On the Treatment of Unstable Ankle Fractures

by

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ABBREVIATIONS

AITFL	Anterior inferior tibiofibular ligament
AO	Arbeitsgemeinschaft für Osteosynthesefragen
AOFAS	American Orthopaedic Foot and Ankle Society
AP	Anteroposterior
ATFL	Anterior talofibular ligament
ATTL	Anterior talotibial ligament
cAPTF	comparative Anteroposterior Tibio Fibular Ratio
CFL	Calcaneofibular ligament
CI	Confidence interval
CONSORT	Consolidated Standards of Reporting Trials
CT	Computed tomography
Eq5d	EuroQol-5d
ITFL	Interosseous tibiofibular ligament
IQR	Interquartile range
K-wire	Kirschner wire
LCP	Lateral compression plate
MCID	Minimally clinically important difference
MCS	Medial clear space
MOxFQ	Manchester-Oxford Foot Questionnaire
MRI	Magnetic resonance imaging
OA	Osteoarthritis
OMA	Olerud and Molander Ankle
ORIF	Open reduction and internal fixation
OTA	Orthopaedic Trauma Association
PA	Posteroanterior
PAB	Pronation abduction
PER	Pronation external rotation
PITFL	Posterior inferior tibiofibular ligament
PMF	Posterior malleolar fracture
PROM	Patient-reported outcome measure

PTFL	Posterior talofibular ligament
PTTL	Posterior talotibial ligament
RCT	Randomized controlled trial
ROM	Range of motion
RR	Relative risk
SA	Supination adduction
SB	Suture button
SD	Standard deviation
SER	Supination external rotation
SPRI	Steadman Philippon Research Institute
ST	Suture tape
TFO	Tibiofibular overlap
TCS	Tibiofibular clear space
VAS	Visual analogue scale

THESIS SUMMARY

Introduction

The incidence of ankle fractures is increasing with an elderly patient population and higher physical activity level. Unstable ankle fractures require surgery to restore ankle stability and joint congruity, thereby improve pain, function, and risk of developing posttraumatic osteoarthritis (OA).

Standard surgical treatment of lateral malleolar fractures today is plate and screw fixation. Due to the high risk of surgical complications in elderly patients, the minimally invasive technique with nail fixation has been introduced as an alternative to plate fixation. The surgical treatment of syndesmotic injuries has been debated for decades, with screw fixation as the traditional choice and suture button (SB) as a newer alternative. Furthermore, if presence of a posterior malleolar fracture (PMF), fixation of the fragment has been suggested to restore the tension of the posterior syndesmotic ligament, thereby restore syndesmosis and ankle joint kinematics.

Aims

The goal of this doctoral thesis was to investigate different surgical methods for treatment of acute unstable ankle fractures. This included to compare nail and plate fixation of acute unstable AO/OTA type 44-B ankle fractures in elderly patients, SB and tricortical screw fixation of acute AO/OTA type 44-C ankle fractures, and PMF fixation with screws and trans-syndesmotic SBs for treatment of ankle injuries with PMF and an unstable syndesmosis.

Materials and methods

Paper I is a multicenter randomized controlled trial (RCT) including patients 60 years or older with an acute unstable AO/OTA type 44-B ankle fracture. A total of 120 patients were randomized to nail or plate fixation and followed for 24 months after surgery. The primary outcome measure was American Orthopaedic Foot and Ankle Society (AOFAS) Ankle-Hindfoot

Scale. Secondary outcome measures were Manchester-Oxford Foot Questionnaire (MOxFQ), Olerud and Molander Ankle (OMA) Scale, EuroQol-5d (Eq5d) index and visual analogue scale (VAS), VAS scores for pain, complications, fracture reduction, radiographic nonunion, and ankle OA.

Paper II is a multicenter RCT including patients 18 to 69 years with an acute AO/OTA type 44-C ankle fracture. A total of 113 patients were randomized to trans-syndesmotic fixation with one SB or one tricortical screw and followed for 24 months after surgery. The primary outcome measure was AOFAS Ankle-Hindfoot Scale. Secondary outcome measures were MOxFQ, OMA Scale, Eq5d index and VAS, VAS scores for pain, ROM, tibiofibular distance, ankle OA, and tibiofibular synostosis.

Paper III is a biomechanical study including 20 cadaveric lower leg specimens that had creation of a PMF (25% or 50%) with syndesmosis injury and were tested using a 6-degrees-of-freedom robotic arm. Four biomechanical tests (external rotation, internal rotation, posterior drawer, lateral drawer) were performed in 7 states: 1) Intact, 2) syndesmosis injury with PMF, 3) trans-syndesmotic SBs, 4) trans-syndesmotic SBs + anterior inferior tibiofibular ligament (AITFL) augmentation, 5) trans-syndesmotic SBs + AITFL augmentation + posterior malleolar screws, 6) posterior malleolar screws + AITFL augmentation, 7) posterior malleolar screws. A 5-camera motion capture system was used to record the relationship between the fibula, tibia, and talus.

Results

In study I, median AOFAS score was 90 (IQR: 82–100) after nail fixation and 95 (IQR: 87–100) after plate fixation (p = .478) at 24 months. This result was equivalent between the groups. The number of complications and secondary surgical procedures were higher after nail than plate fixation (p = .024, p = .028, respectively). No other differences were found between the groups.

In study II, median AOFAS score after both SB and tricortical screw fixation at 24 months was 97 (IQR SB: 87-100, IQR tricortical screw: 90-100, p = .7) and the mean score was equivalent between the groups. There was no significant difference in tibiofibular distance and the malreduction rates were comparable (SB: 35%, tricortical screw: 29%). No difference was found in complication or reoperation rate.

In study III, with external rotation, posterior malleolar screws with AITFL augmentation resulted in best stability of the fibula and ankle joint. With internal fixation, all repairs that included posterior malleolar screws stabilized the fibula and ankle joint. Posterior and lateral drawer resulted in only small differences between the intact and injured states. No differences were found in the efficacy of treatments between 25% and 50% PMFs.

Conclusions

The functional outcome after nail and plate fixation was equivalent; however, the number of complications and secondary surgical procedures were higher after nail fixation. Plate fixation should be the treatment of choice for acute unstable ankle fractures in elderly patients in general.

The functional outcome after SB and tricortical screw fixation was equivalent, and there was no difference in tibiofibular distance. Tricortical screw is a cheaper alternative than SB when treating acute syndesmosis injuries.

Posterior malleolar screw fixation with AITFL augmentation may be the preferred surgical method when treating patients with acute ankle injury involving an unstable syndesmosis and a PMF of 25% or larger.

NORSK SAMMENDRAG

Bakgrunn

Forekomsten av ankelfrakturer er økende med en eldre pasientpopulasjon og et høyere fysisk aktivitetsnivå. Ustabile ankelfrakturer bør opereres for å gjenopprette ankelstabiliteten og leddkongruiteten, og på den måten bedre smerte, funksjon, og risiko for å utvikle posttraumatisk artrose.

Standard operasjonsmetode for fraktur i laterale malleol i dag er plate og skrueosteosyntese. På grunn av økt risiko for komplikasjoner ved kirurgi hos eldre pasienter, har en mindre invasiv operasjonsmetode med naglefiksasjon blitt introdusert som et alternativ til platefiksasjon. Operativ behandling av syndesmoseskader har vært omdiskutert i lang tid, hvor tradisjonell metode har vært skruefiksasjon og en nyere metode har vært sutur button (SB). Videre har det blitt foreslått at frakturer i bakre malleol kan behandles med fiksasjon av det fragmentet som kan gjenopprette tensjonen til det bakre syndesmoseligamentet og dermed gjenopprette kinematikken i syndesmosen og ankelleddet.

Mål

Målet med denne avhandlingen var å se på ulike operasjonsmetoder for behandling av akutte ustabile ankelbrudd. Vi sammenlignet nagle- og platefiksasjon av akutte ustabile AO/OTA type 44-B ankelfrakturer hos eldre pasienter, SB- og trikortikal skruefiksasjon av akutte AO/OTA type 44-C ankelfrakturer, og fiksasjon av bakre malleolfraktur med skruer og syndesmosefiksasjon med SB for behandling av ankelskader med fraktur i bakre malleol og ustabil syndesmose.

Materiale og metoder

Artikkel I presenterer en multisenter randomisert kontrollert studie (RCT) som inkluderer pasienter 60 år og eldre med en akutt ustabil AO/OTA type 44-B ankelfraktur. Totalt ble 120 pasienter randomisert til nagle- eller platefiksasjon og fulgt i 24 måneder etter operasjon.

Hovedendepunkt var American Orthopaedic Foot and Ankle Society (AOFAS) ankel-bakfot skala. Sekundære endepunkter var Manchester-Oxford Foot Questionnaire (MOxFQ), Olerud og Molander Ankel (OMA) score, EuroQol-5d (Eq5d) index og visual analogue scale (VAS), VAS for smerte, komplikasjoner, frakturreposisjon, radiologisk tilheling og ankelartrose.

Artikkel II presenterer en multisenter RCT som inkluderer pasienter 18 til 69 år med en akutt AO/OTA type 44-C ankelfraktur. Totalt ble 113 pasienter randomisert til syndesmosefiksasjon med én SB eller én trikortikal skrue og fulgt i 24 måneder etter operasjon. Hovedendepunkt var AOFAS ankel-bakfot skala. Sekundære endepunkter var MOxFQ, OMA score, Eq5d index og VAS, VAS for smerte, bevegelsesutslag, avstand i syndesmosen, ankelartrose og tibiofibular synostose.

Artikkel III presenterer en biomekanisk studie som inkluderer 20 ankelkadavre hvor det ble lagd en fraktur i bakre malleol (25% eller 50%) med syndesmoseskade. Disse ble testet med en robot-arm med 6 frihetsgrader. Fire biomekaniske tester (utadrotasjon, innadrotasjon, bakre skuffetest, lateral skuffetest) ble gjort i 7 stadier: 1) Intakt, 2) syndesmoseskade med bakre malleolfraktur, 3) syndesmosefiksasjon med SB, 4) syndesmosefiksasjon med SB + fremre syndesmosefiksasjon, 5) syndesmosefiksasjon med SB + fremre syndesmosefiksasjon + skruefiksasjon av bakre malleol, 6) skruefiksasjon av bakre malleol + fremre syndesmosefiksasjon, 7) skruefiksasjon av bakre malleol. Et kamerasystem ble brukt for å registrere forholdet mellom fibula, tibia, og talus.

Resultater

I artikkel 1 var median AOFAS score 90 (IQR: 82-100) etter naglefiksasjon og 95 (IQR: 87–100) etter platefiksasjon (p = .478) etter 24 måneder. Disse resultatene var ekvivalente. Antallet komplikasjoner og reoperasjoner var høyere etter nagle- enn platefiksasjon (p = .024, p = .028, respektivt). Ingen andre forskjeller ble funnet mellom gruppene.

I artikkel II var median AOFAS score 97 etter både SB og trikortikal skruefiksasjon etter 24 måneder (IQR SB: 87-100, IQR trikortikal skrue: 90-100, p = .7) og gjennomsnittlige scorer var ekvivalente. Det var ingen signifikant forskjell i avstand i syndesmosen, og antallet pasienter med dårlig reposisjon var sammenlignbart (SB: 35%, trikortikal skrue: 22%). Det var ingen forskjell i antallet komplikasjoner eller reoperasjoner.

I artikkel III var det best stabilitet av fibula og ankelleddet ved utadrotasjon dersom det var gjort skruefiksasjon av bakre malleol og fremre syndesmosefiksasjon. Ved innadrotasjon var fibula og ankelleddet stabilisert ved alle fiksasjoner som inkluderte skruefiksasjon av bakre malleol. Bakre og lateral skuffetest resulterte kun i små forskjeller mellom intakt og skadet stadium. Det var ingen forskjell i effekten av behandlingen mellom 25% og 50% fragment.

Konklusjoner

Det funksjonelle resultatet etter nagle- og platefiksasjon var ekvivalent, men antallet komplikasjoner og reoperasjoner var høyere etter naglefiksasjon. Platefiksasjon bør være førstevalget ved behandling av akutte ustabile ankelfrakturer hos eldre pasienter generelt.

Det funksjonelle resultatet etter SB- og trikortikal skruefiksasjon var ekvivalent, og det var ingen forskjell i avstand i syndesmosen. Trikortikal skrue er et billigere alternativ enn SB ved behandling av akutte syndesmoseskader.

Skruefiksasjon av bakre malleol i tillegg til fremre syndesmosefiksasjon bør være den foretrukne operasjonsmetoden når man behandler pasienter med akutt ankelskade som involverer en ustabil syndesmose og en fraktur i bakre malleol som er 25% eller større.

ARTICLES IN THE THESIS

Paper I

Higher Complication Rate After Nail Compared to Plate Fixation of Ankle Fractures in Patients 60 Years or Older. A Prospective, Randomized Controlled Trial.
Stake IK, Ræder BW, Gregersen MG, Molund M, Wang J, Madsen JE, Husebye EE.
Bone Joint J. 2023 Jan;105-B(1):72-81.

Paper II

Randomized trial comparing suture button with single 3.5 mm syndesmotic screw for ankle syndesmosis injury: similar results at 2 years.
Ræder BW, Stake IK, Madsen JE, Frihagen F, Jacobsen SB, Andersen MR, Figved W.
Acta Orthop. 2020 Sep;1–6.

Paper III

The Impact of Posterior Malleolar Fixation on Syndesmotic Stability.
Stake IK, Bryniarski AR, Brady AW, Miles JW, Dornan GJ, Madsen JE, Haytmanek Jr. CT, Husebye EE, Clanton TO.
Accepted by The American Journal of Sports Medicine.

INTRODUCTION

Epidemiology

In recent years, the incidence of ankle fractures has shown an increasing trend, and possible explanations are higher life expectancy and a more physically active population (1, 2). Additionally, a higher number of multiple fractures is seen with higher age (1). As a result, an increased burden on the health care system with more financial and logistical challenges may be expected (2).

A Swedish registry study from 2020 reported that ankle fractures constitute about 10% of all fractures, with an incidence of 126.6 per 100,000 person-years (3). In this study, the mean age was 52.8 years with a higher incidence with increasing age starting from 40 years of age (3). In elderly patients, ankle fractures represent the fourth most common extremity fracture (1). The distribution demonstrates age-gender dependency, where females account for the highest proportion of patients after 40 years of age, which can be explained by an increased predisposition due to age-related osteoporosis (2, 4, 5). Traditionally, about 43% to 56% of all ankle fractures have been treated surgically (6, 7).

A posterior malleolar fracture (PMF) has been reported in 7% to 44 % of ankle fractures (8, 9). A proximal fibula fracture with syndesmosis injury has been reported in 12% to 37% of surgically treated ankle fractures (10-12). Both a PMF and a syndesmosis injury are associated with poorer functional outcome and earlier development of osteoarthritis (OA) (13, 14).

Isolated PMFs and syndesmosis injuries, so called high ankle sprains, will not be elaborated in this thesis.

Anatomy

The ankle joint, also called the tibiotalar joint, sustains loads of almost 4 times the bodyweight during normal physiological weightbearing (15), with 77% to 90% transferred through the tibial plafond and the remainder through the medial and lateral talar facets (16). The lateral, medial, and posterior malleolus constitute the bony stabilizers of the joint and act to constrain the talus within the mortise (17). The lateral collateral ligaments, the medial collateral ligaments, and the syndesmotic ligaments constitute the ligamentous stabilizers of the ankle joint.

The lateral collateral ligaments consist of the anterior talofibular ligament (ATFL), calcaneofibular ligament (CFL), and posterior talofibular ligament (PTFL) (Figure 1a and 1b) (18). Four superficial (tibionavicular, tibiospring, tibiocalcaneal, and superficial posterior tibiotalar ligaments) and 2 deep components (anterior and posterior talotibial ligaments (ATTL and PTTL)) constitute the medial collateral ligament, or the deltoid ligament (Figure 1c) (19). The superficial layer spans from the medial malleolus and crosses both the ankle and subtalar joint, and the deep layer from the medial malleolus and across the ankle joint only. The syndesmotic ligaments connect the distal tibia and fibula and consist of the anterior inferior tibiofibular ligament (AITFL), the interosseous tibiofibular ligament (ITFL), and the posterior inferior tibiofibular ligament (PITFL) including superficial and deep components (Figure 1a and 1b) (20). The AITFL attaches at the anterior border of the fibula (Le Fort, Wagstaffe) and runs proximally in a trapezoidal shape to attach at the anterolateral tibial tubercle (Tillaux-Chaput). The ITFL is a pyramidal shaped distal extension of the interosseous membrane. The interosseous membrane starts at about 5 cm proximal to the ankle joint and maintains the tibiofibular relationship all the way to the proximal tibiofibular joint. Like the AITFL, the superficial fibers of the PITFL have a trapezoidal shape. It has a broad attachment to the posterior malleolus (Volkmann) and a narrower attachment to the fibular tubercle. The deep fibers of the PITFL, the transverse tibiofibular ligament (TTFL), runs parallel to the distal margin of the superficial fibers to attach to the fibula.

Biomechanics

The ankle joint functions as a hinge joint where the primary movement is dorsiflexion and plantarflexion (21). The axis of rotation, the bimalleolar axis, is slightly oblique with about 8 degrees angle in the coronal plane and 6 degrees angle in the axial plane. Additionally, the cone-shaped talar dome is wider anteriorly and laterally. Both the axis of rotation and the shape of the talus result in a few degrees external rotation during dorsiflexion and internal rotation during plantarflexion (22, 23). Clinically, the normal range of motion (ROM) of the ankle is a combined motion at the ankle, subtalar, and talocalcaneonavicular joints, which

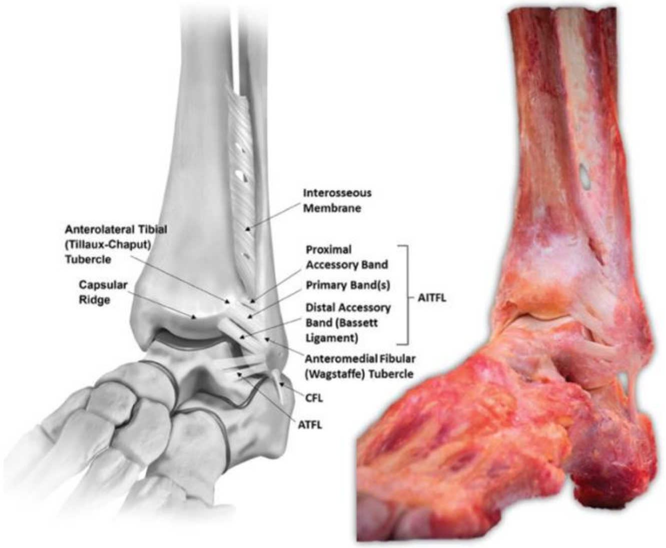


Figure 1a. Anterolateral view of a left foot and ankle in neutral plantar flexion and dorsiflexion depicting the anatomic sites of attachment and course of the anterior inferior tibiofibular ligament (AITFL). The capsular ridge is defined as the ridge along the anterior tibia coincident with the superior attachment of the anterior joint capsule. ATFL, anterior talofibular ligament; CFL, calcaneofibular ligament. Figure by Williams et al., The American Journal of Sports Medicine 2014 (20).

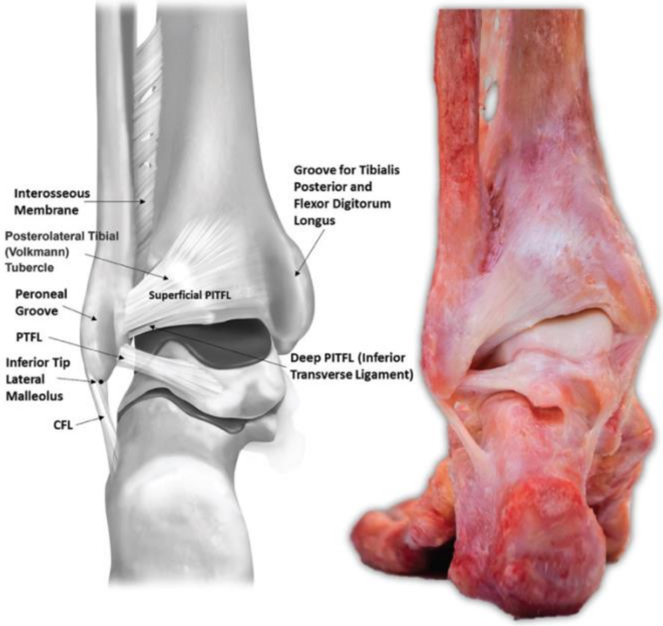


Figure 1b. Posterior view of a left foot and ankle in neutral plantar flexion and dorsiflexion diagramming the anatomic sites of attachment and course of the posterior inferior tibiofibular ligament (PITFL). CFL, calcaneofibular ligament; PTFL, posterior talofibular ligament. Figure by Williams et al., The American Journal of Sports Medicine 2014 (20).

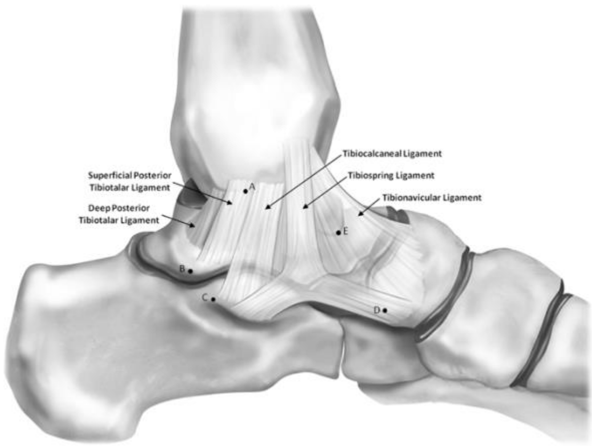


Figure 1c. Illustration of the medial view of a left ankle showing the anatomical attachment sites of the ligamentous bands of the deltoid ligament and their spatial relationships to surgically relevant osseous landmarks: (A) distal center of the intercollicular groove, (B) posteromedial talar tubercle, (C) posterior point of the sustenaculum tali, (D) tuberosity of the navicular, and (E) anteromedial corner of the trochlea. Figure by Campbell et al., Journal of Bone and Joint Surgery 2014 (19). Reprinted with permission.

results in motions in the sagittal (dorsiflexion/plantarflexion), coronal (inversion/eversion) and axial (abduction/adduction) planes, in addition to multiplanar (pronation/supination) motions (24). The motion in the sagittal plane occurs mainly at the ankle joint and is approximately 20 degrees of dorsiflexion and 40 to 50 degrees of plantarflexion (25). Only about 30 degrees of ROM in the sagittal plane is required for walking (24). The motions are restricted by the medial and lateral collateral ligaments as well as the syndesmotic ligaments.

The lateral collateral ligaments provide stability to the lateral side of the ankle joint and resists varus stress of the foot (24, 26). Additionally, the ATFL resists plantarflexion and internal rotation and the PTFL resists dorsiflexion and external rotation of talus in relation to tibia.

The deltoid ligament is stronger than the lateral collateral ligaments (27, 28), and is considered the most important component of ankle stability (29). Both the superficial and deep layer help maintain talus alignment by limiting anterior and lateral translation of talus in relation to tibia (30). Additionally, the superficial layer resists valgus stress and external rotation (30, 31). The deep layer mainly resists external rotation as well as plantarflexion. The PTTL is considered the strongest ligament (28). This ligament is tight when the foot is in neutral position as during weightbearing. In plantarflexed position, the PTTL is loose. These characteristics of the deltoid ligament have important implications for the classification and treatment of ankle fractures.

The syndesmotic ligaments play an important role for ankle stability by maintaining the integrity of the syndesmosis and ankle joint. Additionally, the syndesmotic elasticity allows for about 1.5 mm increase in intermalleolar distance during dorsiflexion to accommodate the anteriorly wider talar dome (22), resulting in lateral translation, posterior translation, and external rotation of the fibula in relation to the tibia (23, 32, 33). Biomechanical studies have tested the contribution of the individual ligaments to syndesmotic stability. Following sequential cutting of the syndesmotic ligaments, Ogilvie-Harris et al. found that the contribution to resist syndesmotic diastasis was 36% for the AITFL, 33% for the deep PITFL, 22% for the ITFL, and 9% for the superficial PITFL (34). Furthermore, the AITFL and superficial PITFL have shown to provide the strongest resistance to external and internal rotation of the foot, respectively (35). Syndesmosis injury results in significant increases in sagittal translation and rotation of the fibula (35), but the deltoid ligament has demonstrated important contributions to syndesmotic stability (36-39). Significant syndesmotic instability has been reported with lateral stress after the AITFL, ITFL, and deltoid ligament were cut (37). This instability was not present after the AITFL and ITFL were cut isolated (39). Another study found significantly increased posterior fibular translation and tibiotalar contact pressure with axial load and external rotation when the ITFL was cut in addition to the AITFL and anterior deltoid ligament (40). Although the magnitude of syndesmotic stability needed to maintain ankle stability is not known, these biomechanical studies suggest that careful restoration of syndesmotic integrity is essential to maintain normal ankle kinematics.

