title and abstract screening (n=299)
Records excluded (n=208)
Full text not available (n=12)
Full-text articles assessed for eligibility (n=79)
Exclusion (n=)
1. Did not meet inclusion criteria (n=8)
2. Os calcis only (n=52)
Studies included in the scoping review (n=19)

Reference	First Author Surname	Title	Journal	Year	Male to female ratio (Total)	Embalming/presevation technique	Description of jigs used to obtain data	Primary aim of study	Secondary aims of study	Summary of results	Conclusion of study
11	Attiah	Comminuted talar neck fractures: a mechanical comparison of fixation techniques	Journal of Orthopaedic Trauma	2007	24:6 (30)	Harvested from lower extremity surgical amputations. Age average 66rs (34-88). Specimen appear to be fresh - frozen, no other preservation methods detailed.	Previously frozen tall osteotomised across talar neck. Wedge of bone 2cm long and extending 50% Of the medial to lateral and superior to inferior dimensions of the talus was removed to create an unstable comminuted fracture. Randomised into 1 of 3 groups. block- randomized design to ensure equal numbers in each group. The ages, weights, and volumes of the specimens did not differ between the groups (one-way analysis of variance; age, P = 0.34; weight, P = 0.52; volumes, P = 0.89). Specimens were kept moist during preparation, fixation, and testing with intermittent saline irrigation.: 1. fixed with 3 AP screws. 2. 2 PA cannulated screws. 3. 1 AP screw with medially applied blade plate. SPecimens embedded in acrylic cement and mounted on Instron servohydraulic 8501 mechanical testing machine. Loading applied in dorsal-medial direction to failure using a cup shaped bone impactor. This represented an element of dorsal shear and varus impaction loading.	To compare the mechanical performance of 3 fixation techniques for comminuted talar neck fractures.	This study was performed to compare posteriorly inserted screw fixation with anterior fixation using plate fixation or multiple screw fixation. This study sought to test the null hypothesis that there is no difference in yield point or fixation stiffness among the fixation techniques tested (anterior-to-posterior screw fixation, blade plate fixation, or posterior-to-anterior screw fixation).	"No statistically significant difference was found between the fixation methods with respect to yield point, 3 mm displacement, or stiffness. With multivariate analysis (Pearson correlation), there was no significant association between fixation technique and variables such as age or sex (r2 , 0.40, P . 0.05). With respect to mode of failure, the AP and PA fixation techniques failed by screw bending or pullout in all cases. In 4 of the 10 specimens fixed with the BP technique, the hardware pulled out of the talar head. However, in 6 of 10 specimens stabilized with the blade plate, the talar head fractured around the plate. In these 6 specimens, the talar neck osteotomy remained undisplaced even after fracture of the talar head around the implant. The observed mode of failure was different (x2 = 15, P = 0.001) with the BP technique compared with that observed using the AP or PA technique. "	The power of this study to detect differences in fixation strength was low. A pretest sample size analysis suggested that the study would detect a difference in yield point of 0.3 kN with a power of 0.80. However, the standard deviations of the test results were substantially higher compared to that of previous studies. Our results suggested that the yield point of the AP screw technique was approximately 25% less compared to the BP or PA technique. Although this difference was not statistically significant, the lack of adequate study power to detect a difference should be considered. Comminuted talar neck fractures may be effectively stabilized with plate fixation, posterior screw fixation, or multiple anterior-to-posterior screws. According to our data, the mean fixation strength of all 3 methods of fixation tested exceeds the theoretical forces across the talar neck during motion. The anterior-to-posterior screws had approximately 20% lower yield point and stiffness compared to the posterior-to-anterior screws or blade plate techniques, but this was not statistically significant within the power of this study. Surgeons who prefer early motion to rehabilitate comminuted talus fractures should allow it judiciously and consider the use of plate fixation or external rotation torque appears to be a critical element in the production of the lateral process fractures. Because the major force vectors involved in this injury have been identified, further study may be directed at refining the injury mechanism and identifying potential preventive interventions.