Mechanism of Injury and Classification

Ankle fractures are fractures of one or more of the malleoli. Ankle fractures are commonly caused by a low energy trauma when the body rotates on a planted foot (17). The most frequently reported mechanism of injury is fall from standing height; however, about 20% of the fractures are related to sports which is more common in males and in patients younger than 20 years (1, 4).

Several classifications are used to describe ankle fractures, including descriptive, causative, and stability-based classifications. Two descriptive classification systems are frequently used in clinical practice. The Danis-Weber classification divides ankle fractures based on the level of the fibula fracture relative to the syndesmosis (41). Weber A fractures are fractures distal to the syndesmosis and result in intact syndesmosis, Weber B fractures are at the level of the syndesmosis and may or may not have concomitant syndesmosis injury, and Weber C fractures are proximal to the syndesmosis and have concomitant ruptured syndesmotic ligaments. This classification has demonstrated good interobserver agreement (42, 43); however, the level of fibula fracture is not consistently predictive of syndesmosis injury and the medial side of the ankle is not considered (44, 45). Therefore, this classification cannot guide treatment (29). The modified Broos and Bisschop system divides ankle fractures into uni-, bi-, or trimalleolar ankle fractures according to the number of malleoli fractured (46). Although the presence of syndesmotic and collateral ligament injury is ignored, the classification has shown to predict stability and therefore, can guide treatment (29, 47). Unimalleolar fractures represent about 70%, bimalleolar 20%, and trimalleolar 10% of all ankle fractures (4). Another descriptive classification is the American Orthopaedic Association /

Orthopaedic Trauma Association (AO/OTA) classification (48). This classification categorizes ankle fractures into 3 groups with subtypes, and additionally, includes injury to the medial and posterior side of the ankle. It is frequently used for documentation and research purposes, but is comprehensive for clinical practice and has limited intra- and interobserver reliability (43). The distribution of ankle fractures has been reported to be 24% type A, 66% type B, and 10% type C fractures (4).

The Lauge-Hansen classification is a causative classification that divides ankle fractures into groups based on the position of the foot, direction of the force, and degree of rotational force at the time of injury (Table 1) (49). Accordingly, 4 different fracture patterns are described: supination external rotation (SER), supination adduction (SA), pronation external rotation (PER), and pronation abduction (PAB). Some studies have reported poor reproducibility of the injury pattern (50, 51), as well as poor intra- and interobserver reliability (42, 43, 52). Nevertheless, since this classification considers medial and posterior structures, it can be used to predict ligamentous injuries as well as plan surgical treatment (53). About 70% of ankle fractures occur when the foot is supinated and 30% when the foot is pronated (27).

Supination external rotation (SER)	Stage 1: AITFL rupture Stage 2: Oblique fibula fracture at syndesmosis level Stage 3: PITFL rupture or posterior malleolar fracture Stage 4: Deltoid ligament rupture or transverse medial malleolar fracture
Supination adduction (SA)	Stage 1: Fibula fracture distal to syndesmosis level Stage 2: Vertical shear medial malleolar fracture
Pronation external rotation (PER)	Stage 1: Deltoid ligament rupture or transverse medial malleolar fracture Stage 2: AITFL rupture Stage 3: Fibula fracture proximal to syndesmosis level Stage 4: PITFL rupture or posterior malleolar fracture
Pronation abduction (PAB)	Stage 1: Deltoid ligament rupture or transverse medial malleolar fracture Stage 2: AITFL or PITFL rupture Stage 3: Transverse fibula fracture at or proximal to syndesmosis level

Table 1. The Lauge-Hansen classification with 4 different groups based on foot position and direction of force, and stages based on degree of rotational force.

The stability-based classification divides ankle fractures into 2 groups; stable and unstable ankle fractures. Unstable ankle fractures are fractures that result in displacement when physiologic forces are applied, and result in abnormal motions of the ankle joint and changed contact pressure of the talus (54, 55). Therefore, unstable ankle fractures require surgical fixation to restore stability and joint congruity. To evaluate if an ankle fracture is unstable, the ankle joint may be thought of as a ring consisting of bony and ligamentous components (27, 28). If the ring is broken at only one site, the ring remains stable. However, if the ring is broken at 2 or more sites, the ring is considered unstable and requires surgical treatment to restore the stability. Consequently, bi- and trimalleolar fractures are clearly unstable. A supra-syndesmotic fibular fracture is usually caused by a PER injury and is, according to the Lauge-Hansen classification, associated with a medial malleolar fracture or a deltoid ligament injury. Therefore, this injury is considered unstable. Similarly, a trans-syndesmotic fibular fracture, usually caused by a SER injury, may be considered unstable if the rotational force involves injury to the medial side. Although this theory can be used to guide treatment of ankle fractures, there are circumstances in which the stability may still be questionable, like when presence of a partial deltoid ligament or syndesmosis injury (29). Still, the stability-based classification has demonstrated high reproducibility and superior prognostic ability to identify patients who need surgical treatment compared to both the Weber and Lauge-Hansen classifications (29, 42).

Syndesmosis injuries may be graded from 1 to 3, depending on the degree of ligament injury (56). Grade 1 injuries are ligamentous sprains that are stable and should be treated conservatively. Grade 2 injuries are partial syndesmosis injuries that demonstrate normal radiographic findings but are unstable on stress tests. These injuries may or may not require surgery. Grade 3 injuries have complete rupture of the syndesmotic complex and demonstrate diastasis on plain radiographs. These injuries can be associated with a supra-syndesmotic fibular fracture, and they require surgical stabilization to regain stability. Concomitant deltoid ligament injury increases the risk of syndesmotic instability (57). In a retrospective study, Chan et al. reported a significant association between deep deltoid ligament injury and need for syndesmotic fixation in Weber B fractures (58). This association was not found in Weber C fractures, where syndesmotic fixation was required in 92% of the fractures. Since syndesmosis injury in Weber B fractures is found inconsistently, the decision to stabilize the syndesmosis in unstable Weber B fractures should be based on intraoperative stress testing (44, 45).

Three classifications are used to describe PMFs on computed tomography (CT) scans (Table 2). The Haraguchi classification was the first classification and is most frequently reported in the literature (59). The Bartonicek and the Mason classifications are modifications of the Haraguchi classification and includes details about the fragment morphology (60, 61). Additionally, the Mason classification combines the fragment morphology and associated injuries with the pathomechanism (61). Therefore, this classification may predict associated injuries and guide treatment. Mason type 1 fracture was described to result from a rotational force on an unloaded plantarflexed talus, type 2A from a rotational force on a loaded talus, type 2B from a continued rotational force, and type 3 from axial loading of a plantarflexed talus. Few studies have assessed the reliability of the classifications; however, better intra- and interreliability has been reported with the Bartonicek classification compared to the Haraguchi and Mason classifications (62).

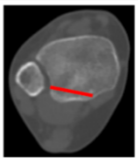
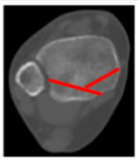
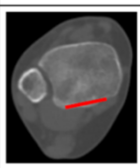
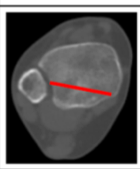
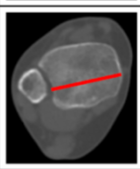
Description	Illustration	Haraguchi classification	Bartonicek classification	Mason classification
Posterolateral fragment		1	2	2a
Medial extension		2	3	2b
Extraincisural fragment		3	1	1
Large posterolateral fragment			4	
Whole posterior plafond				3

Table 2. The 3 classifications of PMFs based on morphology. The red lines represent fracture lines. CT scan from Department of radiology, Østfold Hospital Trust.

Diagnosis

The diagnosis of ankle fractures depends on a thorough medical history, clinical assessment, radiographic examination, and intraoperative testing of the ankle. The medical history provides information about comorbidities, social habits, and functional level, as well as the trauma mechanism which can be used to predict fractures, ligament ruptures, and soft tissue injuries. Initial clinical assessment includes deformities, soft tissues (swelling, blisters, wounds, closed or open fracture), and neurovascular examination. Pain on palpation suggests injury to the underlying structures. The proximal fibula should specifically be palpated to examine for fracture of the proximal third of the fibula (Maisonneuve fracture). Examination of deltoid ligament injury includes medial-sided ecchymosis, swelling, and tenderness on palpation, but none of these findings are reliable predictors of ankle instability (63, 64). Tenderness on palpation of the AITFL has been found to be significantly associated with syndesmosis injury on magnetic resonance imaging (MRI) (57, 65). Clinical stress tests for syndesmosis injury are rarely tolerated by the patient in the acute setting (66). If the patient presents with an ankle fracture dislocation, the ankle should be reduced and temporarily stabilized with a splint before radiographic examination.

Plain radiographs of the ankle (anterior, lateral, and mortise), and of the entire lower leg if a Maisonneuve fracture is suspected, is part of the initial evaluation and gives an overview of the injury. If presence of an isolated lateral malleolar fracture, the integrity of the deltoid ligament needs to be assessed to evaluate stability. When the deltoid ligament is ruptured, the talus shifts laterally and the distance between the medial malleolus and the talus, the medial clear space (MCS), increases. Traditionally, deltoid ligament injury was assessed by measuring the MCS on the initial nonweightbearing mortise view radiographs. If more than 4 mm, the fracture was considered unstable (Figure 2) (28); however, if 4 mm or less, a gravity stress test under fluoroscopy was performed (67). If the MCS on gravity stress test was more than 4 mm, the ankle was considered unstable. Other stress tests, like the external rotation stress test and valgus stress test, have also been utilized (29, 67). These stress tests for ankle stability have been criticized for overestimating the need for surgery (68-71). Recent studies have shown that isolated lateral malleolar fractures with positive stress radiographs but intact mortise on weightbearing radiographs are stable and can be treated nonsurgically with successful functional outcome, few complications, and preserved ankle congruency (68, 70-72). It has been suggested that rupture of the superficial deltoid ligament and/or ATTL results in increased MCS on gravity stress test (28). However, if the PTTL is intact, neutral foot position during weightbearing radiographs results in tightening of the PTTL and restoration of joint congruity. In other words, if the PTTL is intact, the ankle is stable. If presence of a complete rupture of the deltoid ligament, including the PTTL, the MCS will be increased on weightbearing radiographs, and the ankle should be determined unstable.

Figure 2. Initial nonweightbearing mortise view radiograph showing an ankle with a Weber B fracture and an increased MCS of more than 4 mm. Department of radiology, Østfold Hospital Trust.

Syndesmosis injury may be diagnosed on plain radiographs using measurements that include tibiofibular clear space (TCS), tibiofibular overlap (TFO), in addition to MCS (73). However, plain radiographs have been described to be inaccurate, with a pooled sensitivity of 53% and a specificity of 98% compared to arthroscopy (74). If presence of a supra-syndesmotic fibular fracture, the syndesmosis should be considered injured, and the ankle is determined unstable (Figure 3a and 3b). If presence of a trans-syndesmotic fibular fracture, the syndesmosis may or may not be injured. Therefore, if the ankle fracture requires surgical treatment based on stability assessment, the decision to surgically stabilize the syndesmosis should be based on intraoperative stress testing under fluoroscopy after the malleolar fractures have been fixed (23). The Cotton test (the hook test) has been found to be superior to the external rotation test due to greater increase in TCS (38, 75). However, fibular translation in the sagittal plane may be more sensitive for detecting syndesmosis injury (76, 77). LaMothe et al. reported higher sensitivity with lateral fluoroscopy and external rotation or sagittal stress test compared to external rotation or Cotton test with mortise view (76). Fibular sagittal translation of more than 2 mm is considered unstable (78).

Figure 3. Radiographs of a supra-syndesmotic fibular fracture with injured syndesmosis. **3a.** Anterior view radiograph of a patient's leg showing a Maisonneuve fracture. **3b.** Mortise view radiograph of the same patient's ankle showing an increased TCS and MCS (6.2 mm). Department of radiology, Østfold Hospital Trust.

A CT scan is obtained if presence of a more complex fracture or uncertainty about the fractures on plain radiographs. Specifically, radiographs may be unreliable to diagnose PMF and assess fragment size and type (79-81), and a CT scan is recommended (82).

The CT scan can provide supplementary information about the fracture pattern, size, and comminution, and is useful for decision making and preoperative planning. In a prospective study, CT scan changed the management plan in 23% of ankle fractures compared to plain radiographs, with most changes in trimalleolar fractures (83). Bilateral CT scan may be considered for assessment of syndesmosis injury by measuring the difference in syndesmotic width (84, 85); however, it cannot diagnose occult instability without weightbearing.

MRI and ultrasound scan are not routinely used in the assessment of ankle fractures today.

Surgical Treatment

The goal of treating unstable ankle fractures is to restore stability and congruity of the ankle joint, thereby improve pain and function and reduce the risk of OA in the long term (86-88). Only 1 mm lateral shift of the talus may decrease tibiotalar contact area by up to 42% and increase the risk for OA (87). Several studies have demonstrated that nonsurgical treatment of unstable ankle fractures results in a high rate of complications including loss of reduction, malunion, and nonunion (89-91). Some studies have also reported better functional outcome and lower incidence of OA after surgical compared to nonsurgical treatment (54, 91, 92). Although close contact casting has demonstrated comparable results with surgical fixation in elderly patients, the treatment is performed under general or spinal anesthesia, can be technically demanding, require close follow-up, and may result in a high rate of malunion and secondary procedures (93). Therefore, surgical fixation is still the recommended treatment for unstable ankle fractures (55).

Fibula fracture

Standard surgical treatment of lateral malleolar fractures is open reduction and internal fixation (ORIF) using plate and screws (48). A skin incision is made over the lateral malleolus. The fracture is exposed, reduced, and temporarily stabilized with reduction forceps or Kirschner wires (K-wires). One or 2 lag screws are placed across the fracture before a one-third tubular plate is placed laterally as a neutralization plate. Alternatively, a posterior antiglide plate has shown superior stability of the fixation and reduced risk of hardware irritation, without increased risk of peroneal tendon irritation (94, 95). Locking plates are often preferred when comminuted fractures or poor bone quality. Biomechanical studies have demonstrated higher stability with anatomical locking plates compared to both laterally and posteriorly placed one-third tubular plates in osteoporotic bone (96, 97). Still, no difference in clinical outcome was reported in a systematic review (98), and the increased risk of wound complications and higher costs with locking plates needs to be considered before deciding on type of plate (99).

Elderly patients have a higher risk of complications; therefore, alternative fixation techniques have been introduced (100). With the intramedullary nail fixation, a small skin incision is made distal to the tip of the fibula (101, 102). A guide wire is inserted into the diaphyseal canal, the metaphysis drilled, and the diaphysis is reamed. The nail is inserted in a slightly externally rotated position, and 1 or 2 anteroposterior (AP) cortical screws are inserted into the distal fragment. Then, the nail is internally rotated to reduce the fracture to anatomical position before insertion of 1 or 2 lateral cortical screws through the proximal fragment. Compared to plate fixation, the minimally invasive approach results in less soft tissue dissection and prominent hardware and has the potential to reduce the risk of complications. Additionally, surgery can be done despite soft tissue swelling. Biomechanical studies have reported better fixation with nail compared to plate fixation when presence of osteoporotic bone (103). Prospective, high-quality studies are needed to conclude on the effect of nail fixation in the elderly population (104).

Syndesmosis injury

Traditionally, a various number of screws with different diameter and number of cortices engaged have been used for trans-syndesmotic fixation (105). Concerns regarding syndesmotic malreduction, screw loosening or breakage, stiffness, and need for screw removal with the risk of infection and recurrent diastasis have been reported (106-108). In more recent years, suture button (SB) has been an alternative to screw fixation. This flexible device allows for a physiologic stabilization of the syndesmosis, less syndesmotic malreduction, and does not require routine removal (109, 110). Several studies have compared fixation with screws and SBs, and meta-analyses have reported better outcomes and lower rates of malreduction and implant removal with SBs (105, 111). However, large heterogeneity with variations in fracture type, number of implants, and method of implant fixation exists between the included studies. Wikeroy et al. found no differences in functional score or radiological result when one 4.5 mm quadricortical screw and two 3.5 mm tricortical screws were compared (112). However, one quadricortical screw has demonstrated inferior functional outcome and more often loss of reduction, malreduction, and presence of OA compared to SB (113-115). Concerns with SBs are insufficient stabilization of sagittal translation of the fibula, compression of the syndesmosis, fracture through the SB canal, injured saphenous vein and nerve, inadequate stabilization of fibula length, and high costs (85, 116-120). A single tricortical screw is less rigid than a quadricortical screw (116); therefore, may obviate the need for routine removal. Additionally, a tricortical screw is an inexpensive alternative to SB. A more rigid fixation, with a quadricortical screw or 2 tricortical screws or

SBs, may be considered in patients with diabetes neuropathy, osteoporotic bone, or overweight, or if presence of a Maisonneuve fracture to ensure rotational stability (23, 85, 121). Controversy exists regarding routine removal of tricortical screw and is probably unnecessary (122). Quadricortical screws are routinely removed 6 to 12 weeks after surgery (48, 123).

Syndesmotic reduction can be performed either manually or with a reduction clamp placed in the anterior third of the medial tibia (124, 125). Studies have demonstrated that the position of the foot during fixation does not impact postoperative ROM (126, 127); however, a neutral foot position is recommended by AO surgery reference (48). A K-wire can be used for temporarily stabilization (48). The quality of the reduction may be confirmed with true lateral fluoroscopy with the contralateral ankle as control (128). The comparative Anteroposterior Tibio Fibular Ratio (cAPTF) can be calculated as the absolute difference between the measured relative position of the fibula of the injured and the contralateral ankle, which has shown to discriminate between malreduced and well reduced syndesmosis injuries (128). The implant should be placed 1 to 2 cm above the joint line, parallel to the tibia plafond, angled 30 degrees from posterior to anterior (48). Open reduction through an anterolateral or lateral approach can improve anatomic reduction (129). Sagi et al. found that 15% of the patients with open reduction had malreduction compared to 44% of the patients with closed reduction of the syndesmosis (130).

<u>Posterior malleolar fractures</u>

Traditionally, the treatment of PMFs has been based on fragment size, measured on lateral radiographs as the fragment length in relation to the AP distance of the tibia. A fragment size larger than 25% to 33% has been recommended for surgical fixation (131); however, studies have failed to find a correlation between fragment size and outcome (132-134). More recent studies have suggested to fix PMFs to reduce intraarticular step (132-135), or to restore the tension of the PITFL, thereby restore syndesmotic stability and fibula alignment (136, 137). Several studies have reported a reduced need for syndesmotic fixation after the posterior malleolus has been fixed (138-140), and improved functional outcome has been found after posterior malleolar fixation compared to no fixation or syndesmotic fixation (141, 142). A recent study by Blom et al. retrospectively reviewed CT scans of surgically treated PMFs and evaluated the outcome in relation to the Haraguchi classification (143). They reported worse functional outcome after Haraguchi type 2 fractures compared to Haraguchi type 1 and 3 fractures. Additionally, they found that for Haraguchi type 1 fractures, intraarticular step-off was an independent predictor of outcome, and for Haraguchi type 3 fractures, quality of syndesmotic reduction was an independent predictor. No independent predictor of outcome was found for Haraguchi type 2 fractures. They concluded that fracture morphology should guide the treatment of PMFs.

Indirect fragment fixation with AP screws or direct fixation with posteroanterior (PA) screws or plate through the posterolateral or posteromedial approach are all alternative techniques for fixation of the posterior malleolar fragment (48, 144). Indirect fixation results in high risk of malreduction and poor fragment compression (145, 146); therefore, this technique should be limited to large fragments without impaction or intercalary fragments (144). Direct fixation through the posterolateral approach allows for direct visualization of the fracture and is suitable for small fragments, intercalary fragments, or comminution (144). However, the sural nerve is at risk of being injured with this approach (147). The posteromedial approach may be preferred if medial extension of the PMF (144). Both PA screws and plate fixation have shown acceptable results (148).

Postoperative Treatment

Early postoperative weightbearing has shown to improve early ankle ROM, functional outcome, and return to preinjury activities with no increase in complication rate, even though concerns with wound complications, construct failure, and union have been reported (149-151). Still, a recent systematic review reported an increased risk of postoperative complications with early ROM, specifically superficial wound complications (152). AO surgery reference recommend a short period with splint and ankle elevation before ROM and partial weightbearing (48). Progressive weightbearing can be commenced as tolerated. In elderly patients, poor bone quality may prevent stable fixation and comorbidities may increase the risk of construct failure (153). Therefore, nonweightbearing may be prolonged in these patients.

If presence of syndesmosis injury, partial weightbearing (20-30 kg) is recommended until the positioning screw has been removed (at 8-10 weeks) due to the risk of early screw breakage or loosening with subsequent recurrent diastasis (48). A stable PMF fixation allows for early postoperative ROM and weightbearing as tolerated (48). In a biomechanical study, no difference in fragment displacement or construct failure was found between fixed and nonfixed PMF after simulating 5 weeks of weightbearing (154).

Complications

Complications after surgically treated ankle fracture have an overall incidence of 1% to 40% (155-157), and a higher risk is seen in some patient groups. Patients with advanced age have increased risk of complications due to presence of compromised soft tissues, osteoporotic bone, and comorbidities (158, 159). A complication rate as high as 40% has been reported in elderly patients compared to 11% in younger patients (158). Accordingly, individual evaluation of each patient preoperatively is necessary before deciding on method of treatment.

Wound complications

Wound complications range from delayed wound healing, skin necrosis, and wound dehiscence to superficial and deep infection, and are the most reported complications after surgically treated ankle fracture (160). The incidence of infection ranges from 1% to 8% (90, 157, 161), with even higher rates in elderly, diabetics, and smokers (159, 162, 163). Also, obesity, alcohol overuse, atherosclerotic disease, peripheral neuropathy, wound-compromising medications, noncompliance, open fracture, trimalleolar fracture, and delayed surgery have been reported to significantly increase the risk of wound complications (157, 164-167). Plate fixation of the lateral malleolus requires a large skin incision and excessive soft tissue dissection of the skin that surrounds the distal fibula, and the prominent hardware after lateral positioning of the plate may result in wound dehiscence and subsequent infection (168). Superficial infections can be treated with wound care and oral antibiotics, while deep infections can be devastating and result in serious consequences including disabilities, amputation, and death (157, 160, 169).

Construct failure

Fracture comminution, osteoporotic bone, and poor surgical technique may predispose to malreduction or loss of reduction which may result in malunion (160, 170, 171). Furthermore, diabetic, noncompliant, and obese patients have an increased risk of loss of reduction due to premature weightbearing and high load (160, 172, 173). Malunion may result in altered biomechanics, instability, and changed load distribution with persistent pain, swelling, stiffness, and limited ankle function, and can progress to deterioration of articular cartilage and posttraumatic OA (174, 175). Adequate reduction of the syndesmosis is difficult, and the incidence of syndesmotic malreduction in the literature is 22% to 52% (106, 176, 177). Syndesmotic malreduction is associated with OA and reduced functional outcome (106, 178-180), and is the most common indication for early reoperation after ankle fracture surgery (181). Also, shortening or malrotation of the fibula results in increased contact pressure of the ankle joint and risk of OA (174, 182).

Symptomatic hardware

Hardware removal is frequently reported after ankle fracture surgery, ranging from 13% to 36% (183-186). Naumann et al. reported that 17% of patients treated for unstable ankle fracture required hardware removal (185). Of these, 84% were due to complaints and 16% due to infection. Male sex, higher age, shorter duration of surgery, and syndesmotic screws were associated with lower risk of removal due to complaints. Improvement of functional outcome has been reported after implant removal, suggesting a value in patients with symptomatic hardware during daily activities (187).

After hardware removal, a complication rate of 14% has been reported (188). After syndesmotic screw removal, infection has been reported in 5% to 9% and recurrent diastasis in 7% of the patients (108, 189).

Osteoarthritis

About 70% of patients with ankle OA have had a previous ankle injury (190). Of these, 37% to 53% have had a rotational ankle fracture (190, 191). Furthermore, 28% to 36% of patients with surgically treated ankle fracture have demonstrated advanced radiographic OA at minimum 5 years follow-up (192, 193). A recent study reported that obesity, fracture-dislocation injury, large PMF, and postoperative articular incongruence were risk factors for posttraumatic OA after surgical treatment (192). The acute injury and the posttraumatic residual incongruity and instability may lead to changes in the articular cartilage, bone, and soft tissues, and subsequently development of OA (175). Common symptoms of ankle OA are pain and stiffness, and the treatment of end stage OA is ankle arthrodesis or total ankle arthroplasty (194).

THESIS AIMS

The overall goal of this doctoral thesis was to investigate different surgical methods for treatment of acute unstable ankle fractures. This included:

Paper I

- To compare functional and radiological outcomes after nail and plate fixation of acute unstable AO/OTA type 44-B ankle fractures in elderly patients.
- To assess if nail fixation results in a reduced complication rate compared to plate fixation.