17	Boon	Snowboarder's talus fracture. Mechanism of injury	American Journal of Sports Medicine	2001	Unspecified (10)	Fresh-frozen stored at -20˚C	Proximal tibia and fibula were potted in polymethyl methacrylate bone cement for subsequent mounting. The normal tibiofibular relationship was maintained. The foot was placed in a metal box mounted on a wooden wedge and secured using plaster of Paris. The subtalar joint was not stabilized. The wedge set the foot at an angle of 20° of dorsiflexion and 10° of inversion. The specimen was secured in the MTS servohydraulic testing machine (MTS Systems Corp., Eden Prairie, Minnesota) by clamping the bone cement block on one end and bolting the box and wedge to the actuator on the other end. Loading was applied to the specimens by first setting a compressive axial load and then introducing the external rotation. The compressive load was applied by manually displacing the actuator under displacement control until the desired load level was reached. The axial loading rate was approximately 2200 N/sec. Then, the external rota- tion was applied, under rotation control, over a 3-second period.	Identifying a loading mechanism that reproduces fracture of the lateral process of the talus.	Development of preventative equipment and interventions for snowboarding	No fractures occurred after axial loading in dorsiflexion and inversion, but six of eight specimens sustained fractures of the lateral process of the talus when similarly loaded with external rotation added, supporting the hypothesis that external rotation is a key component in the mechanism of injury.	
12	Capelle	Fixation strength of anteriorly inserted headless screws for talar neck fractures	Foot & Ankle International	2013	Unspecified (9)	Unspecified	Rigidly fixed within a polymer casting compound (Smooth-Cast 300, Smooth-On, Inc, Easton, PA) in an aluminium potting box, leaving the head and neck exposed. The potting box was rigidly attached to the load cell of an MTS 858 Mini-Bionix (MTS Systems Corporation, Grand Prairie, MN) mechanical testing system. The tali were positioned so that the anterior and middle subtalar facets came into contact with the testing actuator fixed with a 31-mm diameter concave tip molded from the aforementioned casting compound. A shearing force was directed dorsally at a displacement rate of 200 mm/min until complete separation of the talar head from the body.	Biomechanical Comparison between conventional small fragment/cannulated screws versus headless variable pitch screws when used for anterior fixation if talar neck fractures. Hypothesis is that there is no significant difference.	-	The variable-pitch screws demonstrated significantly lower displacement than the conventional screws (P = .039). However, no significant differences in failure load (P = .388), failure energy (P = .065), or stiffness (P = .058) were found. Post hoc power analysis revealed that to achieve 80% power across these measures, the number of specimens required would be 13 for displacement, 20 for stiffness, 36 for energy, and 359 for failure load.	There are some advatnges of the newer screws however these come with a higher price tag and the ultimate decision for use lies with the comfort of the operating surgeon.
8	Chan	Clinical accuracy of imaging techniques for talar neck malunion	Journal of Orthopaedic Trauma	2008	8:0 (8)	5 right and 3 left specimens. These were fresh frozen from amputations occurring due to peripheral vascular disease.	Talus removed, osteotomy at talar neck with 3 RSA beads inserted in each of 2 fragments. 3.5mm AP small fragment screws then used to anatomically reduce the fracture. K wires were used to direct rotational and translational measurements. The specimens were then placed in a styrofoam block for standardisation of radiographic assessment. The imaging was taken in several planes followed with removal of the screws and positioning and fixation in malreduced positions: varus, supination and dorsal translation.	Compare the accuracy of plain radiographs, CT and radiostereometric analysis (RSA) in the assessment of talar neck malunion invitro.	Surgeons ability to detect malunion would be less than the reported accuracy of the imaging techniques.	Upon comparison among the three groups, in terms of displacement measurements, the CT scan results were closest to the measured displacement (P <= 0.002). In terms of rotation there were no significant differences among the 3 groups (P = 0.23). In both displacement and rotation surgeons underestimated measurements.	Although RSA imaging is very useful for the assessment of wear after total joint arthroplasty, RSA in talar neck fractures was less accurate and more complicated to use compared to CT. Perhaps most importantly, all 3 techniques underestimate the amount of malunion. CT should be considered the diagnostic study of choice to assess malalignment after talus fracture surgery.