Paper II

- To compare functional and radiological outcomes after stabilization of acute AO/OTA type 44-C ankle fractures with SB and tricortical screw.
- To determine if tricortical screw fixation is an equal or better alternative to SB.

Paper III

- To determine if PMF fixation with screws can restore tibiofibular and ankle joint kinematics better than trans-syndesmotic SBs in acute ankle injuries with PMF and an unstable syndesmosis.
- To determine if AITFL augmentation using ST can improve tibiofibular and ankle joint kinematics compared to PMF and trans-syndesmotic fixation alone.
- To assess if fragment size has an impact on the preferred method of fixation.

MATERIALS AND METHODS

Paper I

Patients

In this randomized controlled trial (RCT), elderly patients with an acute unstable ankle fracture admitted to Østfold Hospital Trust, Kalnes; Vestre Viken Hospital Trust, Bærum; or Oslo University Hospital, Ullevål from June 2016 to June 2019 were considered for study inclusion. Inclusion criteria were patients 60 years or older with an acute and displaced unstable ankle fracture classified as AO/OTA type 44-B, amenable to operative fixation with both nail and plate within 3 weeks of injury. The ankle was determined unstable on plain radiographs when presence of a MCS of more than 4 mm, talar tilt of more than 2 mm, shortening of the fibula, or tibiofibular clear space of more than 5 mm. If in doubt, an increased MCS of 4 mm or more on gravity test confirmed ankle instability. The patients were included in the study in the emergency department by the orthopaedic resident on call or at the orthopaedic ward. In total, 108 patients were included (Østfold Hospital Trust: 87, Vestre Viken Hospital Trust: 12, Oslo University Hospital: 9). A web-based system for randomization was used, provided by Unit for Applied Clinical Research (Faculty of Medicine, Norwegian University of Science and Technology, Trondheim, Norway). The patients were randomized to either nail or plate fixation of the lateral malleolar fracture (Figure 4).

Intervention and comparison

Surgery was performed by the surgeons on call, either by a less experienced resident and an experienced resident / consultant, an experienced resident, or a consultant. All patients received preoperative prophylactic antibiotics as per hospital routines with either Cefalotin, Cefazolin, or Clindamycin. Postoperative thromboprophylactic treatment with Dalteparin was given as per hospital routines or as decided by the surgeon. After surgery, the patients received a short leg-splint for up to 14 days. After removal of the splint, all patients were allowed partial weightbearing until 6 weeks postoperatively and full weightbearing after 6 weeks.

Patients randomized to nail fixation were treated with the Acumed Fibular nail (Acumed Fibula Rod System, Acumed, Hillsboro, Oregon, USA) (Figure 5a) (101). The fracture was preferably

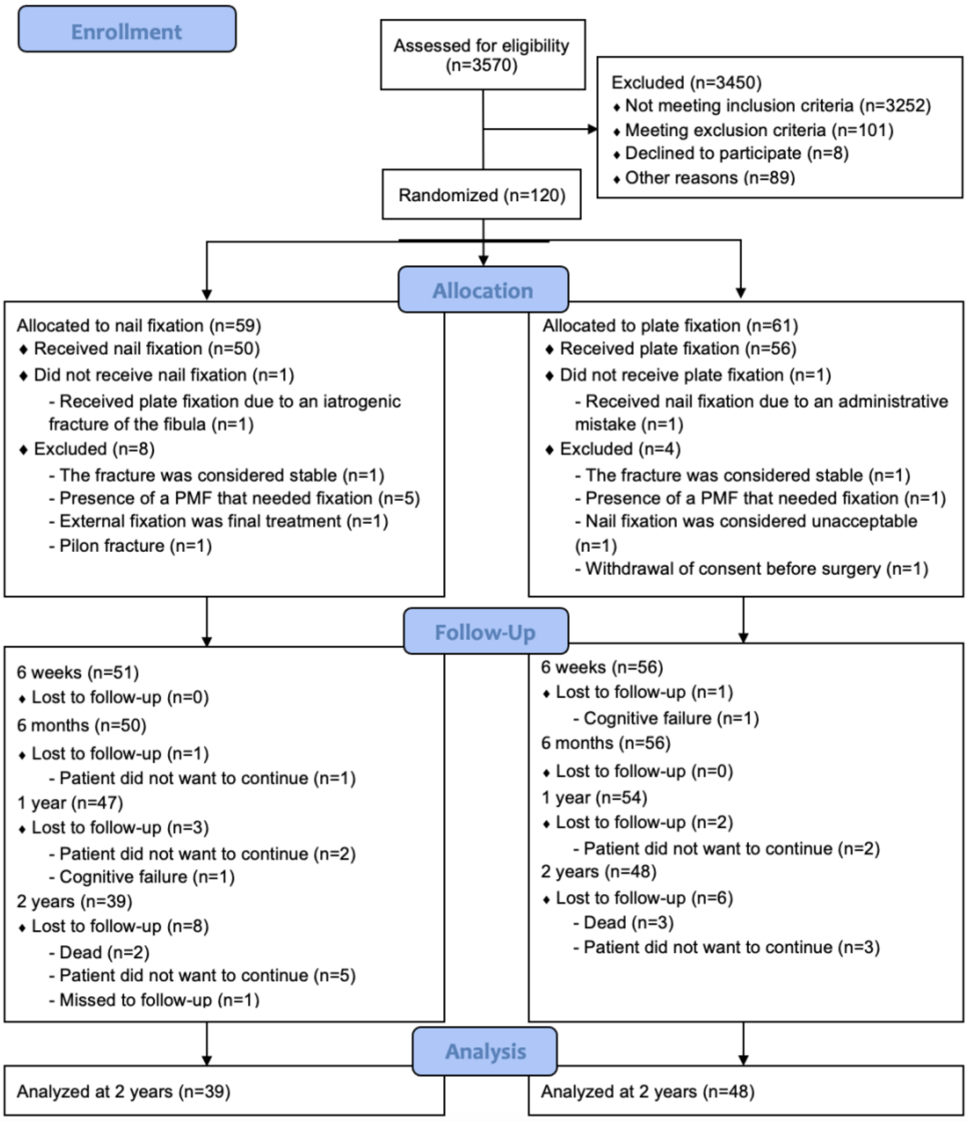


Figure 4. Consort Flow Diagram of the inclusion and follow-up process of patients treated with nail or plate fixation. Figure by Stake et al., The Bone & Joint Journal 2023 (195).

reduced with a closed technique. If acceptable reduction was not achieved, a percutaneous or open technique using forceps was performed. With this technique, the syndesmosis is stabilized regardless of syndesmosis injury. A medial malleolar fracture was treated according to the surgeon's preference.

Patients randomized to plate fixation were treated with a one-third tubular neutralization plate with or without lag screw (DePuy Synthes, West Chester, PA, USA) (Figure 5b) or a locking plate (Lateral Compression Plate (LCP) Distal Fibula Plate, DePuy Synthes, West Chester, PA, USA or Variax distal fibula plate, Stryker, Kalamazoo, MI, USA) placed laterally onto the fibula (48). When the bone quality and the fracture allowed for it, 1 or 2 lag screws were placed across the fracture before the neutralization plate was placed laterally. In cases with poor bone quality, a locking plate was utilized. A medial malleolar fracture or a syndesmosis injury was treated according to the surgeon's preference.

Figure 5. Radiographs of the two fixations for AO/OTA type 44-B ankle fractures. **5a.** Mortise view radiograph of AO/OTA type 44-B ankle fracture treated with Acumed fibular nail. **5b.** Mortise view radiograph of AO/OTA type 44-B ankle fracture treated with a one-third tubular neutralization plate with lag screw. Department of radiology, Østfold Hospital Trust.

Outcomes

The primary outcome measure was the American Orthopaedic Foot and Ankle Society (AOFAS) Ankle-Hindfoot Scale. Secondary outcome measures included Manchester-Oxford Foot Questionnaire (MOxFQ), Olerud and Molander Ankle (OMA) Scale, EuroQol-5d (Eq5d) index and visual analogue scale (VAS), VAS scores for pain, complications, fracture reduction, radiographic nonunion, and ankle OA.

The patients met for follow-ups at 6 weeks and 6, 12, and 24 months after surgery. At 6 weeks, Eq5d index and VAS was completed. At 6, 12, and 24 months, all patient-reported outcome measures (PROMs) were completed, including AOFAS Ankle-Hindfoot Scale, MOxFQ, OMA Scale, Eq5d index and VAS, and VAS scores for pain. Additionally, Eq5d index and VAS was completed preoperatively. Plain radiographs were obtained postoperatively, at 6 weeks, and at 6 months, and bilateral CT scans were obtained postoperatively and at 12 and 24 months after surgery. The CT scans were obtained standardized with the feet placed in a custom-made box that positioned the ankles in neutral dorsi-/plantarflexion and 20 degrees internal rotation.

American Orthopaedic Foot and Ankle Society (AOFAS) Ankle-Hindfoot Scale

The AOFAS Ankle-Hindfoot Scale is frequently reported after ankle fractures and is a foot and ankle-specific PROM that includes both subjective and objective questions (196, 197). It consists of the subscales pain, function, and alignment that are summarized to a score on a 100-point scale, where 100 is the best (198). The scale has been criticized for not to entirely reflect the patient outcome (199), being clinician-dependent with interobserver variability (200), and producing skewed data with ceiling effect (201). The Dutch language version was recently validated for ankle fractures (201).

Manchester-Oxford Foot Questionnaire (MOxFQ)

MOxFQ is a foot and ankle-specific PROM that includes 16 questions on the domains walking/standing, pain, and social interactions (202). Each question is scored from 0 to 4. The summarized score of maximum 64 is converted to a metric index from 0 to 100 where 0 is the best (203). MOxFQ has not been validated for ankle fractures (204).

Olerud and Molander Ankle (OMA) Scale

OMA is an ankle fracture-specific PROM that comprises 9 items regarding symptoms, function, and daily activities (205). The total score is between 0 to 100 where higher score is better. The Norwegian version was recently validated for ankle fractures and has demonstrated test-retest reliability (206).

EuroQol-5d-3L (Eq5d-3L) index and visual analogue scale (VAS)

Eq5d is a validated general outcome measure and consists of the Eq5d self-classifier and the Eq5d VAS (207). The Eq5d descriptive part comprises the 5 dimensions mobility, self-care, usual activities, pain/discomfort, and anxiety/depression, with 3 levels (3L) of response for each dimension (1 = no problems, 2 = some problems, 3 = extreme problems). The response from the 5 dimensions is combined to a 5-digit number that is converted into a summary index that can range from less than 0 (0 is equivalent to death) to 1 (perfect health), where higher score is consistent with higher health utility. For the Eq5d VAS, the patient marks on a scale from 0 (worst imaginable health state) to 100 (best imaginable health state) to indicate their health state today. Eq5d is available in Norwegian.

VAS scores for pain

For the VAS scores for pain, the patient marks on scales from 0 (best) to 10 (worst) the pain experienced during rest, during walking, at nights, and during daily activities. Additionally, the patient ticks off if the pain is caused by the ankle injury or not.

Complications

Complications related to the ankle fracture surgery included wound complications, symptomatic hardware, construct failure, nonunion, and neurologic complications. Wound complications included superficial infection, that was treated with oral antibiotics only, and deep infection, which required treatment with revision surgery in addition to intravenous antibiotics (99). Symptomatic hardware was defined as requiring removal of hardware due to local irritation or pain. Construct failure included failure of obtaining or maintaining reduction or fixation during the surgical procedure or at follow-up. If presence of pain and no signs of fracture healing on radiographs at 6 months or more postoperatively, this was classified as symptomatic nonunion (160). Neurologic complications included nerve injury or complex regional pain syndrome. In addition to the complications related to the ankle fracture surgery, thromboembolic events were recorded including deep vein thrombosis, pulmonary embolism, and cerebral venous thrombosis.

Fracture reduction

Fracture reduction was evaluated on postoperative CT scans and classified as good, fair, or poor reduction according to the criteria reported by McLennan et al. (208).

Radiographic nonunion

Radiographic nonunion was defined as no signs of fracture healing at 6 months or later after surgery (160).

Ankle osteoarthritis

OA was graded on postoperative and follow-up CT scans as no, mild, moderate, and severe OA according to the classification by Cohen et al. (209). This classification was published with a CT atlas and demonstrated high inter- and intraobserver reproducibility. Additionally, we defined advanced OA as presence of moderate or severe OA, or the requirement for ankle arthrodesis.

Statistical analysis

A priori sample size calculation was conducted. The minimally clinically important difference (MCID) of AOFAS for ankle fractures is not known (210); however, previous studies have suggested that half of the standard deviation (SD) can be used as an estimate for the MCID (211). Based on the SD of two previous studies, half of the SD was 6 (112, 113). We decided to use a MCID of 10 to also ensure a clinically significant difference. In total, 38 patients had to be included in each group to reach a power of 95% and a significance level of 5%. A total of 120 patients were included to account for loss to follow-up.

Categorical data were analyzed with chi-squared test (all cells 5 or more or contingency table larger than 2x2) or Fisher's exact test (one or more cells less than 5). Continuous data were analyzed with independent-samples t-test (normally distributed data) or Mann-Whitney U test (non-normally distributed data). Both intention-to-treat and as-treated analyses were performed. P = 0.05 was set as significance level.

Paper II

<u>Patients</u>

In this RCT, patients aged 18 to 69 years with an acute ankle fracture classified as AO/OTA type 44-C, admitted to Østfold Hospital Trust, Kalnes; Vestre Viken Hospital Trust, Bærum; or Oslo University Hospital, Ullevål from January 2016 to September 2017 were considered for study inclusion. Exclusion criteria were polytrauma, open fracture, previous fracture or OA of the same ankle, neurologic impairment of the lower limbs, or inability to consent. The patients were randomized using the same web-based system as in Paper I (Unit for Applied Clinical Research, Faculty of Medicine, Norwegian University of Science and Technology, Trondheim, Norway). In total, 113 patients were included (Oslo University Hospital: 54, Vestre Viken

Hospital Trust: 34, Østfold Hospital Trust: 25). The patients were randomized to fixation of the syndesmosis with either one SB or one tricortical screw (Figure 6).

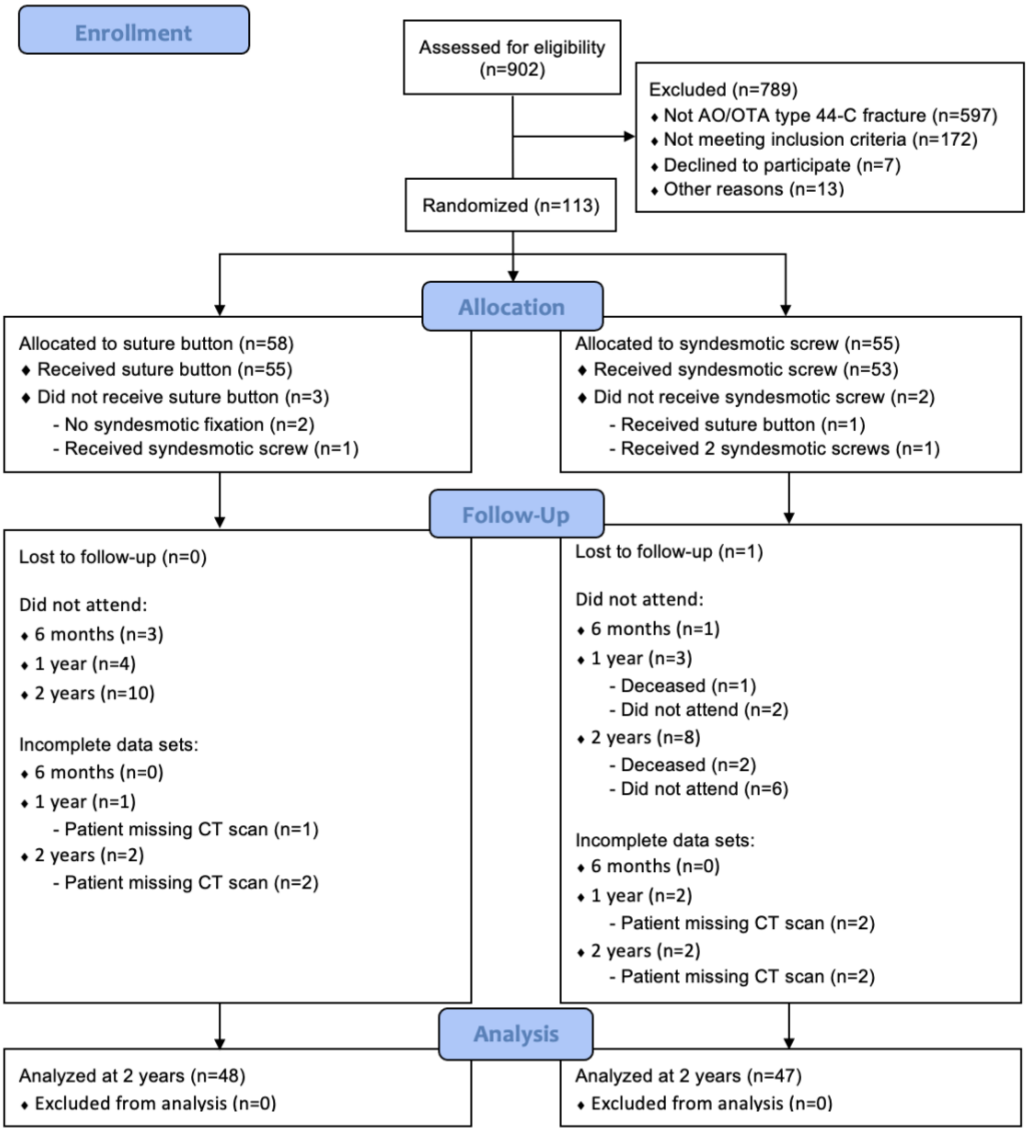


Figure 6. Consort Flow Diagram of the inclusion and follow-up process of patients treated with suture button or tricortical screw fixation. Figure by Ræder et al., Acta Orthopaedica 2020 (212), modified.

Intervention and comparison

Surgery was performed by the surgeons on call, and preoperative prophylactic antibiotics were given as per hospital routines. Fractures of the malleoli were treated with ORIF before the syndesmosis was reduced and stabilized (48). Reduction was performed closed, guided by fluoroscopy, with the use of a reduction clamp or K-wire if preferred by the surgeon. Patients randomized to tricortical screw were treated with a single, fully threaded, self-tapping 3.5 mm tricortical screw (DePuy Synthes, Warsaw, Indiana, USA) (Figure 7a). A 2.5 mm canal was drilled just proximal to the tibiofibular joint, with the ankle in neutral position, before the screw was placed. The screw was not routinely removed. Patients randomized to SB were treated with a single ZipTight^{TM} (Zimmer Biomet, Warsaw, Indiana, USA) (Figure 7b). A guidewire was inserted just proximal to the tibiofibular joint before a 3.2 mm canal was drilled. The ZipTight^{TM} was inserted with the use of the attached needle guide and pull-through sutures. The button was flipped at the medial cortex and the sutures were tightened until the button at the lateral cortex had a firm fit. Postoperative weightbearing was decided by the surgeon. All patients were allowed partial weightbearing from 2 to 6 weeks postoperatively and full weightbearing after 6 weeks. A splint and thromboprophylactic treatment were not routinely used postoperatively.

Figure 7. Radiographs of the two fixations for AO/OTA type 44-C ankle fractures. **7a.** Mortise view radiograph of AO/OTA type 44-C ankle fracture treated with tricortical screw. **7b.** Mortise view radiograph of AO/OTA type 44-C ankle fracture treated with a SB. Department of radiology, Østfold Hospital Trust.

Outcomes

The primary outcome measure was the AOFAS Ankle-Hindfoot Scale. Secondary outcome measures included MOxFQ, OMA Scale, Eq5d index and VAS, VAS scores for pain (during rest, during walking, at nights, and during daily activities), ROM, tibiofibular distance, ankle OA, and tibiofibular synostosis.

The patients met for follow-ups at 6 weeks and 6, 12, and 24 months after surgery. AOFAS Ankle-Hindfoot Scale, MOxFQ, Eq5d index and VAS, and VAS scores for pain were completed at all follow-ups. Additionally, OMA Scale was completed at 12 and 24 months. Plain radiographs were obtained postoperatively, at 6 weeks, and at 6 months, and bilateral CT scans were obtained postoperatively and at 12 and 24 months after surgery. The CT scans were obtained standardized as in Paper I.

Ankle range of motion

The injured foot was placed on a 25 cm high benchlet and the angle between the lateral margin of the foot and the longitudinal axis of the fibula was measured with a goniometer. Active dorsiflexion was measured when the ankle was loaded and dorsiflexed while the heel was still in contact with the benchlet (Figure 8a) (213). Active plantarflexion was measured when the ankle was plantarflexed while the first metatarsophalangeal joint remained in contact with the benchlet (Figure 8b). The result was compared to the contralateral ankle. The measurements were conducted unblinded at 6 weeks and 6 months, and by a physiotherapist that was blinded to the treatment allocation at 12- and 24-months follow-ups.

Figure 8. Ankle range of motion ad modum Lindsjö. **8a.** Measurement of active dorsiflexion when loaded ankle. **8b.** Measurement of active plantarflexion when the 1. Metatarsophalangeal joint remained in contact with the benchlet. Photos by LBW Ræder, thesis, University of Oslo 2021 (214). Reprinted with permission.

Tibiofibular distance

The tibiofibular distance was measured on postoperative and follow-up CT scans, at 1 cm proximal to the midpoint of the tibial plafond, at the anterior, central, and posterior portion of the joint (Figure 9). A difference of less than 2 mm between the injured and uninjured ankle was defined as acceptable syndesmotic reduction (106). The measurements were obtained by a senior musculoskeletal radiologist and an orthopaedic surgeon.

Figure 9. Axial CT scan of a left ankle at 1 cm proximal to the midpoint of the tibial plafond. The tibiofibular distance was measured anteriorly (a), centrally (b), and posteriorly (c). Department of radiology, Østfold Hospital Trust.

Ankle osteoarthritis

Presence of ankle OA was classified on CT scans according to the Kellgren-Lawrence grading system (215). This grading system is not ankle specific, but is widely used to describe ankle OA (179), and has been validated for assessment of ankle OA on weightbearing plain radiographs (216). The severity is based on the presence of osteophytes, joint space narrowing, and subchondral sclerosis. Furthermore, Kellgren-Lawrence grade 1 and 2 were defined as mild OA and Kellgren-Lawrence grade 3 and 4 as advanced OA.

Tibiofibular synostosis

Presence of tibiofibular synostosis was assessed on CT scans at 24 months follow-up and classified as no calcifications, calcifications present, or synostosis. Synostosis was defined as complete ossification connecting the tibia to the fibula.

Statistical analysis

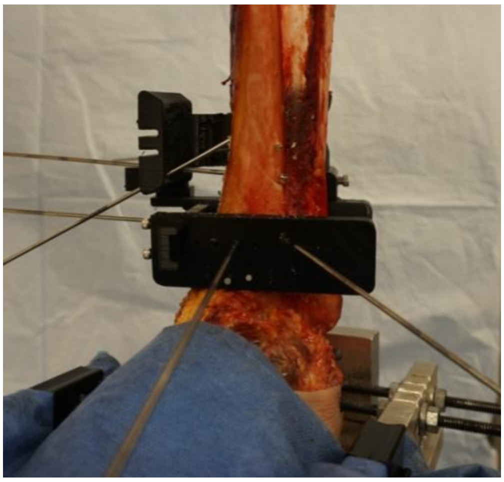
Like paper I, a priori sample size calculation was conducted with AOFAS score as the outcome measure. With MCID of 10, power of 95%, and significance level of 5%, 38 patients had to be included in each group. We included 120 patients to account for loss to follow-up.

Fishers exact test was used to compare categorical data. Normally distributed data were compared with independent-samples t-test, and non-normally distributed data were compared with Mann-Whitney U test. Both intention-to-treat and as-treated analyses were performed. P = 0.05 was set as significance level.

Paper III

<u>Specimens</u>

In this biomechanical study, 20 cadaveric lower leg specimens were included. A custom-made 3D printed cutting guide was used to create standardized PMFs (Figure 10a and 10b). The PMFs involved either 25% or 50% of the AP distance of the tibia at the level of the tibial plafond (Figure 11). Additionally, the distal 5 cm of the syndesmosis was cut to create syndesmotic instability. This injury simulated a Weber C fracture with syndesmosis injury. The fibula and medial side of the ankle was left intact to simulate perfectly fixed fracture and ideally ligament repair, respectively.