13	Charlson	Comparison of plate and screw fixation and screw fixation alone in a comminuted talar neck fracture model	Foot & Ankle International	2006	Unspecified	Fresh frozen	Talus mounted on cylindrical jig with dental acrylic. Post section of talus free from acrylic. The talar neck was fractured using a dorsally directed shear force at a rate of 200 mm per minute on a Mini Bionix Servohydraulic load frame (MTS Systems, Eden Prairie, MN). The force was focused on the anterior and middle facets of the talar neck with a padded concave plunger. This produced transverse or oblique fractures and dorsal comminution was simulated by removing a 2mm section from the distal fracture fragment that included medial and lateral cortex.	To evaluate the two fixation methods: plate and screw fixation versus retrograde axial screw fixation in a comminuted talar neck fracture by determining load to failure	Whether this varied from the noncomminuted fracture model used in Swanson et al's study which showed retrograde axial screws to be superior in strength. Thus identifying the importance of the dorsal commination to structural and load integrity	The mean load to failure for the group fixed with posterior-to-anterior screw was 120.7 ± 68.5 N. The mean load to failure for the group fixed with miniFragment plates and screws was 89.7 ± 46.6 N. This difference was statistically significant (p < 0.05). Dorsal comminution greatly weakend the construct when compared to values reported by Swanson et al.	Dorsal comminution is a high risk fracture with resultant dramatic loss of strength. In this setting, plates provide good anatomic control over these fragments but no biomechanical benefit compared to axial screw fixation. The difference in the two fixation techniques is small when compared to the overall loss of strength resulting from the dorsal comminution.
2	Daniels	Varus malalignment of the talar neck. Its effect on the position of the foot and on subtalar motion	Journal of Bone & Joint Surgery - American Volume	1996	Unspecified (12)	Fresh frozen	Tibiotalar and tarsometatarsal joints were stabilised in neutral position with Steinmann pins and fixed to an aluminium block post aspect of calcaneus for reference. A wedge measuring five millimeters at its base was removed from the medial side of the talar neck of all twelve specimens. This shortened the medial column of the foot and simulated the clinical situation frequently seen with comminution and impaction of the medial side of the talus. A constant light source with artists papers and K wires were used to cast directional shadows to measure arcs of movement.	To evaluate the effect of varus malalignment to the biomechanics that would influence clinical guidance for fixation - particularly looking at subtalar motion and foot positioning.	Achieve a better clarity on what degree of displacement at the talar neck can cause increased morbidity and what defines acceptable reduction.	varus deformity of the talar neck linearly correlated with foot postion, being statistically significant in the cases of hindfoot internal rotation and forefoot adduction. For every 2˚ of varus deformity there was 1˚ of internal rotation and for every 3˚ of varus deformity there was 2 ˚ of adduction of the forefoot. The adduction paralleled the varus malalignment of the talar neck.	Varus misalignment locks the hindfoot in varus and internal rotation. There is a linear relationship between the degree of varus malalignment and the change in the postion of the foot and in subtalar motion thus re-emphasising the importance of anatomical reduction in fractures of the talar neck.
5	Ebraheim	Talar neck fractures: anatomic considerations for posterior screw application	Foot & Ankle International	1996	Unspecified (62)	50 dry bone and 12 cadavers used. Embalming process unspecified.	No specific jig used - cadaver used to study surgical approach for posterior screw placement.	Anatomical considerations to be made when using a posterior screw fixation of talar neck fractures		No statistical differences found between male and female tali. Once the deep fascia surrounding the ankle has been incised, lat tubercle of the post process of the talus can be palpated as a landmark for the bony window for screw placement	The best position for screw insertion is through the lateral tubercle of the posterior process of the talus. Insertion of another screw will necessitate injury of the posterior talofibular ligament; thus, a Kirschner wire may be a recommended alternative. Visualisation of the subtalar joint in posterolateral approach is poor.
10	Ebraheim	Radiographic evaluation of talonavicular joint after talar screw placement: A cadaver study	Foot and Ankle International	1999	3:9 (12)	Intact embalmed feet - process unspecified.	Posterior approach screw placed into a disarticulated talus at varying degrees at insertion. After re-articulation they were radiographically assessed for the screw tip in the talonavicular joint	assess the best radiographic view to assess the talonavicular joint with respect of screw tip violation of the articular surface.		The lateral oblique view was the only view to consistently show screw tip violation in inferomedial quadrant. Similarly medial oblique showed this for inferolateral quadrant. The dorsoplantar view was able to show violations in the superior half (and inferior half with the above giving a more accurate delinlation of the inferior half)	The dorsoplantar view clearly demon- strates the position of the screw tip when violating the joint space of the superior half of the talar head and also determines the next radiographic view as per the results.
14	Karakasli	Mechanical Comparison of Headless Screw Fixation and Locking Plate Fixation for Talar Neck Fractures	Journal of Foot & Ankle Surgery	2015	9:5 (14)	Fresh frozen	The body of talus was rigidly fixed within acrylic cement in aluminum potting box, with the head and neck exposed. Each potting box was attached to load cell of electromechanical universal testing machine. Anterior and middle subtalar facets made contact with the testing actuatorfixed with a 15-mm diameter concave tip. A shearing force was directed dorsally at a displacement rate of 25 mm/min until the talar head completely separated from the body	to compare the biomechanical fixation strength of cannulated headless variable-pitch screwfixation and locking plate fixation	-	No statistically significant differences were found in failure stiffness, yield stiffness(p\.655), yield load (p\.142), or ultimate load between the 2fixation techniques. Headless variable-pitch screw fixation had lower failure displacement than dldlocking platefixation	no statistically significant result. "locking plate fixation might be preferred only for comminuted fractures, and for simple fractures,headless variable-pitch screwfixation would seem to be advantageous"
18	Langer	Effect of simulated lateral process talus "fracture excision" on its ligamentous attachments	American Journal of Orthopedics (Chatham, NJ)	2009	6:1 (7)	Fresh frozen	No mechanical jig used, rulers and calipers for measurements. Chisel	to evaluate the effects of lateral talar process fracture on the footprints of 3 lateral stabilizing ligaments of the ankle and subtalar joint	-	Footprint of LTCL, ATFL and PTFL- pre and post excision of simulated # frag: mean decrease of the original areas were 97.5% ± 3.5% (LTCL), 11.7% ± 13.0% (ATFL), and 14.3% ± 12.3% (PTFL).	1.) that removal of a 1-cm3 "fracture fragment" from the lateral talar process compromised 3 of the major lateral sta-bilizing ligaments (LTCL, ATFL, PTFL). 2.) Mean decreases in ligament footprint attachment areas, calculated as a percentage of the original areas, were approximately 100% of the LTCL origin and 10% to 15% of the ATFL and PTFL insertions.
19	Langer	In vitro evaluation of the effect lateral process talar excision on ankle and subtalar joint stability	Foot and Ankle International	2007	0:5 (5)	Fresh frozen	Clinical stress apparatus (Model SE 200, Telos, Marburg, Germany). 150N applied. pre and post measurements taken via radiographs	to determinethe effect that excision of this 1 cm3 fragment has on ankle andsubtalar joint stability	-	The mean increases in AT, TT, TCM, and TCT before and after excision of a simulated 1cm3 fracture fragment: AT=1.0mm±0.94mm (p=0.008S); TT=0.4±0.52degrees (p=0.0368); TCM=1.0mm±1.25mm (p=0.0319); TCT=1.2±1.32degrees (p=0.0181)	that excision of a 1 cm3 fragment causes neither ankle nor subtalar instability as defined by radiographic stress examination.
3	Mullen	The anterior approach for the fixation of displaced talar neck fractures-A cadaveric study	Foot	2013	Unspecified (5)	Fresh frozen	No mechanical jig. Immersion digital microscribe and Rhinoceros 3D software used for measurements pre and post instrumentation of specimens.	to compare the surface area of talus visible and quality of exposure via the anterior approach, with anteromedial and anterolateal approaches	-	talar surface area visible in anterior approach sig greater than that in anterolateral or anteromedial approahces, with and without medial malleolar osteotomy	anterior approach offers excellent visualisation in the fixation of displaced talar neck #s (1160mm2 compared to 570 (in AL) and 395 (in AM) or 474 (AM + med mall osteotomy). greater talar surface area visible compared to traditional approaches. Med mal osteotomy - improved view but little improvement to access to neck.
6	Roberts	Soft Tissue Structures at Risk With Percutaneous Posterior to Anterior Screw Fixation of the Talar Neck	Foot & Ankle International	2018	Unspecified (11)	Fresh frozen	Nil	Determine the specific risk to the posterolateral and posteromedial neurovasular and tendinous structures during percutaneous placement of 2 post to ant directed paralell screws from a posterior starting point	Determine total number of attemptsrequired to achieve acceptable placement	The mean number of passes needed to obtain optimal placement was 2.9 +/- 0.7. Distance between wire an structures is summaried in table. Sural nerve was in contact with a guidewire in all specimens.	Technically demanding and multiple guidewires are needed. High risk of damaging tendinous and neurovascular structures, in particular sural nerve. Recommend maximum fluroscopy-guided planning to minimise attempts and a formal small posteriolateral approach to visualise and restract structures at risk.