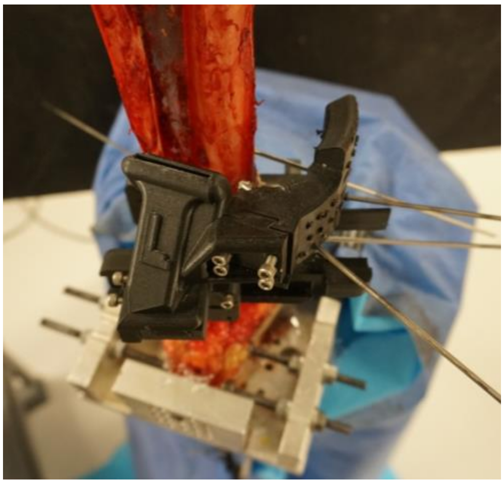


Figure 10. The custom-made 3D printed cutting guide fixed to a cadaveric lower leg specimen to create standardized PMFs. **10a.** Anterior view. **10b.** Posterior superior view. Photos by IK Stake.

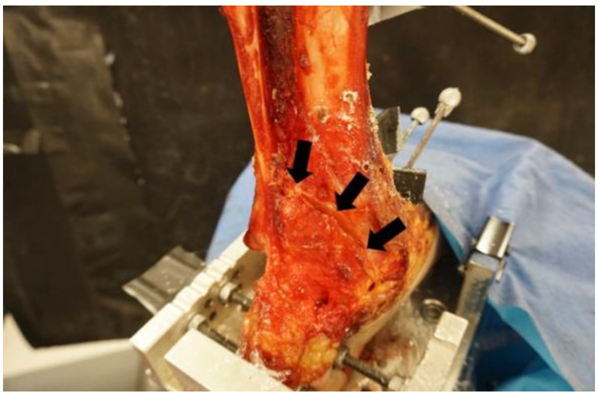


Figure 11. Posterior view of a specimen after creation of a 25% PMF. The black arrows demonstrate the fracture line. Photo by IK Stake.

Intervention and comparison

The ankle injury was treated as demonstrated in Figure 12; thereby, all specimens had fixation with all the various combinations of surgical techniques.

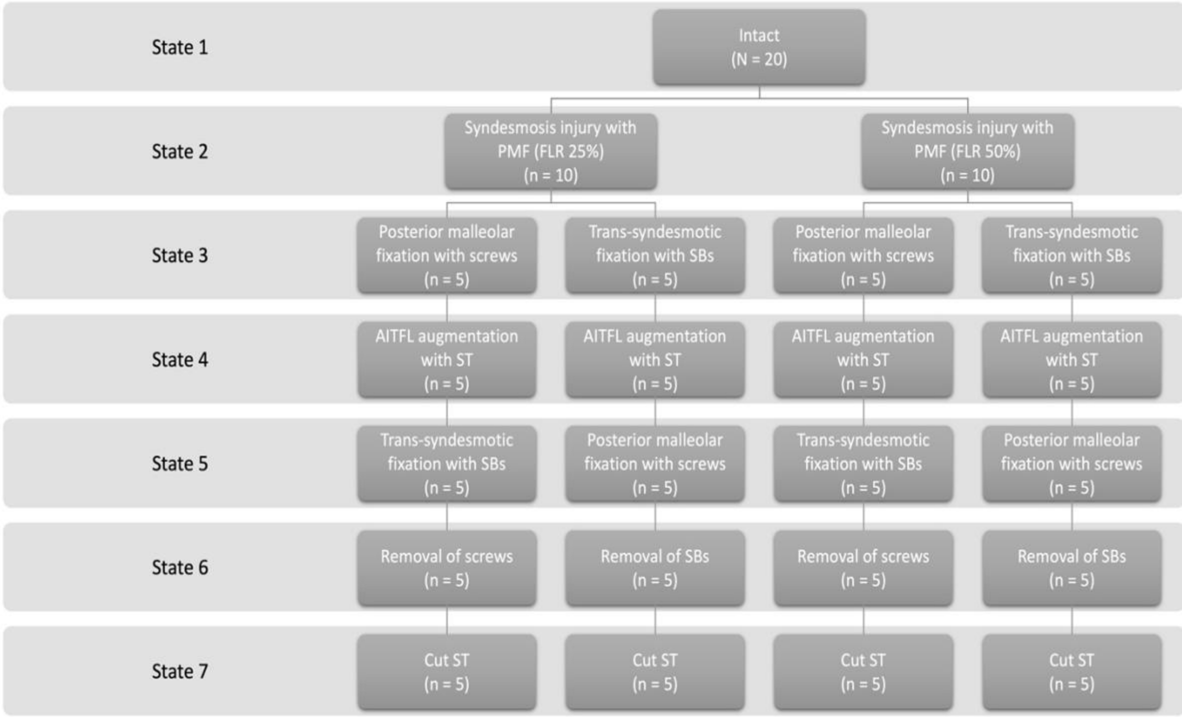
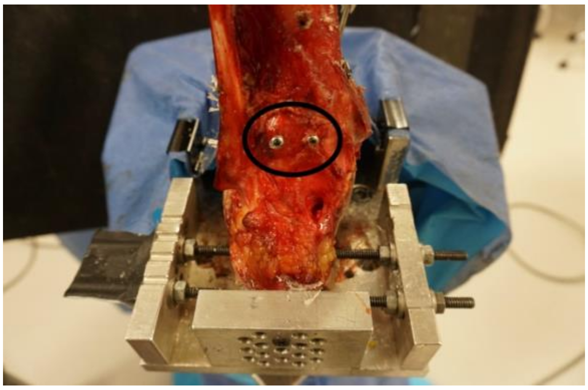


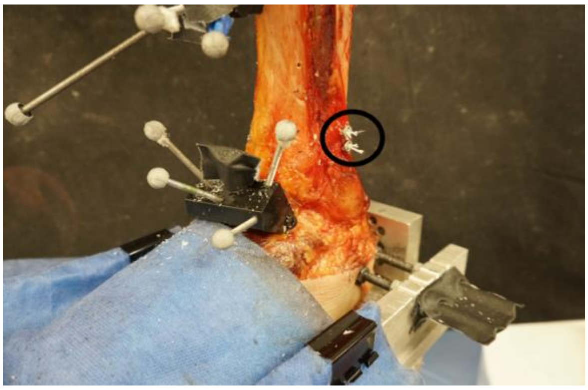
Figure 12. The flowchart demonstrates the steps that were made to achieve the 7 test states.

The posterior malleolar fragment was reduced and temporarily fixed using two 1.6 mm K-wires inserted from posterior to anterior, perpendicular to the fracture plane (48). The screw holes were drilled with a 2.6 mm cannulated drill bit and the K-wires were removed. The fragment was finally stabilized with 2 partially threaded 4.0 mm cannulated screws inserted form posterior to anterior (Figure 13a).

Trans-syndesmotic fixation with 2 SBs (TightRope®, Arthrex Inc., Naples, FL, USA) was performed using a goniometer for verification. The first SB tunnel was drilled parallel and 2 cm proximal to the tibial plafond, at 30 degrees angle anteriorly to the coronal plane. The second SB tunnel was drilled 1 cm proximal to the first, at 15 degrees angle posteriorly to the first tunnel. The syndesmosis was manually reduced before the SBs were inserted and appropriately tensioned (Figure 13b).

The two surgical techniques were also compared with AITFL augmentation using suture tape (ST) (*Internal*Brace™, Arthrex Inc., Naples, FL, USA). The first anchor hole was drilled at Chaput's tubercle, angled slightly cephalad and medially. The second anchor hole was drilled as a tunnel through the fibula, at the Wagstaffe's tubercle, horizontally and parallel to the long axis of the fibula. The holes were tapped before insertion of 4.75-mm and 3.5 mm suture anchors (SwiveLock®, Arthrex Inc., Naples, FL, USA) loaded with ST (FiberTape®, Arthrex Inc., Naples, FL, USA) (Figure 13c).





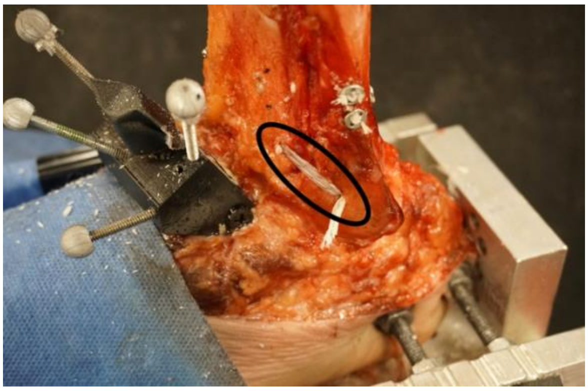


Figure 13. The figures demonstrate the different methods of fixations, highlighted with black circles. **13a.** PMF fixation with 2 PA screws. **13b.** Trans-syndesmotic fixation with 2 SBs. **13c.** AITFL augmentation using ST. Photos by IK Stake.

<u>Outcomes</u>

3D-printed reflective marker clusters were drilled into the fibula, tibia, and talus, and the relationship between the marker clusters was continuously recorded using a system of 5 Miqus motion capture cameras (Qualysis AB, Göteborg, Sweden). The specimens were tested in 7 states using a 6-degrees of freedom robotic arm: 1) Intact, 2) syndesmosis injury with PMF, 3) trans-syndesmotic SBs, 4) trans-syndesmotic SBs + AITFL augmentation, 5) trans-syndesmotic SBs + AITFL augmentation + posterior malleolar screws, 6) posterior malleolar screws + AITFL augmentation, 7) posterior malleolar screws. The tests included external rotation, internal rotation, posterior drawer, and lateral drawer, at both neutral and 30 degrees of plantarflexed position of the foot. Sagittal translation, rotation, and coronal translation of the fibula in relation to the tibia were recorded. Additionally, talar motion in relation to the tibia was recorded.

Statistical analysis

A priori sample size calculation was conducted. An effect size of Cohen's d = 1.0 is comparable to effect sizes reported in previous biomechanical literature (116, 217). With an effect size of 1.0, statistical power of 80%, and significance level of 0.05, 10 specimens had to be included. We included 20 specimens, with 10 specimens with 25% PMF and 10 specimens with 50% PMF.

Separate random-intercepts linear mixed-effects models were used to compare the 7 states. This was done for each combination of PMF size, biomechanical test, and measurement type. The final model had the smallest Bayesian Information Criterion and acceptable residual diagnostics. The data were reported as estimated marginal means. Tukey's method was used to make all pairwise comparisons. P = 0.05 was set as significance level.

RESULTS

Paper I

At 6 months follow-up, statistically significantly better median AOFAS and MOxFQ score was found in the plate group (AOFAS: nail: 83 (IQR: 71-95), plate: 90 (IQR: 82-97), p = .023; MOxFQ: nail: 14 (IQR: 5-41), plate: 9 (IQR: 3-23), p = .046); however, this difference was not clinically significant (Figure 14a and 14b). At 12- and 24-months follow-up, no difference in median AOFAS score was found statistically (p = .112, p = .478, respectively), and at 24 months, the fixations were equivalent since the 95% CI of the mean was within the equivalence margins (Figure 15). Similarly, no significant difference was found in median MOxFQ or OMA score at 24 months follow-up (p = .392, p = .134, respectively).

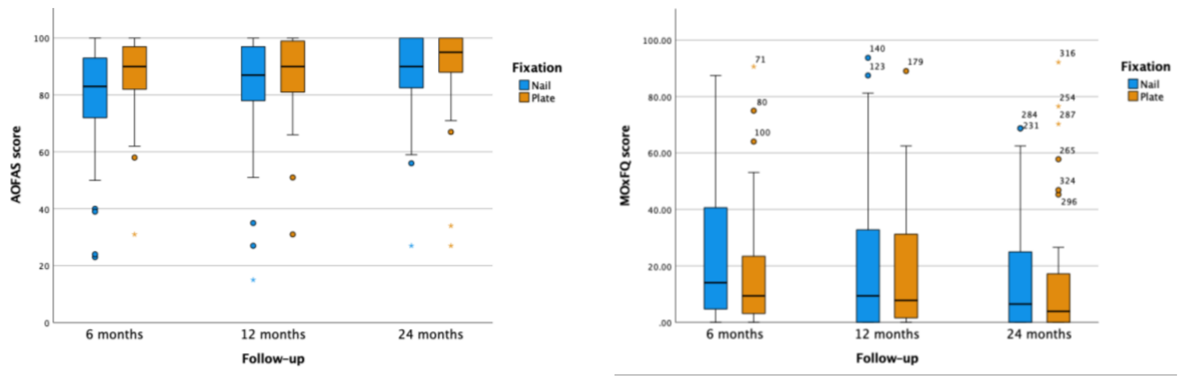


Figure 14. Boxplots of AOFAS and MOxFQ score after nail and plate fixation of AO/OTA type 44-B ankle fractures. **14a.** Boxplot of AOFAS score at 6-, 12-, and 24-months follow-up. **14b.** Boxplot of MOxFQ score at 6-, 12-, and 24-months follow-up. The boxes represent the scores within the IQR and the black line represent the median score. The whiskers represent the outliers within 1.5 times the IQR, and the dots represent the extreme outliers.

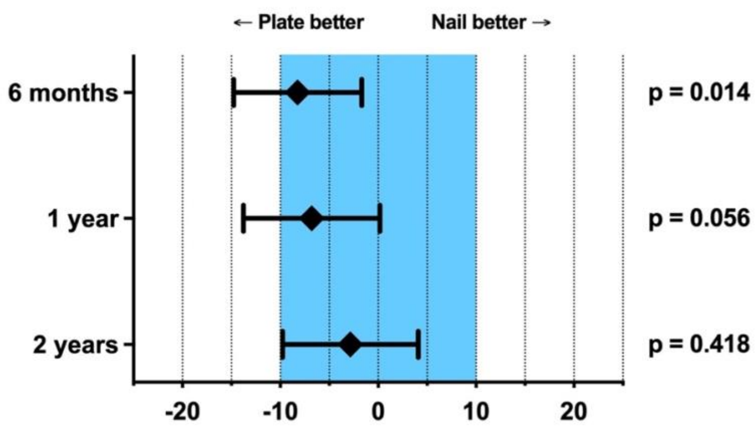


Figure 15. Equivalence diagram of the AOFAS score showing the mean differences between the groups. Error bars indicate 95% CI of the mean. The blue area indicates the margins of equivalence defined as a difference of plus/minus ten points. At 6 months, plate fixation was statistically better as the entire 95% CI of the mean lies to the left of zero. At one year, there was no statistical difference and no equivalence. At 2 years, there is no statistical difference, and the treatments were equivalent as the entire 95% CI of the mean lies within the blue area. Figure by Stake et al., The Bone & Joint Journal 2023 (195).

Interestingly, a higher number of lateral-sided complications was seen after nail compared to plate fixation, with 14 (27%) complications in the nail and 6 (11%) complications in the plate group (p = .024). The number of construct failures was also significantly different (p = .047). Furthermore, a higher number of secondary surgical procedures was seen in the nail group (nail: 12 (24%), plate: 4 (7%), p = .028). No significant difference was found in presence of advanced OA at 24 months follow-up (p = .973).

Paper II

At 24 months follow-up, median AOFAS score after both SB and tricortical screw fixation was 97 (IQR SB: 87-100, IQR tricortical screw: 90-100, p = .7) (Figure 16). When comparing the groups, the results were equivalent with a difference in mean AOFAS score of less than 2 and the 95% CI of the mean within the equivalence margins at all follow-ups (Figure 17). The difference in median MOxFQ and OMA score were also not statistically significant (p = .2 for both comparisons). The ankle ROM was similar between the groups.

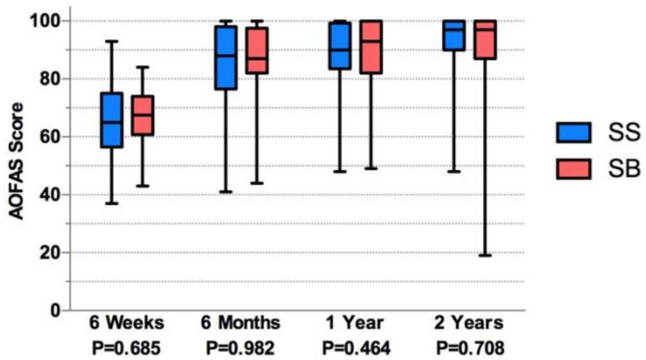


Figure 16. Boxplot of AOFAS score at 6-, 12-, and 24-months after SB and tricortical screw fixation. The boxes represent the scores within the IQR and the black line represent the median score. The whiskers represent the minimum and maximum recorded score. SS = tricortical screw, SB = suture button. Figure by LBW Ræder, thesis, University of Oslo 2021 (214). Reprinted with permission.

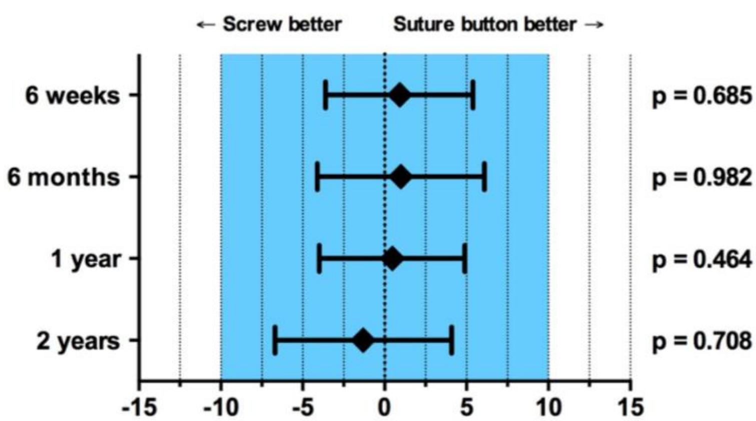


Figure 17. Equivalence diagram of the AOFAS score showing the mean differences between the groups. Error bars indicate 95% CI of the mean. The blue area indicates the margins of equivalence defined as a difference of plus/minus ten points. Results at all follow-ups are equivalent as the entire 95% CI of the mean lies within the blue area. Figure by LBW Ræder, thesis, University of Oslo 2021 (214). Reprinted with permission.

At 24 months, the mean difference in tibiofibular distance was 1 mm or less at the anterior, central, and posterior portion of the joint in both groups. Additionally, the groups had similar rates of malreduction, with 19 (35%) patients in the SB group and 16 (29%) patients in the tricortical screw group with a difference in anterior tibiofibular distance of 2 mm or more (RR 1.2, CI 0.7-2.1). Radiological signs of ankle OA were seen in 30 patients in the SB group and 27 patients in the tricortical screw group, which was not statistically different (RR 1.1, CI 0.7-1.7). Eight patients in the SB group and 1 patient in the tricortical screw group had advanced OA (RR 8, CI 1-60).

Interestingly, 2 patients suffered a low-energy fracture of the tibia through the SB canal during the follow-up period. Both these patients were females that were diagnosed with osteoporosis on dual energy X-ray absorptiometry. Five patients in the tricortical screw group had tibiofibular synostosis. There was no difference in the number of complications or reoperations between the two groups.

Paper III

External rotation test: All states with ST significantly reduced posterior translation of the fibula towards normal and were not significantly different from the intact state (screws + ST: 1.3 mm, p = .446; SBs + ST: 1.6 mm, p = .159; screws + ST + SBs: 0.9 mm, p = .817). Furthermore, screws + ST and screws + ST + SBs significantly reduced external rotation of the fibula and talus towards normal and were not significantly different from the intact state (screws + ST: 1.2 degrees, p = .407; screws + ST + SBs: 1.7 degrees, p = .096) (Figure 18a). Comparable results were found with neutral and 30 degrees of plantarflexed foot position, and with 25% and 50% PMFs.

Internal rotation test: All states with screws were significantly different from the injured state and comparable to the intact state with anterior translation of the fibula (screws only: 0.1 mm, p = .996; screws + ST: 0.0 mm, p =1.000; screws + ST + SBs: 0.0 mm, p =1.000), internal rotation of the fibula (screws only: 0.3 degrees, p = .725; screws + ST: 0.4 degrees, p = .655; screws + ST + SBs: 0.7 degrees, p = .113), and internal rotation of the talus (screws only: 0.2 degrees, p = .954; screws + ST: 0.2 degrees, p = .962; screws + ST + SBs: 0.3 degrees, p = .925). States with

SBs tended to translate the fibula medially compared to the intact (SBs only: 0.3 mm, p = .005; screws + ST + SBs: 0.4 mm, p <.001) and cut (SBs only: 0.3 mm, p = .003; screws + ST + SBs: 0.4 mm, p <.001) states (Figure 18b). Comparable results were found with neutral and 30 degrees of plantarflexed foot position, and with 25% and 50% PMFs.

Posterior and lateral drawer tests: Smaller differences were seen between the states.

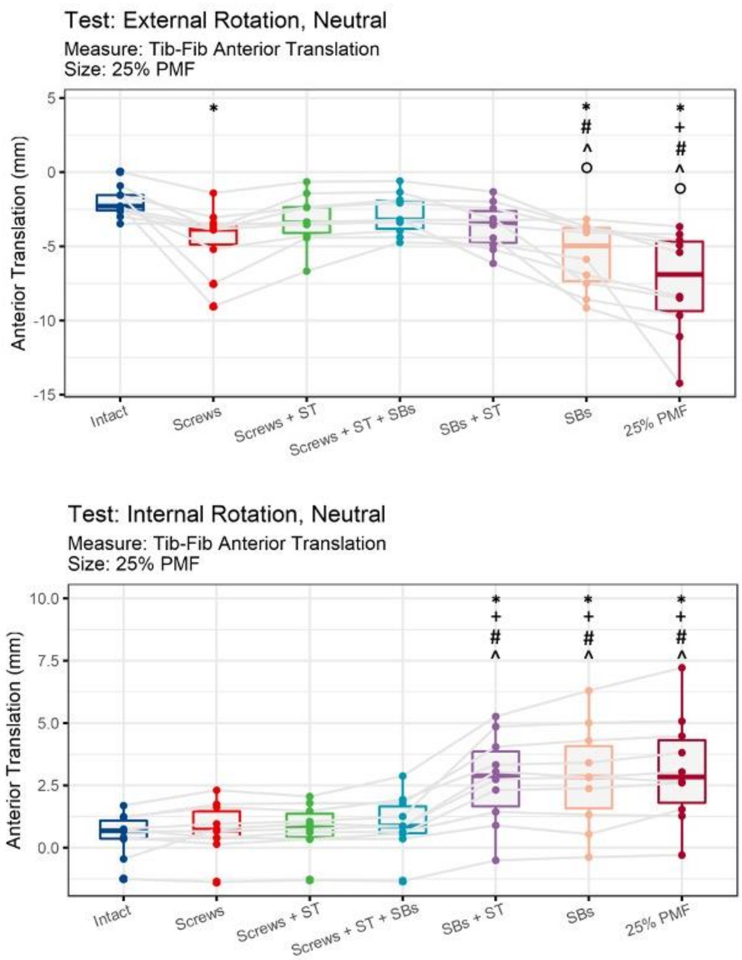


Figure 18. Boxplots of fibular translation in relation to the tibia with testing in intact, various methods of fixed, and injured state. **18a.** Boxplot of the anterior translation of the fibula in relation to the tibia during the external rotation test with neutral ankle orientation and 25% PMF. **18b.** Boxplot of the anterior translation of the fibula in relation to the tibia during the internal rotation test with neutral ankle orientation and 25% PMF.

* Sig. diff. compared to intact

+ Sig. diff. compared to screws

Sig. diff. compared to screws + ST

^ Sig. diff. compared to screws + ST + SBs

○ Sig. diff. compared to SBs + ST

■ Sig. diff. compared to SBs

DISCUSSION OF MAIN FINDINGS

Paper I

We found equivalent AOFAS score after nail and plate fixation at 24 months after surgery. Previous studies have reported similar findings. In a RCT including 100 patients 65 years and older, White et al. found no significant difference in OMA score at 12 months follow-up (218). Also, Kho et al. and Badenhorst et al. reported no significant difference in AOFAS and/or OMA score at 12 months follow-up in the population in general (219, 220). Contrary, Peeperkorn et al. found a significantly higher AOFAS score in the nail group in elderly patients (221).

Interestingly, we found a higher number of complications and secondary surgical procedures after nail fixation. A lower complication rate after nail compared to plate fixation has been reported previously. In the study by White et al., no patient in the nail group had superficial infection compared to 8 in the plate group, and a total of 12% had complications after nail fixation compared to 18% after plate fixation (218). No significant difference in complications was reported in the elderly population by either Peeperkorn et al. (nail: 13%, plate: 29%) or Tas et al. (nail: 15%, plate: 33%) (221, 222). In a second study including younger patients, White et al. reported a complication rate of 29% in both groups (223). In the present study, the complication rate was 27% after nail fixation and 18% after plate fixation. We believe that our low complication rate after plate fixation may be explained by different reporting of complications, e.g. other studies have included ankle arthrodesis (224), OA (219), and medial sided complications (223). Also, the previous literature has reported a high infection rate after plate fixation which may be explained by different type of implant used, with a higher risk of infections with locking plates compared to tubular plates (219, 224). Furthermore, there is an increased risk of infection after plate fixation if surgery is delayed (166), but previous literature lacks reporting of time from injury to surgery. The postoperative rehabilitation protocol, with immediate ROM and weightbearing, has been recommended in some previous literature which may increase the risk of infections (224). An increased risk of symptomatic hardware may be present with locking plates (224), and non-locking plates in osteoporotic patients may result in screw loosening and construct failure (218).