1	Sangeorzan	Contact characteristics of the subtalar joint: The effect of talar neck misalignment	Journal of Orthopaedic Research	1992	Unspecified (7)	Fresh frozen	(Fig 2 in the paper) Speciments were instrumented and mounted in a loading frame that allowed only vertical loading. Force 90% through tibia 10% through fibula; Load distrubution achieved using a strain-gauged plate. The foot was mounted on a metal plate which inturn was supported on ball bearings to allow free movement in the horizontal plane to allow normal relative motions of the hindfoot in the horizontal plane under compressive loading	Report on changes in the contact characteristics in the subtalar joint as a result of prescribed misalignment patters of the talar neck in lab model of talar neck fractures	-	Contact aread decreased with displacement. It decreased more with dorsal displacement than lateral displacement but not significantly. Talar neck misalignment resulted in significantly less pressure loading of anterior and middle facets. 2mm talar neck misalignment resulted in no statistically significant reduction in posterior facet contact area.	displacement as small as 2 mm significantly alters the contact characteristics of the subtalar joint, dorsal medial or varus displacement causes the greatest change. Changes to contact charcersitics included more focal posterior facet contact area and unloading of anterior/middle facets. Since no subtalar articulation showed an increase in loading to compensate for the ant/middle facet; either an extra-articular pathway or an alternate intraarticular pathway may transfer the force.
4	Swanson	Fractures of the talar neck. A mechanical study of fixation	Journal of Bone & Joint Surgery - American Volume	1992	20:20 (40)	Fresh frozen	(Fig 1 in paper) Specimens were mounted in acrylic cement ina cylindrical jig allowing exposure of the head and neck. The posterior aspect of each body was kept free of cement to allow access for posterior fixation. Fractures of the talar neck were produced by applying a dorsally directed shear force to the talar head with a mechanical testing system (Model 1122 Instron, Canton, Massachusetts). Shear forces were applied to the anterior and middle subtalar facets with a 20mm cylindrical plunger, resulting in transverse or slightly oblique fractures of the talar neck.	Assess the strength provided by various types of internal fixation for fractures of the talar neck.	-	The two configurations of screws that were inserted posterior to anterior provided yield strengths superior to those inserted anterior to posterior. All combinations of screws were stronger than Kirschner wires. Comparisons of yield deformities, stiffness, and energy absorbed corroborated these results. The calculated theoretical maximum shear force across teh talar neck during active motion was 1129 newtons. This exceeded the strength that was provided by the Kirschner wires and anteriorly inserted screws but not that provided by screws that were placed posteriorly.	While operative approach is determined by a number of factors, posterior insertion of a screw or screws when possible, provides fixation superior to that of Kirschner wires or anteriorly inserted screws. Their model indicates that this may allow early motion with a reduced risk of failure of fixation or displacement of teh fracture

9	Thomas	Radiographic Analysis of the Canale View for Displaced Talar Neck Fractures	Journal of Foot and Ankle Surgery.	2021	Unspecified (6)	Unspecified	Custom jig secured the proximal tibia and the ankle was placed in maximal plantarflexion. Solid styrofoam blocks used to customise the angle.	Although canal view is accepted as beneficial in evaluation of varus rotation 15 degrees of rotation is not consistently rhe most effective angle for evaluating this. Alternative angles > and < than 15 degreees may allow better evaluation of the varus displacement at the fracture site. Eversion is a better desctiption of positioning than pronation.	-		10 degrees was satistically significantly ranked as less useful for evaluation of varus displacement when compared to 5, 15, 20 and 25 degrees. Higher eversion values (15, 20, 25 degrees) received the highest rankings (stat significant) for evaluating varus displacement comparted to the lower values (0, 5, 10)	A range of angles may be most beneficial in evaluating varus displacment in talar neck fractures
15	Trovato	Analysis of a generic talar prosthetic with a biological talus: A cadaver study	Journal of Orthopaedics	2018	4:6 (10)	Unspecified	(Fig 3 in paper) Custom wooden jig allowing a CT scan of the ankle in neutral, and in 20 degrees of plantarflexion and dorsiflexion with both the biological and prsthetic talus in place.	Assess suitable fit of generic talar implants compared to biological talus.			The averages among speci- mens' positive and negative average-deviations were 0.91 mm and 0.70 mm. Seventy percent of talar dome deviations between the biological talus and implant were within an acceptable range	This study yields promising results to support a generic talus bone prosthetic.