The complication rate after nail fixation in the present study was at the upper range compared to the literature. We cannot neglect the learning curve with nail fixation and the challenges with the nail design which may explain some of the differences in the complication rate between nail and plate fixation in the present study. Although a criterion for being the operating surgeon was to previously have assisted 3 nail fixations, a low number of previous nail fixations compared to plate fixations may have impacted our results. Additionally, a significantly higher number construct failures were found in the nail group. The 4 construct failures included 1 syndesmotic malreduction on postoperative CT scan, 1 intraoperative fibular shaft fracture during reaming of the canal, and 2 talar lateralizations. We think that the malreduction may be explained by increased recognition with the use of postoperative CT scan. We do not obtain postoperative CT scan on regular basis, and this malreduction would most likely have been missed on standard radiographs. The fibular shaft fracture may be explained by technical errors and this surgery should have been converted to plate fixation based on preoperative measurement of the fibula canal. We believe that premature weightbearing and reduced compliance were important factors for failure in the two patients with talar lateralization, and, in retrospect, they should have been protected in a splint until fracture healing.

Presently, only 3 studies that compare nail and plate fixation in elderly patients have been published (218, 221, 222). The study group of the RCT by White et al. was involved in the development of the nail design and the surgical technique (102). Furthermore, details about the inclusion process, inclusion period, and number of patients lost to inclusion is not described, and limited patient and fracture characteristics are reported. The non-randomized study by Peeperkorn et al. compared a prospective cohort with nail fixation and a retrospective cohort with plate fixation, and additionally, as few as 15 patients were included in the nail group (221). Similar limitations were present in the study by Tas et al., with only 13 patients included in the nail group (222). Our study is a RCT that include a high number of patients followed for 24 months after surgery. We found equivalent functional outcome after nail and plate fixation of acute unstable AO/OTA type 44-B ankle fractures in patients 60 years or older. Still, a higher number of complications and secondary surgical procedures were found after nail fixation. Our results suggest that plate fixation should be the treatment of choice in the elderly population in general.

Paper II

The functional outcome after SB and tricortical screw fixation at 24 months after surgery was equivalent. This contrasts with several previous studies which have reported better outcomes with SB compared to screw (105). However, previous studies report on various types of screw fixation, with different screw diameter, number of cortices engaged, and number of screws. Wikeroy et al. reported no difference in functional outcome when one 4.5 mm quadricortical screw and two 3.5 mm tricortical screws was compared (112). Other studies have reported inferior outcome with one quadricortical screw compared to SB (113-115). It is thought that the rigid properties of the screw may explain the inferior clinical results (225). Less rigidity has been suggested with one tricortical screw (116). Kortekangas et al. compared one tricortical screw and one SB and found no significant difference in OMA score at least 2 years after surgery (226). Comparable to Kortekangas et al., we found no significant difference in functional score, with equivalent AOFAS score at 2 years follow-up.

In our study, the difference in tibiofibular distance and rate of malreduction was comparable between the two groups, although as many as 19 (35%) patients in the SB group and 16 (29%) patients in the tricortical screw group had a difference of 2 mm or more measured anteriorly. A difference of 2 mm or more has been associated with a reduced functional outcome (106). The tibiofibular distance depends on the reduction technique, type of implant, and measurement technique. Previously, a better reduction has been suggested with SB compared to screw fixation, which is believed to be related to the dynamic properties of the SB (105).

Paper III

Posterior malleolar screws resulted in better restoration of native tibiofibular and ankle joint kinematics compared to trans-syndesmotic SBs. Fixation of the PMF may restore the tension of the PITFL and thereby restore the syndesmotic stability. With external rotation of the foot, Gardner et al. found that 70% of the ankle stiffness was restored with PMF screw fixation compared to 40% with trans-syndesmotic screw fixation (137). Trans-syndesmotic fixation using SB allows for more physiologic motion of the syndesmosis than screws; however, previous studies have highlighted concerns with inadequate stabilization of the fibula in the sagittal and axial plane compared to the intact state (116, 227). These concerns were confirmed in the present study, where SBs alone demonstrated increased fibular sagittal translation and rotation in the rotation tests. Additionally, we found that posterior malleolar fixation resulted in significantly increased syndesmotic stability compared to trans-syndesmotic fixation with SBs.

We found that AITFL augmentation using ST improved restoration of the kinematics during external rotation of the foot. AITFL augmentation has been suggested to restore the restraint of the AITFL, thereby increasing fibular stability. In the study by Shoji, both SB with ST augmentation and ST only were comparable to the intact state, and SB only was significantly different from the intact state (217). Wood et al. found that 1 or 2 SBs with ST had significantly less fibular translation and rotation than the injured state, while 1 or 2 SBs alone were not significantly different from the injured state (228). In the present study, states with ST in combination with screws and/or SBs, demonstrated highest syndesmotic stability with external rotation of the foot. ST augmentation ensured that the syndesmotic integrity was anatomically restored for 2 of the 3 syndesmotic ligaments: the PITFL and AITFL. Restoration of all 3 syndesmotic ligaments, including SBs for the ITFL/IOM, did not provide any additional stability to the syndesmosis compared to posterior malleolar screws and ST, and trans-syndesmotic fixation with SBs tended to over-reduce the syndesmosis.

METHODOLOGICAL CONSIDERATIONS

Paper I and II

Both papers I and II were RCTs which are considered level I or II evidence for clinical studies (229). Both studies were conducted as equivalence trials in accordance with the Consolidated Standards of Reporting Trials (CONSORT) statement for reporting noninferiority and equivalence trials (230). We chose equivalence trial design because we did not know which one of the surgical methods was the best, and a difference between the groups in either direction would be of importance.

A priori sample size calculation was conducted with a web-based power calculator for continuous outcomes in equivalence trials (www.sealedenvelope.com) in both paper I and II. Initially, we planned to include 100 patients in both studies. In paper I, some patients were included but had to be excluded after randomization. This was mainly due to presence of a posterior malleolar fragment that required fixation (an exclusion criteria) or because the ankle was considered stable and did not require surgical treatment. Also in paper II, some patients were lost to follow-up. Therefore, we decided to increase the number of included patients to 120 in both studies. This number accounted for patients that had to be excluded after enrollment and loss to follow-up.

All patients were randomly assigned to nail or plate fixation (Paper I) or SB or tricortical screw (Paper II). This was done by a web-based system provided by Unit for Applied Clinical Research (Faculty of Medicine, Norwegian University of Science and Technology, Trondheim, Norway). In paper I, the patients were randomized using block randomization with block size of 60. In paper II, the patients were randomized using block randomization with block size of 10.

In both paper I and II, the follow-up examinations were done by a physiotherapist that was blinded to the type of surgical device. In paper I, the patients had to wear a sock during the examination, so that the physiotherapist could not see the surgical scar which could reveal the treatment group. In paper II, the surgical scar is similar after both surgical techniques, and the examination could be done without a sock.

The advantage with the randomized study design is that baseline patient characteristics are over all equally distributed between the groups, and that testing of significance is inappropriate (231). Still, in paper I, we compared the various baseline characteristics between the groups, and we found that gender was the only variable that was statistically different between the groups, with more females in the plate groups. Although significant, we think that this is a random finding, and we have not reported this in the manuscript. Unfortunately, we did not have a predefined plan for the statistical analysis in paper I or II.

All patients were treated according to hospital routines for ankle fractures. The only difference in treatment between the groups was the different surgical technique and implant used. Three different hospitals included patients in both paper I and II. The patients were treated by the surgeons on call; either by a less experienced resident and an experienced resident / consultant, an experienced resident, or a consultant. This increases the generalizability of the studies. However, in paper I, we cannot neglect the learning curve with nail fixation and the challenges with this generation of nail design which may explain some of the differences in the complication rate between nail and plate fixation. In paper II, a lack of standardized surgical technique for syndesmotic fixation may have had an impact on the result.

The 2-years follow-up rate in both paper I and II is high (Paper I: 81%, paper II: 84%). Still, some patients had to be excluded after randomization and some were lost to follow-up after surgery. The reasons are elaborated in Figures 4 and 6. In paper I, all patients 60 years or older were included. This patient population has large differences in daily function and expectations of postoperative result. Some patients may have been prevented from attending follow-ups due to physical challenges which may have resulted in loss to follow-up. It is also possible that some patients did not want to continue follow-ups because of no complaints from the ankle. Patients were lost to follow-up in both groups in both papers, and we do not think that selection bias played a significant role for the outcome. In both paper I and II, both intention-to-treat and as-treated analysis were performed to account for the crossovers.

The AOFAS Ankle-Hindfoot Scale was used as the primary outcome measure in paper I and II. At the time of study planning, AOFAS was considered the most commonly used outcome score for ankle fractures (232). This score was chosen as the primary outcome to enable comparison of our results with previously published results, despite the well-known concerns with the measurement properties. We decided to include additional scores to compensate for the weaknesses with the AOFAS score. More recently, McKeown et al. reported that the OMA score is the most frequently reported outcome measure (197), and in retrospect, we think that this score would have been a better choice as the primary outcome measure. In a systematic review of patients with foot/ankle diseases, the MOxFQ demonstrated the best psychometric properties (233). Based on the literature available today, the SEFAS score would have been a good score to include since it is validated for ankle fractures in Norwegian language (206).

In paper II, the syndesmosis width was measured on bilateral CT scans at 3 different locations: anterior, central, and posterior. Additionally, malreduction should be suspected if the fibula is located posteriorly in the incisura on postoperative radiographs (234). Fibular translation and rotation have also been suggested as important signs of malreduction (235). In our study, we did not measure fibular translation or rotation which is a weakness of the paper.

OA was evaluated on CT scans in both paper I and II. Compared to plain radiographs, CT scans is more sensitive when assessing OA. In paper I, the severity of OA was graded according to the classification by Cohen et al. that is based on CT scans (209). In paper II, OA was graded according to the Kellgren-Lawrence grading system (215). Although not specific for the ankle joint, it is frequently used for ankle OA. OA was further classified as mild (Kellgren-Lawrence 1-2 or Cohen 1-2) or severe OA (Kellgren-Lawrence 3-4 or Cohen 3-4). In both studies, all CT evaluations were done by one orthopaedic surgeon and one radiologist.

Based on the extension for equivalence trials (230), equivalence diagrams were created to demonstrate the difference between the surgical methods, including mean difference, confidence intervals (CI), and equivalence margins.

Paper III

A biomechanical study was conducted to compare syndesmotic stability after posterior malleolar fixation and syndesmotic fixation. Few previous studies have compared the two fixations (137). Furthermore, the degree of stability provided by each of the two fixation methods is not known. A biomechanical study was believed to provide important information about the fixations before clinical research may be conducted.

We tested 20 cadaveric specimens with a robot arm, including 10 specimens with a 25% PMF and 10 specimens with a 50% PMF. This was based on the power calculation, assuming a mean difference of 0.91 (217), SD of 0.89 (217), significance level of 5%, and power of 80%.

The ankle injury simulated a Weber C fracture with syndesmosis injury and involved a PMF with cut syndesmotic ligaments (AITFL and IOM); however, the fibula and medial side of the ankle were left intact to limit confounding variables. This resulted in an injury that do not directly correspond to injuries seen in clinical practice. Additionally, some decisions about the posterior malleolar fragment had to be made. The fragment was created based on previously reported measurements obtained from CT scans, including axial and sagittal angle (59, 236). Two different fragment length ratios, 25% and 50%, were created to increase the clinical relevance of the study. The posterolateral fragment simulated a Mason type 2A fracture, which is the fragment type that is most frequently associated with Weber C fracture (60, 236). A concomitant syndesmosis injury is present in 70% of Mason type 2A fractures (237). Although this fracture is not representative for all PMFs, it represents a fracture pattern that is often seen in unstable ankle fractures.

ETHICAL CONSIDERATIONS, APPROVALS, FUNDING, AND CONFLICTS OF INTEREST

In paper I and II, the participants were thoroughly informed about the study and the consequences of participation by an orthopaedic surgeon before they signed a written informed consent for voluntary study inclusion. The patients that declined study inclusion were treated according to standard hospital routines. It was not known which of the two compared surgical procedures that were the best; however, both procedures in both studies were accepted procedures and already in use at all hospitals. Per- and postoperative treatment followed standard hospital routines. In addition to the standard 6-weeks follow up, the patients were closely followed with follow-up visits and radiographs or CT scans until 24 months postoperatively. The radiation dosage with an ankle CT scan is extremely low (238). At any time, the patient could withdraw his/her informed consent without any justification and could have the already collected data deleted. All data were saved anonymously with a code that connected the patient identification data and the anonymized data. Only personnel involved in the project had access to the patient identification data.

Paper I and II were approved by the Norwegian National Research Ethics Committees (2016/137 and 2015/1860, respectively). Additionally, both studies were registered at each of the involved hospitals, with the data protection officer, and at www.clinicaltrials.gov (NCT03377205 and NCT02930486, respectively). For paper III, approval by the institutional review board was not required because de-identified cadaveric specimens are exempt from approval at the Steadman Philippon Research Institute (SPRI). The cadaveric specimens had been donated to registered tissue banks for medical research purpose and had been purchased by SPRI.

Paper I and II did not receive any external funding. Paper III was funded by Arthrex regarding the products that were used to conduct the study (award number US20083). The following conflicts of interest were reported: IKS: The position at the SPRI was partially supported by Arthrex. EEH: I am the president of the Norwegian Foot and Ankle Society. JEM: I have received payment or honoraria for lectures, presentations, speaker's bureaus, manuscript writing, or educational events from Smith & Nephew, DePuy Synthes, and Stryker. TOC: I have been a paid consultant for the following entities: Arthrex, Inc.; Stryker, Inc.; Wright Medical

Technology; SubioMed; and BICMD. I have received royalties from Arthrex and Stryker. I have received hospitality payments from Arthrex, Stryker and Wright Medical as a paid speaker for them at meetings, as well as from Gentleman Orthopaedics and Gemini Mountain Medical which are regional companies connected to Arthrex. I have stock options with SubioMed, Inc. I have been on the Managerial Board of Foot and Ankle International and Foot and Ankle Online for the American Orthopaedic Foot and Ankle Society. I am an Associate Editor for Foot and Ankle International and Foot and Ankle Online. CTH: I have been a paid consultant for the following entities: Arthrex, Inc. I have received hospitality payments from Arthrex, Inc. as a paid speaker for them at meetings. I have received research support from Stryker, Inc.

CONCLUSIONS

- Functional outcome after nail and plate fixation of unstable ankle fractures in elderly patients is equivalent at 24 months follow-up, and there is no difference in radiological outcome. Nail fixation results in a higher rate of complication and number of secondary surgical procedures compared to plate fixation.
- Plate fixation should be the treatment of choice for acute unstable AO/OTA type 44-B ankle fractures in elderly patients in general.
- Functional outcome after stabilization of acute syndesmosis injuries with a SB and a tricortical screw is equivalent at 24 months follow-up, and there is no difference in radiological outcome.
- Tricortical screw fixation is an equal alternative to SB fixation of acute AO/OTA type 44-C ankle fractures.
- PMF fixation with screws restores tibiofibular and ankle joint kinematics better than trans-syndesmotic SBs in acute ankle injuries with PMF and an unstable syndesmosis. AITFL augmentation using ST improves the kinematics during external rotation of the foot compared to PMF fixation alone. Minor differences were found between 25% and 50% PMFs.
- Posterior malleolar fixation with AITFL augmentation may be the preferred surgical treatment of acute ankle injuries with an unstable syndesmosis and a PMF of 25% or larger.

FUTURE PERSPECTIVES

The medial deltoid ligament has been suggested as the primary stabilizer of the ankle joint. Based on a clinical study from our hospital (72), our hospital routines have changed, and ankle stability is now assessed by obtaining weightbearing radiographs. This has resulted in a markedly reduced number of ankle fractures that are assessed unstable and require surgical stabilization. In Norway, clinical studies are in progress comparing surgical and nonsurgical treatment of Weber C fractures (NCT04615650) and nonsurgical treatment of bi- and trimalleolar fractures based on weightbearing radiographs.

In the RCT comparing nail and plate fixation of ankle fractures in elderly patients, the results were reported after 24 months follow-up. Few studies have reported results after nail fixation at long-term follow-up. Therefore, the patients in our study are invited for a 5-years follow-up where all the PROMs are completed, and a bilateral CT scan is obtained.

The best diagnostic test to assess syndesmosis injury is not known. Although biomechanical testing using the sagittal translation test has shown to be more sensitive than the Cotton and external rotation tests for detecting syndesmosis injury (76-78), this has, to our knowledge, not been confirmed clinically. Clinical studies that validate the sagittal translation test against arthroscopy (the gold standard), assess functional outcome according to sagittal instability, and determine a cut of for need for stabilization are highly desired.

Clinical studies that have compared trans-syndesmotic fixation and PMF fixation have reported a reduced need for syndesmotic fixation after the PMF has been fixed (138-140). To our knowledge, the published studies are retrospective and nonrandomized. Clinical, prospective studies will be important for understanding the impact of PMFs on syndesmotic stability and verify the results from our biomechanical study. Two studies comparing posterior malleolar and trans-syndesmotic fixation are registered at clinicaltrials.gov (NCT02599285 and NCT05413707).

Biomechanical studies have reported improved syndesmotic stability when trans-syndesmotic fixation and AITFL augmentation compared to trans-syndesmotic fixation alone (217, 228). These findings were confirmed in our biomechanical study. Additionally, we found improved stability with external rotational of the foot when AITFL augmentation was added to the PMF fixation. This finding has not been confirmed clinically. A clinical study comparing PMF fixation with or without AITFL augmentation in Weber C fractures may add information to the literature regarding the best treatment of PMFs with syndesmosis injury.

It has been suggested that posterior malleolar fragment morphology should guide the treatment of PMFs (239). Clinical studies with standardized treatment protocols according to fragment classification may provide increased knowledge about fixation of PMFs.

REFERENCES

1. Court-Brown CM, Duckworth AD, Clement ND, McQueen MM. Fractures in older adults. A view of the future? Injury. 2018;49(12):2161-6.
2. Hemmann P, Friederich M, Korner D, Klopfer T, Bahrs C. Changing epidemiology of lower extremity fractures in adults over a 15-year period - a National Hospital Discharge Registry study. BMC Musculoskelet Disord. 2021;22(1):456.
3. Bergh C, Wennergren D, Moller M, Brisby H. Fracture incidence in adults in relation to age and gender: A study of 27,169 fractures in the Swedish Fracture Register in a well-defined catchment area. PLoS One. 2020;15(12):e0244291.
4. Elsoe R, Ostgaard SE, Larsen P. Population-based epidemiology of 9767 ankle fractures. Foot Ankle Surg. 2018;24(1):34-9.
5. Milstrey A, Baumbach SF, Pfleiderer A, Evers J, Boecker W, Raschke MJ, et al. Trends of incidence and treatment strategies for operatively treated distal fibula fractures from 2005 to 2019: a nationwide register analysis. Arch Orthop Trauma Surg. 2021.
6. Lindsjö U. Operative treatment of ankle fracture-dislocations. A follow-up study of 306/321 consecutive cases. Clin Orthop Relat Res. 1985(199):28-38.
7. Jensen SL, Andresen BK, Mencke S, Nielsen PT. Epidemiology of ankle fractures. A prospective population-based study of 212 cases in Aalborg, Denmark. Acta Orthop Scand. 1998;69(1):48-50.
8. Court-Brown CM, McBirnie J, Wilson G. Adult ankle fractures—an increasing problem? Acta Orthop Scand. 2009;69(1):43-7.
9. Jaskulka RA, Ittner G, Schedl R. Fractures of the posterior tibial margin: their role in the prognosis of malleolar fractures. J Trauma. 1989;29(11):1565-70.
10. Weening B, Bhandari M. Predictors of functional outcome following transsyndesmotic screw fixation of ankle fractures. J Orthop Trauma. 2005;19(2):102-8.
11. Vieira Cardoso D, Dubois-Ferriere V, Gamulin A, Barea C, Rodriguez P, Hannouche D, et al. Operatively treated ankle fractures in Switzerland, 2002-2012: epidemiology and associations between baseline characteristics and fracture types. BMC Musculoskelet Disord. 2021;22(1):266.
12. Jenkinson RJ, Sanders DW, Macleod MD, Domonkos A, Lydestadt J. Intraoperative diagnosis of syndesmosis injuries in external rotation ankle fractures. J Orthop Trauma. 2005;19(9):604-9.
13. Tejwani NC, Pahk B, Egol KA. Effect of posterior malleolus fracture on outcome after unstable ankle fracture. J Trauma. 2010;69(3):666-9.
14. Egol KA, Pahk B, Walsh M, Tejwani NC, Davidovitch RI, Koval KJ. Outcome after unstable ankle fracture: effect of syndesmotic stabilization. J Orthop Trauma. 2010;24(1):7-11.
15. Procter P, Paul JP. Ankle joint biomechanics. J Biomech. 1982;15(9):627-34.
16. Calhoun JH, Li F, Ledbetter BR, Viegas SF. A comprehensive study of pressure distribution in the ankle joint with inversion and eversion. Foot Ankle Int. 1994;15(3):125-33.
17. Yufit P, Seligson D. Malleolar ankle fractures. A guide to evaluation and treatment. Orthopaedics and Trauma. 2010;24(4):286-97.
18. Clanton TO, Campbell KJ, Wilson KJ, Michalski MP, Goldsmith MT, Wijdicks CA, et al. Qualitative and Quantitative Anatomic Investigation of the Lateral Ankle Ligaments for Surgical Reconstruction Procedures. J Bone Joint Surg Am. 2014;96(12):e98.

19. Campbell KJ, Michalski MP, Wilson KJ, Goldsmith MT, Wijdicks CA, LaPrade RF, et al. The ligament anatomy of the deltoid complex of the ankle: a qualitative and quantitative anatomical study. J Bone Joint Surg Am. 2014;96(8):e62.
20. Williams BT, Ahrberg AB, Goldsmith MT, Campbell KJ, Shirley L, Wijdicks CA, et al. Ankle syndesmosis: a qualitative and quantitative anatomic analysis. Am J Sports Med. 2015;43(1):88-97.
21. Zwipp H, Randt T. Ankle joint biomechanics. Foot Ankle Surg. 1994;1(1):21-7.
22. Close JR. Some applications of the functional anatomy of the ankle joint. J Bone Joint Surg Am. 1956;38-a(4):761-81.
23. Rammelt S, Obruba P. An update on the evaluation and treatment of syndesmotic injuries. Eur J Trauma Emerg Surg. 2015;41(6):601-14.
24. Brockett CL, Chapman GJ. Biomechanics of the ankle. Orthop Trauma. 2016;30(3):232-8.
25. Juel NG, Faugli HP, Ludvigsen TC. Klinisk undersøkelse av bevegelsesapparatet. Bergen: Fagbokforlaget; 2012.
26. Rasmussen O, Tovborg-Jensen I. Mobility of the ankle joint: recording of rotatory movements in the talocrural joint in vitro with and without the lateral collateral ligaments of the ankle. Acta Orthop Scand. 1982;53(1):155-60.
27. Lampridis V, Gougoulias N, Sakellariou A. Stability in ankle fractures: Diagnosis and treatment. EFORT Open Rev. 2018;3(5):294-303.
28. Gougoulias N, Sakellariou A. When is a simple fracture of the lateral malleolus not so simple? how to assess stability, which ones to fix and the role of the deltoid ligament. Bone Joint J. 2017;99-b(7):851-5.
29. Michelson JD, Magid D, McHale K. Clinical utility of a stability-based ankle fracture classification system. J Orthop Trauma. 2007;21(5):307-15.
30. Savage-Elliott I, Murawski CD, Smyth NA, Golano P, Kennedy JG. The deltoid ligament: an in-depth review of anatomy, function, and treatment strategies. Knee Surg Sports Traumatol Arthrosc. 2013;21(6):1316-27.
31. Rasmussen O, Kromann-Andersen C, Boe S. Deltoid ligament. Functional analysis of the medial collateral ligamentous apparatus of the ankle joint. Acta Orthop Scand. 1983;54(1):36-44.
32. Ahl T, Dalen N, Lundberg A, Selvik G. Mobility of the ankle mortise. A roentgen stereophotogrammetric analysis. Acta Orthop Scand. 1987;58(4):401-2.
33. Svensson OK, Lundberg A, Walheirn G, Selvik G. In vivo fibular motions during various movements of the ankle. Clinical Biomechanics. 1989;4(3):155-60.
34. Ogilvie-Harris DJ, Reed SC, Hedman TP. Disruption of the ankle syndesmosis: biomechanical study of the ligamentous restraints. Arthroscopy. 1994;10(5):558-60.
35. Clanton TO, Williams BT, Backus JD, Dornan GJ, Liechti DJ, Whitlow SR, et al. Biomechanical Analysis of the Individual Ligament Contributions to Syndesmotic Stability. Foot Ankle Int. 2017;38(1):66-75.
36. Beumer A, Valstar ER, Garling EH, Niesing R, Ginai AZ, Ranstam J, et al. Effects of ligament sectioning on the kinematics of the distal tibiofibular syndesmosis: a radiostereometric study of 10 cadaveric specimens based on presumed trauma mechanisms with suggestions for treatment. Acta Orthop. 2006;77(3):531-40.
37. Massri-Pugin J, Lubberts B, Vopat BG, Wolf JC, DiGiovanni CW, Guss D. Role of the Deltoid Ligament in Syndesmotic Instability. Foot Ankle Int. 2018;39(5):598-603.