7	Wang	Talar neck fractures: anatomic landmarks of suitable position for posterolateral screw insertion	Acta Orthopaedica et Traumatologica Turcica	2015	Unspecified (15)	Unspecified	No Jig	To define the anatomic landmarks associated with the posterolateral window for screw insertion of talar neck fractures.	Investigate the distance to surrounding anatomical structures from screw insertion point in order to provide guidance for clinical surgery		The posterolateral window was bound medially by the lateral ubercle of the posterior process of the talus (LTPT), laterally by the posterior border of the lateral malleolus (PBLM), superiorly by the trochlear articular surface (TAS) and inferiorly by the posterior calcaneal facet (PCF). Average hight and width of the window were 1.89+/-0.04cm and 0.91+/-0.02cm respectively. Vertical distance from centre to the lateral mal tip was 0.40+/-0.01cm. Horizontal distance from the centre of the window to the lateral border of achilles tendon (LAT) was 0.19+/-0.02cm, horizontal distance from LAT to sural nerve was 0.62+/-0.04cm. Introducing the screw through the posterolateral window doesnt significantly affect neighboring tissues.	Posterolateral window is a safe point fo insertion of posterolateral screws. The screw head should be countersunk to avoid voilating the posterior talofibular ligament.
16	Funk	Snowboarder's talus fractures experimentally produced by eversion and dorsiflexion	The American Journal of Sports Medicine	2003	Unspecified (6)	Unspecified	(Fig 1 in paper) Originally constructed by CEESAR (nanterre, France) the apparatus incorportates and adjustable footplate free to rotatae about an offset fixed vertical axis. Rotation of the footplate was driven by a pneumatic actuator against a cam. The limb was mounted in the jig by using an aluminium rod fixed into a reamed tibia with epoxy resin, and the foot mounted to the baseplate using a steinman pin through the calcaneous set in resin, and metal wires passing over the first and fifth metatarsals.	To investigate wether forced eversion and axial loading of a dorsiflexed ankle would lead to a latral process fracture of the talus.	-		Inversion and dorsiflexion failed to produce a lateral process fracture of the talus in any of the tested specimens. All specimens subjected to an eversion force along with forced dorsiflexion sustained a lateral process fracture of the talus. Fractures were typically worse iin those specimens subjected to a higher degree of eversion. Higher degrees of eversion were also associated with medial soft tissue injuries.	Eversion of an axially loaded and dorsiflexed ankle may be an important injury mechanism for fracture of the lateral process of the talus among snowboarders.

Literature search strategy

MEDLINE (Ovid Online) 23/10/2020	1 exp Cadaver/ 2 (cadaver* or corpse*).mp. 3 exp Models, Structural/ 4 (anatom* adj3 specimen*).mp. 5 (anatom* adj3 model*).mp. 6 (anatom* adj3 donor*).mp. 7 1 OR 2 OR 3 OR 4 OR 5 OR 6 8 exp Talus/ 9 (talus*).mp. 10 exp Calcaneus/ 11 (calcane* or os calci*).mp. 12 8 OR 9 OR 10 OR 11 13 exp Fractures, Bone/ 14 (bone adj3 fracture).mp. 15 13 or 14 16 12 and 15 17 7 and 16 162 documents
Embase (Ovid Online) 23/10/2020	1 exp Cadaver/ 2 (cadaver* or corpse*).mp. 3 exp Models, Structural/ 4 (anatom* adj3 specimen*).mp. 5 (anatom* adj3 model*).mp. 6 (anatom* adj3 donor*).mp. 7 1 OR 2 OR 3 OR 4 OR 5 OR 6 8 exp Talus/ 9 (talus*).mp. 10 exp Calcaneus/ 11 (calcane* or os calci*).mp. 12 8 OR 9 OR 10 OR 11 13 exp Fractures, Bone/ 14 (bone adj3 fracture).mp. 15 13 or 14 16 12 and 15 17 7 and 16 225 documents
SCOPUS (23/10/20)	(TITLE-ABS-KEY((cadaver*) OR (corpse*))) AND ((TITLE-ABS-KEY ((bone w/3 fracture))) AND (TITLE-ABS-KEY (talus* OR calcane*))) OR (TITLE-ABS-KEY (os calcis*)) 97 documents