38. Stoffel K, Wysocki D, Baddour E, Nicholls R, Yates P. Comparison of two intraoperative assessment methods for injuries to the ankle syndesmosis. A cadaveric study. J Bone Joint Surg Am. 2009;91(11):2646-52.
39. Massri-Pugin J, Lubberts B, Vopat BG, Guss D, Hosseini A, DiGiovanni CW. Effect of Sequential Sectioning of Ligaments on Syndesmotic Instability in the Coronal Plane Evaluated Arthroscopically. Foot Ankle Int. 2017;38(12):1387-93.
40. Hunt KJ, Goeb Y, Behn AW, Criswell B, Chou L. Ankle Joint Contact Loads and Displacement With Progressive Syndesmotic Injury. Foot Ankle Int. 2015;36(9):1095-103.
41. Weber B. Die Verletzungen des oberen Sprunggelenkes. Aktuelle Probleme in der Chirurgie Bern, Stuttgart, Wien: Hans Huber; 1972.
42. Delaney JP, Charlson MD, Michelson JD. Ankle Fracture Stability-Based Classification: A Study of Reproducibility and Clinical Prognostic Ability. J Orthop Trauma. 2019;33(9):465-71.
43. Fonseca LLD, Nunes IG, Nogueira RR, Martins GEV, Mesencio AC, Kobata SI. Reproducibility of the Lauge-Hansen, Danis-Weber, and AO classifications for ankle fractures. Rev Bras Ortop. 2018;53(1):101-6.
44. Ebraheim NA, Elgafy H, Padanilam T. Syndesmotic disruption in low fibular fractures associated with deltoid ligament injury. Clin Orthop Relat Res. 2003(409):260-7.
45. Nielson JH, Sallis JG, Potter HG, Helfet DL, Lorich DG. Correlation of interosseous membrane tears to the level of the fibular fracture. J Orthop Trauma. 2004;18(2):68-74.
46. Broos PL, Bisschop AP. A new and easy classification system for ankle fractures. Int Surg. 1992;77(4):309-12.
47. Pakarinen HJ, Flinkkil TE, Ohtonen PP, Ristiniemi JY. Stability criteria for nonoperative ankle fracture management. Foot Ankle Int. 2011;32(2):141-7.
48. Barbosa P, Bonnaire F, Kojima K. AO Surgery reference. [Available from: http://www.aofoundation.org.
49. Lauge-Hansen N. Fractures of the ankle. II. Combined experimental-surgical and experimental-roentgenologic investigations. Arch Surg. 1950;60(5):957-85.
50. Gardner MJ, Demetrakopoulos D, Briggs SM, Helfet DL, Lorich DG. The ability of the Lauge-Hansen classification to predict ligament injury and mechanism in ankle fractures: an MRI study. J Orthop Trauma. 2006;20(4):267-72.
51. Rodriguez EK, Kwon JY, Herder LM, Appleton PT. Correlation of AO and Lauge-Hansen classification systems for ankle fractures to the mechanism of injury. Foot Ankle Int. 2013;34(11):1516-20.
52. Nielsen JO, Dons-Jensen H, Sorensen HT. Lauge-Hansen classification of malleolar fractures. An assessment of the reproducibility in 118 cases. Acta Orthop Scand. 1990;61(5):385-7.
53. Warner SJ, Garner MR, Hinds RM, Helfet DL, Lorich DG. Correlation Between the Lauge-Hansen Classification and Ligament Injuries in Ankle Fractures. J Orthop Trauma. 2015;29(12):574-8.
54. Gougoulias N, Khanna A, Sakellariou A, Maffulli N. Supination-external rotation ankle fractures: stability a key issue. Clin Orthop Relat Res. 2010;468(1):243-51.
55. Aiyer AA, Zachwieja EC, Lawrie CM, Kaplan JRM. Management of Isolated Lateral Malleolus Fractures. J Am Acad Orthop Surg. 2019;27(2):50-9.
56. Porter DA. Evaluation and treatment of ankle syndesmosis injuries. Instr Course Lect. 2009;58:575-81.

57. van Dijk CN, Longo UG, Loppini M, Florio P, Maltese L, Ciuffreda M, et al. Classification and diagnosis of acute isolated syndesmotic injuries: ESSKA-AFAS consensus and guidelines. Knee Surg Sports Traumatol Arthrosc. 2016;24(4):1200-16.
58. Chan KB, Lui TH. Role of Ankle Arthroscopy in Management of Acute Ankle Fracture. Arthroscopy. 2016;32(11):2373-80.
59. Haraguchi N, Haruyama H, Toga H, Kato F. Pathoanatomy of posterior malleolar fractures of the ankle. J Bone Joint Surg Am. 2006;88(5):1085-92.
60. Bartonicek J, Rammelt S, Kostlivy K, Vanecek V, Klika D, Tresl I. Anatomy and classification of the posterior tibial fragment in ankle fractures. Arch Orthop Trauma Surg. 2015;135(4):505-16.
61. Mason LW, Marlow WJ, Widnall J, Molloy AP. Pathoanatomy and Associated Injuries of Posterior Malleolus Fracture of the Ankle. Foot Ankle Int. 2017;38(11):1229-35.
62. Pflüger P, Harder F, Müller K, Biberthaler P, Crönlein M. Evaluation of ankle fracture classification systems in 193 trimalleolar ankle fractures. Eur J Trauma Emerg Surg. 2022.
63. Egol KA, Amirtharajah M, Tejwani NC, Capla EL, Koval KJ. Ankle stress test for predicting the need for surgical fixation of isolated fibular fractures. J Bone Joint Surg Am. 2004;86(11):2393-8.
64. DeAngelis NA, Eskander MS, French BG. Does medial tenderness predict deep deltoid ligament incompetence in supination-external rotation type ankle fractures? J Orthop Trauma. 2007;21(4):244-7.
65. Calder JD, Bamford R, Petrie A, McCollum GA. Stable Versus Unstable Grade II High Ankle Sprains: A Prospective Study Predicting the Need for Surgical Stabilization and Time to Return to Sports. Arthroscopy. 2016;32(4):634-42.
66. Bejarano-Pineda L, Guss D, Waryasz G, DiGiovanni CW, Kwon JY. The Syndesmosis, Part I: Anatomy, Injury Mechanism, Classification, and Diagnosis. Orthop Clin North Am. 2021;52(4):403-15.
67. Gill JB, Risko T, Raducan V, Grimes JS, Schutt RC, Jr. Comparison of manual and gravity stress radiographs for the evaluation of supination-external rotation fibular fractures. J Bone Joint Surg Am. 2007;89(5):994-9.
68. Dawe EJ, Shafafy R, Quayle J, Gougoulias N, Wee A, Sakellariou A. The effect of different methods of stability assessment on fixation rate and complications in supination external rotation (SER) 2/4 ankle fractures. Foot Ankle Surg. 2015;21(2):86-90.
69. Weber M, Burmeister H, Flueckiger G, Krause FG. The use of weightbearing radiographs to assess the stability of supination-external rotation fractures of the ankle. Arch Orthop Trauma Surg. 2010;130(5):693-8.
70. Hoshino CM, Nomoto EK, Norheim EP, Harris TG. Correlation of weightbearing radiographs and stability of stress positive ankle fractures. Foot Ankle Int. 2012;33(2):92-8.
71. Seidel A, Krause F, Weber M. Weightbearing vs Gravity Stress Radiographs for Stability Evaluation of Supination-External Rotation Fractures of the Ankle. Foot Ankle Int. 2017;38(7):736-44.
72. Gregersen MG, Molund M. Weightbearing Radiographs Reliably Predict Normal Ankle Congruence in Weber B/SER2 and 4a Fractures: A Prospective Case-Control Study. Foot Ankle Int. 2021;42(9):1097-105.
73. Harper MC, Keller TS. A radiographic evaluation of the tibiofibular syndesmosis. Foot Ankle. 1989;10(3):156-60.

74. Chun DI, Cho JH, Min TH, Park SY, Kim KH, Kim JH, et al. Diagnostic Accuracy of Radiologic Methods for Ankle Syndesmosis Injury: A Systematic Review and Meta-Analysis. J Clin Med. 2019;8(7).
75. Jiang KN, Schulz BM, Tsui YL, Gardner TR, Greisberg JK. Comparison of radiographic stress tests for syndesmotic instability of supination-external rotation ankle fractures: a cadaveric study. J Orthop Trauma. 2014;28(6):e123-7.
76. LaMothe JM, Baxter JR, Karnovsky SC, Murphy CI, Gilbert S, Drakos MC. Syndesmotic Injury Assessment With Lateral Imaging During Stress Testing in a Cadaveric Model. Foot Ankle Int. 2018;39(4):479-84.
77. Bhimani R, Lubberts B, Sornsakrin P, Massri-Pugin J, Waryasz G, DiGiovanni CW, et al. Do Coronal or Sagittal Plane Measurements Have the Highest Accuracy to Arthroscopically Diagnose Syndesmotic Instability? Foot Ankle Int. 2021;42(6):805-9.
78. Lubberts B, Massri-Pugin J, Guss D, Wolf JC, Bhimani R, Waryasz GR, et al. Arthroscopic Assessment of Syndesmotic Instability in the Sagittal Plane in a Cadaveric Model. Foot Ankle Int. 2020;41(2):237-43.
79. Ferries JS, DeCoster TA, Firoozbakhsh KK, Garcia JF, Miller RA. Plain radiographic interpretation in trimalleolar ankle fractures poorly assesses posterior fragment size. J Orthop Trauma. 1994;8(4):328-31.
80. Meijer DT, Doornberg JN, Sierevelt IN, Mallee WH, van Dijk CN, Kerkhoffs GM, et al. Guesstimation of posterior malleolar fractures on lateral plain radiographs. Injury. 2015;46(10):2024-9.
81. Raeder BW, Andersen MR, Madsen JE, Jacobsen SB, Frihagen F, Figved W. Prognostic value of the Haraguchi classification in posterior malleolar fractures in A0 44-C type ankle fractures. Injury. 2021;52(10):3150-5.
82. Rammelt S, Boszczyk A. Computed Tomography in the Diagnosis and Treatment of Ankle Fractures: A Critical Analysis Review. JBJS Rev. 2018;6(12):e7.
83. Kumar A, Mishra P, Tandon A, Arora R, Chadha M. Effect of CT on Management Plan in Malleolar Ankle Fractures. Foot Ankle Int. 2018;39(1):59-66.
84. Carrozzo M, Vicenti G, Pesce V, Solarino G, Rifino F, Spinarelli A, et al. Beyond the pillars of the ankle: A prospective randomized CT analysis of syndesmosis' injuries in Weber B and C type fractures. Injury. 2018;49 Suppl 3:S54-S60.
85. Kaiser PB, Bejarano-Pineda L, Kwon JY, DiGiovanni CW, Guss D. The Syndesmosis, Part II: Surgical Treatment Strategies. Orthop Clin North Am. 2021;52(4):417-32.
86. Earll M, Wayne J, Brodrick C, Vokshoor A, Adelaar R. Contribution of the deltoid ligament to ankle joint contact characteristics: a cadaver study. Foot Ankle Int. 1996;17(6):317-24.
87. Ramsey PL, Hamilton W. Changes in tibiotalar area of contact caused by lateral talar shift. J Bone Joint Surg Am. 1976;58(3):356-7.
88. Tunturi T, Kemppainen K, Patiala H, Suokas M, Tamminen O, Rokkanen P. Importance of anatomical reduction for subjective recovery after ankle fracture. Acta Orthop Scand. 1983;54(4):641-7.
89. Sanders DW, Tieszer C, Corbett B. Operative versus nonoperative treatment of unstable lateral malleolar fractures: a randomized multicenter trial. J Orthop Trauma. 2012;26(3):129-34.
90. Javed OA, Javed QA, Ukoumunne OC, Di Mascio L. Surgical versus conservative management of ankle fractures in adults: A systematic review and meta-analysis. Foot Ankle Surg. 2020;26(7):723-35.

91. Makwana NK, Bhowal B, Harper WM, Hui AW. Conservative versus operative treatment for displaced ankle fractures in patients over 55 years of age. A prospective, randomised study. J Bone Joint Surg Br. 2001;83(4):525-9.
92. Phillips WA, Schwartz HS, Keller CS, Woodward HR, Rudd WS, Spiegel PG, et al. A prospective, randomized study of the management of severe ankle fractures. J Bone Joint Surg Am. 1985;67(1):67-78.
93. Willett K, Keene DJ, Mistry D, Nam J, Tutton E, Handley R, et al. Close Contact Casting vs Surgery for Initial Treatment of Unstable Ankle Fractures in Older Adults: A Randomized Clinical Trial. JAMA. 2016;316(14):1455-63.
94. Minihane KP, Lee C, Ahn C, Zhang LQ, Merk BR. Comparison of lateral locking plate and antiglide plate for fixation of distal fibular fractures in osteoporotic bone: a biomechanical study. J Orthop Trauma. 2006;20(8):562-6.
95. Deng Y, Staniforth TL, Zafar MS, Lau YJ. Posterior Antiglide Plating vs Lateral Neutralization Plating for Weber B Distal Fibular Fractures: A Systematic Review and Meta-analysis of Clinical and Biomechanical Studies. Foot Ankle Int. 2022;43(6):850-9.
96. Zahn RK, Frey S, Jakubietz RG, Jakubietz MG, Doht S, Schneider P, et al. A contoured locking plate for distal fibular fractures in osteoporotic bone: a biomechanical cadaver study. Injury. 2012;43(6):718-25.
97. Switaj PJ, Wetzel RJ, Jain NP, Weatherford BM, Ren Y, Zhang LQ, et al. Comparison of modern locked plating and antiglide plating for fixation of osteoporotic distal fibular fractures. Foot Ankle Surg. 2016;22(3):158-63.
98. Hasami NA, Smeeing DPJ, Pull Ter Gunne AF, Edwards MJR, Nelen SD. Operative Fixation of Lateral Malleolus Fractures With Locking Plates vs Nonlocking Plates: A Systematic Review and Meta-analysis. Foot Ankle Int. 2022;43(2):280-90.
99. Schepers T, Van Lieshout EM, De Vries MR, Van der Elst M. Increased rates of wound complications with locking plates in distal fibular fractures. Injury. 2011;42(10):1125-9.
100. Luong K, Huchital MJ, Saleh AM, Subik M. Management of Distal Fibular Fractures With Minimally Invasive Technique: A Systematic Review. J Foot Ankle Surg. 2021;60(1):114-20.
101. Walton DM, Adams SB, Parekh SG. Intramedullary Fixation for Fractures of the Distal Fibula. Foot Ankle Int. 2016;37(1):115-23.
102. Bugler KE, Watson CD, Hardie AR, Appleton P, McQueen MM, Court-Brown CM, et al. The treatment of unstable fractures of the ankle using the Acumed fibular nail: development of a technique. J Bone Joint Surg Br. 2012;94(8):1107-12.
103. Smith G, Mackenzie SP, Wallace RJ, Carter T, White TO. Biomechanical Comparison of Intramedullary Fibular Nail Versus Plate and Screw Fixation. Foot Ankle Int. 2017;38(12):1394-9.
104. Backer HC, Vosseller JT. Intramedullary fixation of fibula fractures: A systematic review. J Clin Orthop Trauma. 2021;18:136-43.
105. Shimozono Y, Hurley ET, Myerson CL, Murawski CD, Kennedy JG. Suture Button Versus Syndesmotic Screw for Syndesmosis Injuries: A Meta-analysis of Randomized Controlled Trials. Am J Sports Med. 2019;47(11):2764-71.
106. Andersen MR, Diep LM, Frihagen F, Hellund JC, Madsen JE, Figved W. The importance of syndesmotic reduction on clinical outcome after syndesmosis injuries. J Orthop Trauma. 2019.
107. Miller AN, Paul O, Boraiah S, Parker RJ, Helfet DL, Lorich DG. Functional outcomes after syndesmotic screw fixation and removal. J Orthop Trauma. 2010;24(1):12-6.

108. Schepers T, Van Lieshout EM, de Vries MR, Van der Elst M. Complications of syndesmotic screw removal. Foot Ankle Int. 2011;32(11):1040-4.
109. Thornes B, Shannon F, Guiney AM, Hession P, Masterson E. Suture-button syndesmosis fixation: accelerated rehabilitation and improved outcomes. Clin Orthop Relat Res. 2005(431):207-12.
110. Westermann RW, Rungprai C, Goetz JE, Femino J, Amendola A, Phisitkul P. The effect of suture-button fixation on simulated syndesmotic malreduction: a cadaveric study. J Bone Joint Surg Am. 2014;96(20):1732-8.
111. Xu K, Zhang J, Zhang P, Liang Y, Hu JL, Wang X, et al. Comparison of Suture-Button Versus Syndesmotic Screw in the Treatment of Distal Tibiofibular Syndesmosis Injury: A Meta-analysis. J Foot Ankle Surg. 2021;60(3):555-66.
112. Wikeroy AK, Hoiness PR, Andreassen GS, Hellund JC, Madsen JE. No difference in functional and radiographic results 8.4 years after quadricortical compared with tricortical syndesmosis fixation in ankle fractures. J Orthop Trauma. 2010;24(1):17-23.
113. Laflamme M, Belzile EL, Bedard L, van den Bekerom MP, Glazebrook M, Pelet S. A prospective randomized multicenter trial comparing clinical outcomes of patients treated surgically with a static or dynamic implant for acute ankle syndesmosis rupture. J Orthop Trauma. 2015;29(5):216-23.
114. Andersen MR, Frihagen F, Hellund JC, Madsen JE, Figved W. Randomized Trial Comparing Suture Button with Single Syndesmotic Screw for Syndesmosis Injury. J Bone Joint Surg Am. 2018;100(1):2-12.
115. Ræder BW, Figved W, Madsen JE, Frihagen F, Jacobsen SB, Andersen MR. Better outcome for suture button compared with single syndesmotic screw for syndesmosis injury: five-year results of a randomized controlled trial. Bone Joint J. 2020;102-b(2):212-9.
116. Clanton TO, Whitlow SR, Williams BT, Liechti DJ, Backus JD, Dornan GJ, et al. Biomechanical Comparison of 3 Current Ankle Syndesmosis Repair Techniques. Foot Ankle Int. 2017;38(2):200-7.
117. Schon JM, Mikula JD, Backus JD, Venderley MB, Dornan GJ, LaPrade RF, et al. 3D Model Analysis of Ankle Flexion on Anatomic Reduction of a Syndesmotic Injury. Foot Ankle Int. 2017;38(4):436-42.
118. Hohman DW, Affonso J, Marzo JM, Ritter CA. Pathologic tibia/fibula fracture through a suture button screw tract: case report. Am J Sports Med. 2011;39(3):645-8.
119. Riedel MD, Miller CP, Kwon JY. Augmenting Suture-Button Fixation for Maisonneuve Injuries With Fibular Shortening: Technique Tip. Foot Ankle Int. 2017;38(10):1146-51.
120. Ramsey DC, Friess DM. Cost-Effectiveness Analysis of Syndesmotic Screw Versus Suture Button Fixation in Tibiofibular Syndesmotic Injuries. J Orthop Trauma. 2018;32(6):e198-e203.
121. Mendelsohn ES, Hoshino CM, Harris TG, Zinar DM. The effect of obesity on early failure after operative syndesmosis injuries. J Orthop Trauma. 2013;27(4):201-6.
122. Peek AC, Fitzgerald CE, Charalambides C. Syndesmosis screws: how many, what diameter, where and should they be removed? A literature review. Injury. 2014;45(8):1262-7.
123. van den Bekerom MP, Hogervorst M, Bolhuis HW, van Dijk CN. Operative aspects of the syndesmotic screw: review of current concepts. Injury. 2008;39(4):491-8.
124. Park YH, Ahn JH, Choi GW, Kim HJ. Comparison of Clamp Reduction and Manual Reduction of Syndesmosis in Rotational Ankle Fractures: A Prospective Randomized Trial. J Foot Ankle Surg. 2018;57(1):19-22.

125. Cosgrove CT, Putnam SM, Cherney SM, Ricci WM, Spraggs-Hughes A, McAndrew CM, et al. Medial Clamp Tine Positioning Affects Ankle Syndesmosis Malreduction. J Orthop Trauma. 2017;31(8):440-6.
126. Tornetta P, 3rd, Spoo JE, Reynolds FA, Lee C. Overtightening of the ankle syndesmosis: is it really possible? J Bone Joint Surg Am. 2001;83(4):489-92.
127. Pallis MP, Pressman DN, Heida K, Nicholson T, Ishikawa S. Effect of Ankle Position on Tibiotalar Motion With Screw Fixation of the Distal Tibiofibular Syndesmosis in a Fracture Model. Foot Ankle Int. 2018;39(6):746-50.
128. Abarca M, Besa P, Mora E, Palma J, Lira MJ, Filippi J. The use of intraoperative comparative fluoroscopy allows for assessing sagittal reduction and predicting syndesmosis reduction in ankle fractures. Foot Ankle Surg. 2022;28(6):750-5.
129. Tornetta P, 3rd, Yakavonis M, Veltre D, Shah A. Reducing the Syndesmosis Under Direct Vision: Where Should I Look? J Orthop Trauma. 2019;33(9):450-4.
130. Sagi HC, Shah AR, Sanders RW. The functional consequence of syndesmotic joint malreduction at a minimum 2-year follow-up. J Orthop Trauma. 2012;26(7):439-43.
131. McDaniel WJ, Wilson FC. Trimalleolar fractures of the ankle. An end result study. Clin Orthop Relat Res. 1977(122):37-45.
132. Langenhuijsen JF, Heetveld MJ, Ultee JM, Steller EP, Butzelaar RM. Results of ankle fractures with involvement of the posterior tibial margin. J Trauma. 2002;53(1):55-60.
133. Xu HL, Li X, Zhang DY, Fu ZG, Wang TB, Zhang PX, et al. A retrospective study of posterior malleolus fractures. Int Orthop. 2012;36(9):1929-36.
134. Verhage SM, Krijnen P, Schipper IB, Hoogendoorn JM. Persistent postoperative step-off of the posterior malleolus leads to higher incidence of post-traumatic osteoarthritis in trimalleolar fractures. Arch Orthop Trauma Surg. 2019;139(3):323-9.
135. Alonso-Rasgado T, Jimenez-Cruz D, Karski M. 3-D computer modelling of malunited posterior malleolar fractures: effect of fragment size and offset on ankle stability, contact pressure and pattern. Journal of foot and ankle research. 2017;10:13.
136. Fitzpatrick E, Goetz JE, Sittapairoj T, Hosuru Siddappa V, Femino JE, Phisitkul P. Effect of Posterior Malleolus Fracture on Syndesmotic Reduction: A Cadaveric Study. J Bone Joint Surg Am. 2018;100(3):243-8.
137. Gardner MJ, Brodsky A, Briggs SM, Nielson JH, Lorich DG. Fixation of posterior malleolar fractures provides greater syndesmotic stability. Clin Orthop Relat Res. 2006;447:165-71.
138. Miller MA, McDonald TC, Graves ML, Spitler CA, Russell GV, Jones LC, et al. Stability of the Syndesmosis After Posterior Malleolar Fracture Fixation. Foot Ankle Int. 2018;39(1):99-104.
139. Li M, Collier RC, Hill BW, Slinkard N, Ly TV. Comparing Different Surgical Techniques for Addressing the Posterior Malleolus in Supination External Rotation Ankle Fractures and the Need for Syndesmotic Screw Fixation. J Foot Ankle Surg. 2017;56(4):730-4.
140. Baumbach SF, Herterich V, Damblemont A, Hieber F, Bocker W, Polzer H. Open reduction and internal fixation of the posterior malleolus fragment frequently restores syndesmotic stability. Injury. 2019;50(2):564-70.
141. Marques Ribeiro H, Silva J, Teixeira R, Fernandes P, Sobral L, Rosa I. Clinical outcomes and trans-syndesmotic screw frequency after posterior malleolar fracture osteosynthesis. Injury. 2021;52(3):633-7.
142. Jeyaseelan L, Bua N, Parker L, Sohrabi C, Trockels A, Vris A, et al. Outcomes of posterior malleolar fixation in ankle fractures in a major trauma centre. Injury. 2021;52(4):1023-7.

143. Blom RP, Hayat B, Al-Dirini RMA, Sierevelt I, Kerkhoffs G, Goslings JC, et al. Posterior malleolar ankle fractures. Bone Joint J. 2020;102-b(9):1229-41.
144. Rammelt S, Bartonicek J. Posterior Malleolar Fractures: A Critical Analysis Review. JBJS Rev. 2020;8(8):e19 00207.
145. Shi HF, Xiong J, Chen YX, Wang JF, Qiu XS, Huang J, et al. Comparison of the direct and indirect reduction techniques during the surgical management of posterior malleolar fractures. BMC Musculoskelet Disord. 2017;18(1):109.
146. Vidović D, Elabjer E, Muškardin Iva, Milosevic M, Bekic M, Bakota B. Posterior fragment in ankle fractures: anteroposterior vs posteroanterior fixation. Injury. 2017;48:S65-S9.
147. Jowett AJ, Sheikh FT, Carare RO, Goodwin MI. Location of the sural nerve during posterolateral approach to the ankle. Foot Ankle Int. 2010;31(10):880-3.
148. Wang X, Yin J, Zhang C, Wang C, Geng X, Ma X, et al. Biomechanical Study of Screw Fixation and Plate Fixation of a Posterior Malleolar Fracture in a Simulation of the Normal Gait Cycle. Foot Ankle Int. 2017;38(10):1132-8.
149. Dehghan N, McKee MD, Jenkinson RJ, Schemitsch EH, Stas V, Nauth A, et al. Early Weightbearing and Range of Motion Versus Non-Weightbearing and Immobilization After Open Reduction and Internal Fixation of Unstable Ankle Fractures: A Randomized Controlled Trial. J Orthop Trauma. 2016;30(7):345-52.
150. Park JY, Kim BS, Kim YM, Cho JH, Choi YR, Kim HN. Early Weightbearing Versus Nonweightbearing After Operative Treatment of an Ankle Fracture: A Multicenter, Noninferiority, Randomized Controlled Trial. Am J Sports Med. 2021;49(10):2689-96.
151. Smeeing DPJ, Houwert RM, Briet JP, Groenwold RHH, Lansink KWW, Leenen LPH, et al. Weight-bearing or non-weight-bearing after surgical treatment of ankle fractures: a multicenter randomized controlled trial. Eur J Trauma Emerg Surg. 2020;46(1):121-30.
152. Sernandez H, Riehl J, Fogel J. Do Early Weight-Bearing and Range of Motion Affect Outcomes in Operatively Treated Ankle Fractures: A Systematic Review and Meta-Analysis. J Orthop Trauma. 2021;35(8):408-13.
153. Dhillon MS, Rajnish RK, Patel S, Chouhan DK, Bansal T. Osteoporotic ankle fractures: A narrative review of management options. J Clin Orthop Trauma. 2020;11(3):380-7.
154. Tan EW, Sirisreetreerux N, Paez AG, Parks BG, Schon LC, Hasenboehler EA. Early Weightbearing After Operatively Treated Ankle Fractures: A Biomechanical Analysis. Foot Ankle Int. 2016;37(6):652-8.
155. Ebraheim NA, Mekhail AO, Gargasz SS. Ankle fractures involving the fibula proximal to the distal tibiofibular syndesmosis. Foot Ankle Int. 1997;18(8):513-21.
156. Leyes M, Torres R, Guillén P. Complications of open reduction and internal fixation of ankle fractures. Foot and Ankle Clinics. 2003;8(1):131-47.
157. SooHoo NF, Krenek L, Eagan MJ, Gurbani B, Ko CY, Zingmond DS. Complication rates following open reduction and internal fixation of ankle fractures. J Bone Joint Surg Am. 2009;91(5):1042-9.
158. Anderson SA, Li X, Franklin P, Wixted JJ. Ankle fractures in the elderly: initial and long-term outcomes. Foot Ankle Int. 2008;29(12):1184-8.
159. Spek RWA, Smeeing DPJ, van den Heuvel L, Kokke MC, Bhashyam AR, Kelder JC, et al. Complications After Surgical Treatment of Geriatric Ankle Fractures. J Foot Ankle Surg. 2021;60(4):712-7.
160. Ovaska M. Complications in ankle fracture surgery. Acta Orthop Suppl. 2015;86(358):1-32.

161. Attia AK, Fayed A, Mahmoud K, Labib SA, Aydogan U, Juliano P. Locked intramedullary nailing provides superior functional outcomes and lower complication rates than plate fixation of distal fibula fractures. A systematic review and meta-analysis of comparative studies. Foot Ankle Surg. 2022.
162. Nasell H, Ottosson C, Tornqvist H, Linde J, Ponzer S. The impact of smoking on complications after operatively treated ankle fractures--a follow-up study of 906 patients. J Orthop Trauma. 2011;25(12):748-55.
163. McCormack RG, Leith JM. Ankle fractures in diabetics. Complications of surgical management. J Bone Joint Surg Br. 1998;80(4):689-92.
164. Miller AG, Margules A, Raikin SM. Risk factors for wound complications after ankle fracture surgery. J Bone Joint Surg Am. 2012;94(22):2047-52.
165. Sato T, Takegami Y, Sugino T, Bando K, Fujita T, Imagama S. Smoking and trimalleolar fractures are risk factors for infection after open reduction and internal fixation of closed ankle fractures: A multicenter retrospective study of 1,201 fractures. Injury. 2021;52(7):1959-63.
166. Schepers T, De Vries MR, Van Lieshout EM, Van der Elst M. The timing of ankle fracture surgery and the effect on infectious complications; a case series and systematic review of the literature. Int Orthop. 2013;37(3):489-94.
167. Olsen LL, Møller AM, Brorson S, Hasselager RB, Sort R. The impact of lifestyle risk factors on the rate of infection after surgery for a fracture of the ankle. Bone Joint J. 2017;99-b(2):225-30.
168. McKenna PB, O'Shea K, Burke T. Less is more: lag screw only fixation of lateral malleolar fractures. Int Orthop. 2007;31(4):497-502.
169. Zalavras CG, Christensen T, Rigopoulos N, Holtom P, Patzakis MJ. Infection following operative treatment of ankle fractures. Clin Orthop Relat Res. 2009;467(7):1715-20.
170. Lindsjo U. Operative treatment of ankle fracture-dislocations. A follow-up study of 306/321 consecutive cases. Clin Orthop Relat Res. 1985(199):28-38.
171. Beauchamp CG, Clay NR, Thexton PW. Displaced ankle fractures in patients over 50 years of age. J Bone Joint Surg Br. 1983;65(3):329-32.
172. Chaudhry S, Egol KA. Ankle injuries and fractures in the obese patient. Orthop Clin North Am. 2011;42(1):45-53, vi.
173. Wukich DK, Joseph A, Ryan M, Ramirez C, Irrgang JJ. Outcomes of ankle fractures in patients with uncomplicated versus complicated diabetes. Foot Ankle Int. 2011;32(2):120-30.
174. van Wensen RJ, van den Bekerom MP, Marti RK, van Heerwaarden RJ. Reconstructive osteotomy of fibular malunion: review of the literature. Strategies Trauma Limb Reconstr. 2011;6(2):51-7.
175. Buckwalter JA, Anderson DD, Brown TD, Tochigi Y, Martin JA. The Roles of Mechanical Stresses in the Pathogenesis of Osteoarthritis: Implications for Treatment of Joint Injuries. Cartilage. 2013;4(4):286-94.
176. Naqvi GA, Cunningham P, Lynch B, Galvin R, Awan N. Fixation of ankle syndesmotic injuries: comparison of tightrope fixation and syndesmotic screw fixation for accuracy of syndesmotic reduction. Am J Sports Med. 2012;40(12):2828-35.
177. Gardner MJ, Demetrakopoulos D, Briggs SM, Helfet DL, Lorich DG. Malreduction of the tibiofibular syndesmosis in ankle fractures. Foot Ankle Int. 2006;27(10):788-92.
178. Kaftandziev I, Bakota B, Trpeski S, Arsovski O, Spasov M, Cretnik A. The effect of the ankle syndesmosis reduction quality on the short-term functional outcome following ankle fractures. Injury. 2021;52 Suppl 5:S70-S4.

179. Ray R, Koohnejad N, Clement ND, Keenan GF. Ankle fractures with syndesmotic stabilisation are associated with a high rate of secondary osteoarthritis. Foot Ankle Surg. 2019;25(2):180-5.
180. Stroh DA, DeFontes K, Paez A, Parks B, Guyton GP. Distal fibular malrotation and lateral ankle contact characteristics. Foot Ankle Surg. 2019;25(1):90-3.
181. Ovaska MT, Makinen TJ, Madanat R, Kiljunen V, Lindahl J. A comprehensive analysis of patients with malreduced ankle fractures undergoing re-operation. Int Orthop. 2014;38(1):83-8.
182. Thordarson DB, Motamed S, Hedman T, Ebramzadeh E, Bakshian S. The effect of fibular malreduction on contact pressures in an ankle fracture malunion model. J Bone Joint Surg Am. 1997;79(12):1809-15.
183. Brown OL, Dirschl DR, Obremskey WT. Incidence of hardware-related pain and its effect on functional outcomes after open reduction and internal fixation of ankle fractures. J Orthop Trauma. 2001;15(4):271-4.
184. Pot J, van Wensen R, Olsman J. Hardware Related Pain and Hardware Removal after Open Reduction and Internal Fixation of Ankle Fractures. The Foot and Ankle Online Journal. 2011.
185. Naumann MG, Sigurdsen U, Utvag SE, Stavem K. Incidence and risk factors for removal of an internal fixation following surgery for ankle fracture: A retrospective cohort study of 997 patients. Injury. 2016;47(8):1783-8.
186. Fenelon C, Murphy EP, Galbraith JG, Kearns SR. The burden of hardware removal in ankle fractures: How common is it, why do we do it and what is the cost? A ten-year review. Foot Ankle Surg. 2019;25(4):546-9.
187. Williams BR, McCreary DL, Chau M, Cunningham BP, Pena F, Swiontkowski MF. Functional Outcomes of Symptomatic Implant Removal Following Ankle Fracture Open Reduction and Internal Fixation. Foot Ankle Int. 2018;39(6):674-80.
188. Kasai T, Matsumoto T, Iga T, Tanaka S. Complications of implant removal in ankle fractures. J Orthop. 2019;16(3):191-4.
189. Andersen MR, Frihagen F, Madsen JE, Figved W. High complication rate after syndesmotic screw removal. Injury. 2015;46(11):2283-7.
190. Saltzman CL, Salamon ML, Blanchard GM, Huff T, Hayes A, Buckwalter JA, et al. Epidemiology of ankle arthritis: report of a consecutive series of 639 patients from a tertiary orthopaedic center. Iowa Orthop J. 2005;25:44-6.
191. Horisberger M, Valderrabano V, Hintermann B. Posttraumatic ankle osteoarthritis after ankle-related fractures. J Orthop Trauma. 2009;23(1):60-7.
192. Beak JS, Kim YT, Lee SH. Predisposing Factors for Posttraumatic Osteoarthritis After Malleolus Fracture Fixation in Patients Younger Than 50 Years. Foot Ankle Int. 2022;43(3):389-97.
193. Lübbeke A, Salvo D, Stern R, Hoffmeyer P, Holzer N, Assal M. Risk factors for post-traumatic osteoarthritis of the ankle: an eighteen year follow-up study. Int Orthop. 2012;36(7):1403-10.
194. Ewalefo SO, Dombrowski M, Hirase T, Rocha JL, Weaver M, Kline A, et al. Management of Posttraumatic Ankle Arthritis: Literature Review. Curr Rev Musculoskelet Med. 2018;11(4):546-57.
195. Stake IK, Ræder BW, Gregersen MG, Molund M, Wang J, Madsen JE, et al. Higher complication rate after nail compared with plate fixation of ankle fractures in patients aged

60 years or older: a prospective, randomized controlled trial. Bone Joint J. 2023;105-b(1):72-81.
196. Hijji FY, Schneider AD, Pyper M, Laughlin RT. The Popularity of Outcome Measures Used in the Foot and Ankle Literature. Foot Ankle Spec. 2020;13(1):58-68.
197. McKeown R, Rabiu AR, Ellard DR, Kearney RS. Primary outcome measures used in interventional trials for ankle fractures: a systematic review. BMC Musculoskelet Disord. 2019;20(1):388.
198. Kitaoka HB, Alexander IJ, Adelaar RS, J AN, Myerson MS, Sanders M, et al. Clinical Rating Systems for the Ankle-Hindfoot, Midfoot, Hallux, and Lesser Toes. Foot Ankle Int. 1997;18(3):187-8.
199. Baumhauer JF, McIntosh S, Rechtine G. Age and sex differences between patient and physician-derived outcome measures in the foot and ankle. J Bone Joint Surg Am. 2013;95(3):209-14.
200. Pinsker E, Daniels TR. AOFAS position statement regarding the future of the AOFAS Clinical Rating Systems. Foot Ankle Int. 2011;32(9):841-2.
201. de Boer AS, Tjioe RJC, Van der Sijde F, Meuffels DE, den Hoed PT, Van der Vlies CH, et al. The American Orthopaedic Foot and Ankle Society Ankle-Hindfoot Scale; translation and validation of the Dutch language version for ankle fractures. BMJ Open. 2017;7(8):e017040.
202. Garrow AP, Papageorgiou AC, Silman AJ, Thomas E, Jayson MI, Macfarlane GJ. Development and validation of a questionnaire to assess disabling foot pain. Pain. 2000;85(1-2):107-13.
203. Morley D, Jenkinson C, Doll H, Lavis G, Sharp R, Cooke P, et al. The Manchester-Oxford Foot Questionnaire (MOXFQ): Development and validation of a summary index score. Bone Joint Res. 2013;2(4):66-9.
204. Dawson J, Doll H, Coffey J, Jenkinson C, Oxford, Birmingham F, et al. Responsiveness and minimally important change for the Manchester-Oxford foot questionnaire (MOXFQ) compared with AOFAS and SF-36 assessments following surgery for hallux valgus. Osteoarthritis Cartilage. 2007;15(8):918-31.
205. Olerud C, Molander H. A scoring scale for symptom evaluation after ankle fracture. Arch Orthop Trauma Surg. 1984;103(3):190-4.
206. Garratt AM, Naumann MG, Sigurdsen U, Utvag SE, Stavem K. Evaluation of three patient reported outcome measures following operative fixation of closed ankle fractures. BMC Musculoskelet Disord. 2018;19(1):134.
207. Rabin R, de Charro F. EQ-5D: a measure of health status from the EuroQol Group. Ann Med. 2001;33(5):337-43.
208. McLennan JG, Ungersma JA. A new approach to the treatment of ankle fractures. The Inyo nail. Clin Orthop Relat Res. 1986(213):125-36.
209. Cohen MM, Vela ND, Levine JE, Barnoy EA. Validating a new computed tomography atlas for grading ankle osteoarthritis. J Foot Ankle Surg. 2015;54(2):207-13.
210. Celik D, Coban O, Kilicoglu O. Minimal clinically important difference of commonly used hip-, knee-, foot-, and ankle-specific questionnaires: a systematic review. J Clin Epidemiol. 2019;113:44-57.
211. Norman GR, Sloan JA, Wyrwich KW. Interpretation of changes in health-related quality of life: the remarkable universality of half a standard deviation. Med Care. 2003;41(5):582-92.
212. Ræder BW, Stake IK, Madsen JE, Frihagen F, Jacobsen SB, Andersen MR, et al. Randomized trial comparing suture button with single 3.5 mm syndesmotic screw for ankle syndesmosis injury: similar results at 2 years. Acta Orthop. 2020;91(6):770-5.

213. Lindsjo U. Operative treatment of ankle fractures. Acta Orthop Scand Suppl. 1981;189:1-131.
214. Ræder LBW. Ankle fractures with associated syndesmotic injuries: Treatment of syndesmosis injuries and the impact of posterior malleolar fractures [dissertation]. Oslo, Norway: University of Oslo; 2021.
215. Kellgren JH, Lawrence JS. Radiological assessment of osteo-arthrosis. Ann Rheum Dis. 1957;16(4):494-502.
216. Holzer N, Salvo D, Marijnissen AC, Vincken KL, Ahmad AC, Serra E, et al. Radiographic evaluation of posttraumatic osteoarthritis of the ankle: the Kellgren-Lawrence scale is reliable and correlates with clinical symptoms. Osteoarthritis Cartilage. 2015;23(3):363-9.
217. Shoji H, Teramoto A, Suzuki D, Okada Y, Sakakibara Y, Matsumura T, et al. Suture-button fixation and anterior inferior tibiofibular ligament augmentation with suture-tape for syndesmosis injury: A biomechanical cadaveric study. Clin Biomech (Bristol, Avon). 2018;60:121-6.
218. White TO, Bugler KE, Appleton P, Will E, McQueen MM, Court-Brown CM. A prospective randomised controlled trial of the fibular nail versus standard open reduction and internal fixation for fixation of ankle fractures in elderly patients. Bone Joint J. 2016;98-B(9):1248-52.
219. Kho DW, Kim HJ, Kim BJ, Choi SM. Intramedullary nailing as an alternative to plate fixation in patients with distal fibular fracture. Orthop Traumatol Surg Res. 2020;106(1):149-54.
220. Badenhorst D, Terblanche I, Ferreria N, Burger MC. Intramedullary fixation versus anatomically contoured plating of unstable ankle fractures: a randomized control trial. Int Orthop. 2020;44(3):561-8.
221. Peeperkorn S, Nijs S, Hoekstra H. Why Fibular Nailing Can Be an Efficient Treatment Strategy for AO Type 44-B Ankle Fractures in the Elderly. J Foot Ankle Surg. 2018;57(5):961-6.
222. Tas DB, Smeeing DPJ, Keizer J, Houwert RM, Emmink BL. Postoperative Complications of Minimally Invasive Intramedullary Nail Fixation Versus Plate Fixation for Distal Fibular Fractures in Elderly Patients: A Retrospective Double Cohort Study in a Geriatric Trauma Unit in the Netherlands. J Foot Ankle Surg. 2021.
223. White TO, Bugler KE, Olsen L, Lundholm LH, Holck K, Madsen BL, et al. A Prospective, Randomized, Controlled, Two-Center, International Trial Comparing the Fibular Nail With Open Reduction and Internal Fixation for Unstable Ankle Fractures in Younger Patients. J Orthop Trauma. 2022;36(1):36-42.
224. Kho DH, Cho BK, Choi SM. Midterm Outcomes of Unstable Ankle Fractures in Young Patients Treated by Closed Reduction and Fixation With an Intramedullary Fibular Nail vs Open Reduction Internal Fixation Using a Lateral Locking Plate. Foot Ankle Int. 2021;42(11):1469-81.
225. Lee JS, Curnutte B, Pan K, Liu J, Ebraheim NA. Biomechanical comparison of suture-button, bioabsorbable screw, and metal screw for ankle syndesmotic repair: A meta-analysis. Foot Ankle Surg. 2021;27(2):117-22.
226. Kortekangas T, Savola O, Flinkkila T, Lepojarvi S, Nortunen S, Ohtonen P, et al. A prospective randomised study comparing TightRope and syndesmotic screw fixation for accuracy and maintenance of syndesmotic reduction assessed with bilateral computed tomography. Injury. 2015;46(6):1119-26.
227. Pang EQ, Bedigrew K, Palanca A, Behn AW, Hunt KJ, Chou L. Ankle joint contact loads and displacement in syndesmosis injuries repaired with Tightropes compared to screw fixation in a static model. Injury. 2019;50(11):1901-7.

228. Wood AR, Arshad SA, Kim H, Stewart D. Kinematic Analysis of Combined Suture-Button and Suture Anchor Augment Constructs for Ankle Syndesmosis Injuries. Foot Ankle Int. 2020;41(4):463-72.
229. Burns PB, Rohrich RJ, Chung KC. The levels of evidence and their role in evidence-based medicine. Plast Reconstr Surg. 2011;128(1):305-10.
230. Piaggio G, Elbourne DR, Pocock SJ, Evans SJ, Altman DG. Reporting of noninferiority and equivalence randomized trials: extension of the CONSORT 2010 statement. JAMA. 2012;308(24):2594-604.
231. Austin PC, Manca A, Zwarenstein M, Juurlink DN, Stanbrook MB. A substantial and confusing variation exists in handling of baseline covariates in randomized controlled trials: a review of trials published in leading medical journals. J Clin Epidemiol. 2010;63(2):142-53.
232. Hunt KJ, Hurwit D. Use of patient-reported outcome measures in foot and ankle research. J Bone Joint Surg Am. 2013;95(16):e118(1-9).
233. Jia Y, Huang H, Gagnier JJ. A systematic review of measurement properties of patient-reported outcome measures for use in patients with foot or ankle diseases. Qual Life Res. 2017;26(8):1969-2010.
234. Lepojärvi S, Pakarinen H, Savola O, Haapea M, Sequeiros RB, Niinimäki J. Posterior translation of the fibula may indicate malreduction: CT study of normal variation in uninjured ankles. J Orthop Trauma. 2014;28(4):205-9.
235. Nault ML, Hebert-Davies J, Laflamme GY, Leduc S. CT scan assessment of the syndesmosis: a new reproducible method. J Orthop Trauma. 2013;27(11):638-41.
236. Yi Y, Chun DI, Won SH, Park S, Lee S, Cho J. Morphological characteristics of the posterior malleolar fragment according to ankle fracture patterns: a computed tomography-based study. BMC Musculoskelet Disord. 2018;19(1):51.
237. Jayatilaka MLT, Philpott MDG, Fisher A, Fisher L, Molloy A, Mason L. Anatomy of the Insertion of the Posterior Inferior Tibiofibular Ligament and the Posterior Malleolar Fracture. Foot Ankle Int. 2019;40(11):1319-24.
238. Biswas D, Bible JE, Bohan M, Simpson AK, Whang PG, Grauer JN. Radiation exposure from musculoskeletal computerized tomographic scans. J Bone Joint Surg Am. 2009;91(8):1882-9.
239. Blom RP, Meijer DT, de Muinck Keizer RO, Stufkens SAS, Sierevelt IN, Schepers T, et al. Posterior malleolar fracture morphology determines outcome in rotational type ankle fractures. Injury. 2019;50(7):1392-7.

APPENDIX

1. **AOFAS Ankle-Hindfoot Scale**
2. **MOxFQ**
3. **OMA Scale**
4. **Eq5d-3L index and VAS**
5. **VAS scores for pain**
6. **Paper I**
7. **Paper II**
8. **Paper III**

Ankle-Hindfoot Scale (100 Points Total)

Pain (40 points)	
None	40
Mild, occasional	30
Moderate, daily	20
Severe, almost always present	0
Function (50 points)	
Activity limitations, support requirement	
No limitations, no support	10
No limitation of daily activities, limitation of recreational activities, no support	7
Limited daily and recreational activities, cane	4
Severe limitation of daily and recreational activities, walker, crutches, wheelchair, brace	0
Maximum walking distance, blocks	
Greater than 6	5
4-6	4
1-3	2
Less than 1	0
Walking surfaces	
No difficulty on any surface	5
Some difficulty on uneven terrain, stairs, inclines, ladders	3
Severe difficulty on uneven terrain, tairs,inclines,ladders	0
Gait abnormality	
None, slight	8
Obvious	4
Marked	0
Sagittal motion (flexion plus extension)	
Normal or mild restriction (30° or more)	8
Moderate restriction (15°-29°)	4
Severe restriction (less than 150)	0
Hindfoot motion (inversion plus eversion)	
Normal or mild restriction (75%-100% normal)	6
Moderate restriction (25%-74% normal)	3
Marked restriction (less than 25% normal)	0
Ankle-hindfoot stability (anteroposterior,varus-valgus)	
Stable	8
Definitely unstable	0
Alignment (10 points)	
Good, plantigrade foot, midfoot well aligned	15
Fair, plantigrade foot, some degree of midfoot malalignment observed, no symptoms	8
Poor, nonplantigrade foot, severe malalignment, symptoms	0
Total=	100

American Orthopaedic Foot and Ankle Society
From: http://www.aofas.org/i4a/pages/index.cfm?pageid=3494

Manchester-Oxford Foot Questionnaire (MOxFQ)

English version for the United Kingdom

Prior to completing the Questionnaire please complete the following:-

Today's Date:

				2	0		
D	D	M	M	Y	Y	Y	Y

On which side of your body is the affected joint, **for which you are receiving/have received treatment**.

Left ❑
Right ❑
Both ❑

If you said 'both', please complete the <u>first</u> questionnaire thinking about the <u>right side</u>. A second questionnaire, for the left side, will follow.

Circle as appropriate **Right / Left**

Please tick (✓) one box for each statement.

1. <u>During the past 4 weeks</u> this has applied to me:

I have pain in my foot/ankle

None of the time	Rarely	Some of the time	Most of the time	All of the time
☐	☐	☐	☐	☐

2. <u>During the past 4 weeks</u> this has applied to me:

I avoid walking long distances because of pain in my foot/ankle

None of the time	Rarely	Some of the time	Most of the time	All of the time
☐	☐	☐	☐	☐

3. <u>During the past 4 weeks</u> this has applied to me:

I change the way I walk due to pain in my foot/ankle

None of the time	Rarely	Some of the time	Most of the time	All of the time
☐	☐	☐	☐	☐

4. <u>During the past 4 weeks</u> this has applied to me:

I walk slowly because of pain in my foot/ankle

None of the time	Rarely	Some of the time	Most of the time	All of the time
☐	☐	☐	☐	☐

5. <u>During the past 4 weeks</u> this has applied to me:

I have to stop and rest my foot/ankle because of pain

None of the time	Rarely	Some of the time	Most of the time	All of the time
☐	☐	☐	☐	☐

6. <u>During the past 4 weeks</u> this has applied to me:

I avoid some hard or rough surfaces because of pain in my foot/ankle

None of the time	Rarely	Some of the time	Most of the time	All of the time
☐	☐	☐	☐	☐

7. __During the past 4 weeks__ this has applied to me:

I avoid standing for a long time because of pain in my foot/ankle

None of the time	Rarely	Some of the time	Most of the time	All of the time
☐	☐	☐	☐	☐

8. __During the past 4 weeks__ this has applied to me:

I catch the bus or use the car instead of walking, because of pain in my foot/ankle

None of the time	Rarely	Some of the time	Most of the time	All of the time
☐	☐	☐	☐	☐

9. __During the past 4 weeks__ this has applied to me:

I feel self-conscious about my foot/ankle

None of the time	Rarely	Some of the time	Most of the time	All of the time
☐	☐	☐	☐	☐

10. __During the past 4 weeks__ this has applied to me:

I feel self-conscious about the shoes I have to wear

None of the time	Rarely	Some of the time	Most of the time	All of the time
☐	☐	☐	☐	☐

11. __During the past 4 weeks__ this has applied to me:

The pain in my foot/ankle is more painful in the evening

None of the time	Rarely	Some of the time	Most of the time	All of the time
☐	☐	☐	☐	☐

12. __During the past 4 weeks__ this has applied to me:

I get shooting pains in my foot/ankle

None of the time	Rarely	Some of the time	Most of the time	All of the time
☐	☐	☐	☐	☐

13. During the past 4 weeks this has applied to me:
The pain in my foot/ankle prevents me from carrying out my work/everyday activities

None of the time	Rarely	Some of the time	Most of the time	All of the time
☐	☐	☐	☐	☐

14. During the past 4 weeks this has applied to me:
I am unable to do all my social or recreational activities because of pain in my foot/ankle

None of the time	Rarely	Some of the time	Most of the time	All of the time
☐	☐	☐	☐	☐

15. During the past 4 weeks...
How would you describe the pain you usually have in your foot/ankle?

None	Very mild	Mild	Moderate	Severe
☐	☐	☐	☐	☐

16. During the past 4 weeks...
Have you been troubled by pain from your foot/ankle in bed at night?

No nights	Only 1 or 2 nights	Some nights	Most nights	Every night
☐	☐	☐	☐	☐

Finally, please check that you have answered every question.

Thank you very much.

Pasientnr. Dagens dato:

Sett ring: 6 uker 6 mndr 1 år 2 år 5 år

Olerud og Molander Ankel score

Utfylles av lege/fysioterapeut Sett ring omkring ett av valgene for hvert spørsmål

Parameter	Grad	Score
1. Smerte	Ingen	25
	Gange på ulendt terreng	20
	Gange på jevnt underlag utendørs	10
	Gange innendørs	5
	Konstante og sterke	0
2. Stivhet	Ingen	10
	Stiv	0
3. Hevelse	Ingen	10
	Bare om kvelden	5
	Konstant	0
4. Trappe-gang	Ingen problemer	10
	Noe vanskeligheter	5
	Umulig	0
5. Løping	Mulig	5
	Umulig	0
6. Hopping	Mulig	5
	Umulig	0
7. Sitte på huk	Ingen problemer	5
	Umulig	0
8. Bruk av støtte	Ingen	10
	Taping, støttebandasje	5
	Stokk, krykke	0
9. Arbeid, daglige gjøremål	Samme som før skaden	20
	Redusert tempo	15
	Byttet til lettere jobb/deltid jobb	10
	Alvorlig redusert arbeidskapasitet	0

Total:

Dårlig (poor)= 0-30 Middels (fair)= 31-60 God (good)= 61-90 Veldig god (excellent)= 91-100

Signatur:

Deltakernr:

SPØRRESKJEMA VEDRØRENDE LIVSKVALITET (Eq5d)

Vis hvilke utsagn som passer best på din helsetilstand i dag ved å sette et kryss i en av rutene utenfor hver av gruppene nedenfor.

1. Hvordan opplever du gangevnen din?

☐1 Jeg har ingen problemer med å gå omkring
☐2 Jeg har litt problemer med å gå omkring
☐3 Jeg er sengeliggende

2. Hvordan klarer du personlig stell?

☐1 Jeg har ingen problemer med personlig stell
☐2 Jeg har litt problemer med å vaske meg eller kle meg
☐3 Jeg klarer ikke å vaske meg eller kle meg

3. Hvordan klarer du dine vanlige gjøremål (f.eks. arbeid, studier, husarbeid, familie- og fritidsaktiviteter)?

☐1 Jeg har ingen problemer med å utføre mine vanlige gjøremål
☐2 Jeg har litt problemer med å utføre mine vanlige gjøremål
☐3 Jeg er ute av stand til å utføre mine vanlige gjøremål

4. Smerter eller ubehag?

☐1 Jeg har verken smerte eller ubehag
☐2 Jeg har moderat smerte eller ubehag
☐3 Jeg har sterk smerte eller ubehag

5. Angst eller depresjon?

☐1 Jeg er verken engstelig eller deprimert
☐2 Jeg er noe engstelig eller deprimert
☐3 Jeg er svært engstelig eller deprimert

6. Din helsetilstand i dag.

For å hjelpe folk til å si hvor god eller dårlig en helsetilstand er, har vi laget en skala (omtrent som et termometer) hvor den beste tilstanden du kan tenke deg er merket 100 og den verste tilstanden du kan tenke deg er merket 0.

Vi vil gjerne at du viser på denne skalaen hvor god eller dårlig helsetilstanden din er i dag, etter din oppfatning. Vær vennlig å gjøre dette ved å trekke en linje fra boksen nedenfor til det punktet på skalaen som viser hvor god eller dårlig din helsetilstand er i dag.

Din egen helsetilstand i dag

Visuell score (pasienten skal selv avmerke)

Smerter i hvile:

Ingen 0........1........2.........3........4........5........6.........7........8........9........10 Utålelige

Smerter ved gange:

Ingen 0........1........2.........3........4........5........6.........7........8........9........10 Uutholdelige

Smerter om natten:

Ingen 0........1........2.........3........4........5........6.........7........8........9........10 Intensive

Daglige aktiviteter:

Normale 0........1........2.........3........4........5........6.........7........8........9........10 Meget reduserte

	J	Delvis	Nei
Hvis hemmet, skyldes hemming ankelskaden?	☐	☐	☐

I

II

OPEN ACCESS

Randomized trial comparing suture button with single 3.5 mm syndesmotic screw for ankle syndesmosis injury: similar results at 2 years

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Background and purpose — Better outcomes are reported for suture button (SB) compared with syndesmotic screws (SS) in patients treated for an acute ankle syndesmotic injury. One reason could be that screws are more rigid than an SB. A single tricortical 3.5 mm syndesmotic screw (TS) is the most dynamic screw option. Our hypothesis is that 1 SB and 1 TS provide similar results. Therefore, in randomized controlled trial, we compared the results between SB and TS for syndesmotic stabilization in patients with acute syndesmosis injury.

Patients and methods — 113 patients with acute syndesmotic injury were randomized to SB (n = 55) or TS (n = 58). The American Orthopedic Foot & Ankle Society (AOFAS) Ankle–Hindfoot Score was the primary outcome measure. Secondary outcome measures included Manchester Oxford Foot Questionnaire (MOXFQ), Olerud–Molander Ankle score (OMA), visual analogue scale (VAS), EuroQol- 5D (EQ-5D), radiologic results, range of motion, complications, and reoperations (no implants were routinely removed). CT scans of both ankles were obtained after surgery, and after 1 and 2 years.

Results — The 2-year follow-up rate was 84%. At 2 years, median AOFAS score was 97 in both groups (IQR SB 87–100, IQR TS 90–100, p = 0.7), median MOXFQ index was 5 in the SB group and 3 in the TS group (IQR 0–18 vs. 0–8, p = 0.2), and median OMA score was 90 in the SB group and 100 in the TS group (IQR 75–100 vs. 83–100, p = 0.2). The syndesmotic reduction was similar 2 years after surgery; 19/55 patients in the SB group and 13/58 in the TS group had a difference in anterior syndesmotic width ≥ 2 mm (p = 0.3). 0 patients in the SB group and 5 patients in the TS group had complete tibiofibular synostosis (p = 0.03). At 2 years, 10 TS were broken. Complications and reoperations were similar between the groups.

Interpretation — We found no clinically relevant differences regarding outcome scores between the groups. TS is an inexpensive alternative to SB.

Since 2018, several meta-analyses have been published evaluating treatment of acute ankle syndesmotic injury, reporting better outcomes for suture button (SB) fixation compared with syndesmotic screw (SS) (Shimozono et al. 2018, McKenzie et al. 2019). Shimozono concluded that the SB technique resulted in improved outcome and lower rates of joint malreduction. These results are based on heterogenous studies: different fracture types were compared; different numbers of implants were used and different diameters and cortices were engaged for SS fixation (Shimozono et al. 2018). Andersen et al. (2018) reported superior results for SB compared with a quadricortical 4.5 mm SS. A quadricortical SS necessitates routine screw removal, with a 5–9% reported risk of wound infection (Schepers et al. 2011, Andersen et al. 2015) and potential loss of reduction after implant removal (Laflamme et al. 2015). A quadricortical SS is a rigid fixation, inhibiting tibiofibular movement throughout the gait cycle (Riedel et al. 2017, Ramsey et al. 2018). The SB has a higher implant cost compared with SS (Ramsey et al. 2018), may not be sufficient to maintain fibular length in Maisonneuve fractures (Riedel et al. 2017), and has an implant removal rate of 6%, mainly due to irritation from the lateral knot (Andersen et al. 2018). The single tricortical 3.5 mm syndesmotic screw (TS) allows for some tibiofibular movement (Clanton et al. 2017), making the TS an inexpensive alternative, without need for routine implant removal. In this study we compare outcomes between a knotless SB and TS. Our hypothesis was that there is no difference in outcomes in patients treated with SB and a 3.5 mm TS.

Patients and methods

Patients and procedures

3 hospitals participated in recruiting and treating patients. Surgery was conducted by 45 different surgeons. Patients were included by the orthopedic resident on call, from January 2016

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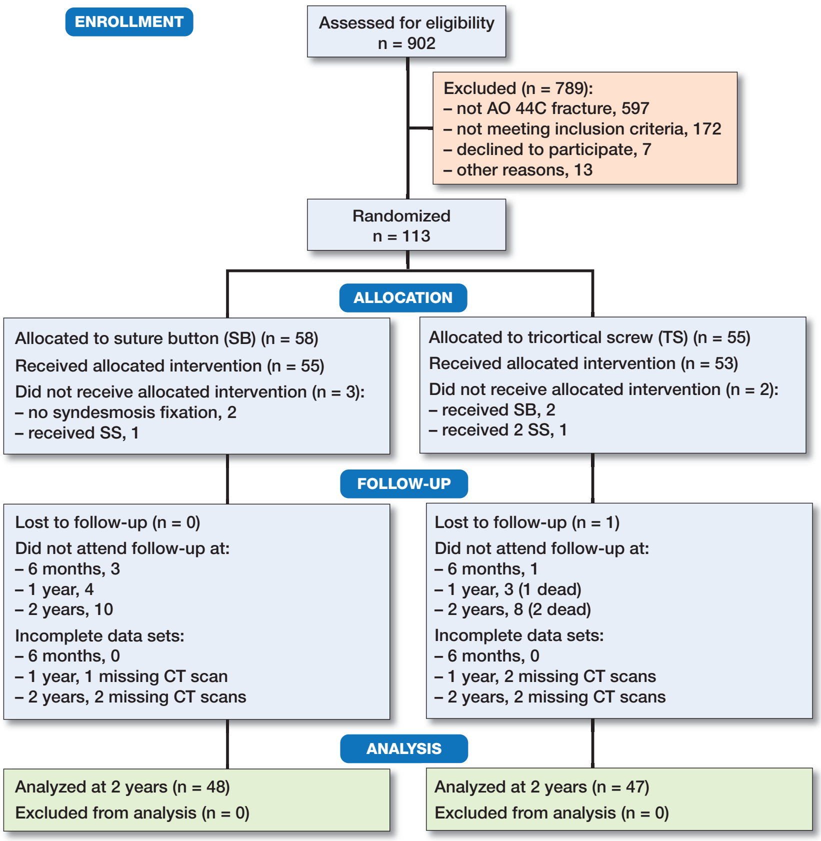

Figure 1. CONSORT flowchart of the trial enrollment and analysis.

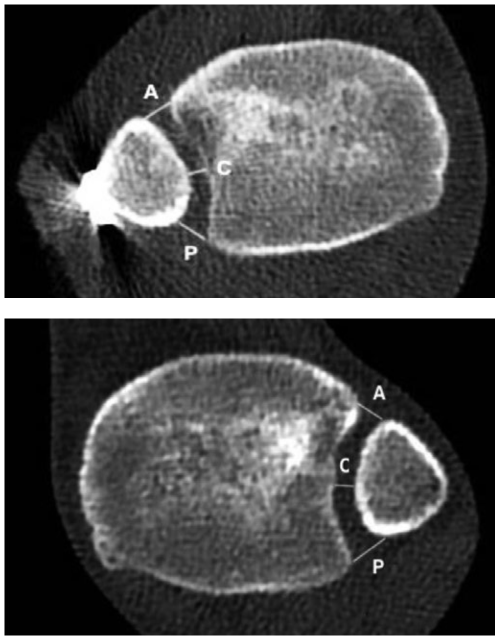

Figure 2. CT of injured ankle (upper panel) and uninjured ankle (lower panel) in a 20-year-old woman, 2 years after injury. Tibiofibular distance is measured on axial CT 1 cm proximal to the ankle joint. Distance measured anterior (A); central (C); and posterior (P).

to September 2017. Patients aged 18 to 69 who had suffered an acute AO type 44-C ankle fracture assessed by radiographs were asked to participate (Figure 1). Exclusion criteria were polytrauma, open fractures, previous fracture or arthritis of the same ankle, or neurologic impairment of the lower limbs. A web-based randomization system was used, developed and administered by Clinical Research Unit Central Norway, Norwegian University of Science and Technology, Trondheim, Norway.

Surgery was performed according to AO principles. The syndesmosis was reduced and fixed in a closed manner, guided by fluoroscopy. Surgeons were recommended to fix the syndesmosis at a level just proximal to the inferior tibiofibular joint (Barbosa et al. 2020), the use of temporary fixators (K-wire or reduction clamp) was decided by the surgeon. Patients allocated to SB were treated with a single knotless SB (Ziptight, Zimmer Biomet, Warsaw, IN, USA). Patients allocated to TS were treated with a fully threaded self-tapping, 3.5 mm tricortical screw (DePuy Synthes, West Chester, PA, USA). The screw length was not specified, but standardized to engage 3 cortices. Surgery was performed by the on-call team, either by an experienced resident, or a less experienced resident accompanied by a consultant or senior resident. Antibiotic prophylaxis was given as a single dose peroperatively. All patients followed the same protocol postoperatively: implants were not routinely removed; plaster casts and thrombosis prophylaxis were not used routinely. Patients were advised partial weight-bearing (20–30 kg) directly after surgery (Barbosa et al. 2020), then weight-bearing as tolerated after 6 weeks.

Outcome measures

Patients were assessed by an orthopedic surgeon and a physiotherapist at 6 weeks, 6 months, 1 and 2 years. The physiotherapists who conducted the physical examinations were blinded to the treatment allocation. The main outcome measure was the American Orthopedic Foot & Ankle Society (AOFAS) Ankle–Hindfoot scale. AOFAS incorporates subjective and objective factors into a numerical scale of 0 to 100, 100 being the best. Secondary outcome measures included the Manchester Oxford Foot Questionnaire (Dawson et al. 2007, 2011) (MOXFQ), a 16-item (each item scored 0–4) patient reported outcome measure (PROM). MOXFQ has 3 separate underlying dimensions: pain, activity, and social interaction. The raw score of maximum 64 was converted to a metric index from 0 (best) to 100 (worst) (Morley et al. 2013). MOXFQ is available in Norwegian and is not validated for ankle fractures. The MOXFQ is validated for hallux valgus surgery and has been found to be highly responsive (Dawson et al. 2007). Other secondary measures were the Olerud–Molander Ankle (OMA) score (Olerud and

Molander 1984), EuroQol-5D (EQ-5D) index, EQ-5D visual analogue scale (VAS), and VAS scores for pain during rest, during walking, at night, and during daily activities. OMA is a self-reported scale validated for ankle fractures, ranging from 0 (worst) to 100 (best). EQ-5D is a well-validated generic health-related quality-of-life instrument. Ankle range of motion was measured, comparing injured with non-injured ankle. The examination was standardized by a blinded physiotherapist, measuring dorsal and plantar flexion with a goniometer, with the foot placed on a 25 cm high foot stool with the knee in flexion.

Radiological measurements

Plain radiographs of the injured ankle were obtained after surgery, and at 6 weeks and 6 months. CT scans of both ankles were obtained postoperatively, and after 1 and 2 years. CT scans were standardized with the patient in a supine position, placing the feet in a purpose-made device, keeping the ankles in neutral position with 20° internal rotation of the legs. Radiological measurements were performed by 1 senior musculoskeletal radiologist (SBJ) and one orthopedic surgeon (BWR). The syndesmosis was assessed postoperatively and after 1 and 2 years by measuring the tibiofibular distance on axial CT scans, 1 cm proximal to the midpoint of the tibial plafond (Figure 2). The difference between injured and uninjured side was calculated. A criterion of < 2 mm difference in tibiofibular distance was selected for acceptable syndesmotic reduction (Andersen et al 2019, Patel et al. 2019). Signs of ankle osteoarthritis (OA), synostosis, talar exostoses, broken screws, and osteochondral lesions were reported. When assessing OA on CT scans, we defined mild OA as presence of osteophytes, and advanced OA as narrowing of the joint space and presence of cysts and sclerosis (Ray et al. 2019).

Statistics

Sample size was calculated according to the equivalence criterion (Piaggio et al. 2012). The minimal clinically important difference (MCID) for ankle fracture patients is not defined for the AOFAS score but has been suggested to be half of the standard deviation (SD) (Norman et al. 2003). Based on data from previous trials with a similar population, the SD was estimated to 12 points (Wikeroy et al. 2010, Andersen et al. 2018), giving an MCID of the AOFAS score of 6 points. A between-group difference of 10 points (AOFAS) was used to ensure a sufficient inclusion of patients. 38 patients had to be included in each group to achieve a power of 0.95 and a significance level of 0.05. To strengthen the data and compensate for loss to follow-up, we planned to include 60 patients in each group. Analyses of endpoint results were performed as both intention-to-treat and per-protocol. Student's T-test was used to compare means of normally distributed data. The Mann–Whitney U-test was used in cases of skewed data. Fisher's exact test was used for categorial data. Data is reported as numbers, mean with SD, or median with interquartile range (IQR). We considered a probability of less than 5% as statistically significant and used 95% confidence intervals (CI) to describe uncertainty. Data analysis was conducted in IBM SPSS Statistics for Mac version 26 (IBM Corp, Armonk, NY, USA).

Table 1. Patient characteristics at time of enrolment. Values are number of patients unless otherwise specified

Characteristic	SB (n = 55)	TS (n = 58)
Mean age (SD)	44 (15)	48 (14)
Male sex	35	30
Right side	32	26
Mean BMI (SD)	27 (5)	26 (4)
Medial malleolar fracture	14	19
Posterior malleolar fracture	37	31
Medial and posterior malleolar fracture	10	15
Maisonneuve fracture	26	20
Osteochondral damage of the talus	2 [a]	4
Intra-articular loose bodies	9 [a]	10
Temporary external fixator	7	2

[a] n = 54

Ethics, registration, funding, and potential conflicts of interest

Patients gave their written consent prior to randomization. The trial was conducted in accordance with the Declaration of Helsinki, approved by the National Committees for Research Ethics in Norway 2015/1860 and registered at ClinicalTrials.gov (NCT02930486). The study did not receive external funding. The authors have no conflicts of interest to declare.

Results

Results are reported according to the CONSORT guidelines.

113 patients were randomized and allocated to SB (= 58) or TS (= 55) (Figure 1). The 2-year follow-up rate was 84%; the radiological follow-up rate was 81%. The baseline demographic patient characteristics and fracture treatment were reported (Table I).

Clinical outcomes

The groups did not differ statistically regarding clinical outcome: at 2 years, the median AOFAS score was 97 in both groups (IQR SB 87–100 vs. TS 90–100, p = 0.7) (Table 2). The difference in mean AOFAS was < 2, equivalent at all controls (Figure 3). Median MOXFQ was 5 in the SB group and 3 in the TS group (IQR SB 0–18 vs. TS 0–8, p = 0.2) (Table 2), and median OMA score was 90 in the SB group and 100 in the TS group (IQR SB 75–100 vs. TS 83–100, p = 0.2). Similarly, no statistically significant difference was detected in VAS, EQ-5D VAS, or EQ-5D (Table 2). Fracture pattern affected clinical outcome when we stratified the groups according to fracture pattern: after 2 years, patients with

Table 2. Primary and secondary outcome measures

Outcome measure	SB [a] n	SB [a] score	TS [a] n	TS [a] score	p-value
AOFAS					
6 weeks	54	67 (10)	52	66 (13)	0.7 [c]
6 months	53	87 (82–98)	54	88 (77–98)	1.0 [b]
1 years	53	93 (82–100)	52	90 (84–99)	0.5 [b]
2 years	48	97 (87–100)	47	97 (90–100)	0.7 [b]
MOXFQ					
6 weeks	52	29 ((11)	48	31 (13)	0.4 [c]
6 months	55	14 (3–31)	53	14 (3–36)	0.7 [b]
1 year	52	5 (0–32)	51	6 (0–13)	0.9 [b]
2 years	48	5 (0–18)	47	3 (0–8)	0.2 [b]
OMA					
1 year	53	90 (73–100)	52	90 (76–100)	0.4 [b]
2 years	47	90 (75–100)	45	100 (83–100)	0.2 [b]
VAS for pain during rest					
6 weeks	53	1.0 (0–2)	49	1.0 (0–2)	0.9 [b]
6 months	54	0.0 (0–1)	54	0.0 (0–2)	0.1 [b]
1 year	53	0.0 (0–1)	52	0.0 (0–1)	0.5 [b]
2 years	48	0.0 (0–1)	47	0.0 (0–0)	0.6 [b]
VAS for pain during walking					
6 weeks	53	2.0 (1–4)	49	3.0 (2–4)	0.3 [b]
6 months	54	1.0 (0–3)	54	1.0 (0–2)	0.8 [b]
1 year	53	1.0 (0–2)	52	1.0 (0–2)	0.9 [b]
2 years	48	0.0 (0–1)	47	0.0 (0–1)	0.2 [b]
VAS for pain at night					
6 weeks	53	1.0 (0–2)	49	1.0 (0–3)	0.6 [b]
6 months	54	0.0 (0–0)	54	0.0 (0–1)	0.01 [b]
1 year	53	0.0 (0–0)	52	0.0 (0–0)	1.0 [b]
2 years	48	0.0 (0–1)	47	0.0 (0–0)	0.2 [b]
VAS for pain during daily activity					
6 weeks	53	3.0 (2–6)	49	4.0 (2–7)	0.4 [b]
6 months	54	1.0 (0–3)	54	1.0 (0–2)	0.9 [b]
1 year	53	0.0 (0–2)	52	1.0 (0–2)	0.6 [b]
2 years	48	0.0 (0–29	47	0.0 (0–0)	0.03 [b]
EQ-5D index					
6 weeks	53	0.7 (0.6–0.8)	53	0.7 (0.3–0.7)	0.1 [b]
6 months	54	0.8 (0.7–1.0)	54	0.8 (0.7–1.0)	0.9 [b]
1 year	53	1.0 (0.8–1.0)	52	1.0 (0.8–1.0)	1.0 [b]
2 years	48	1.0 (0.8–1.0)	47	1.0 (0.9–1.0)	0.3 [b]
EQ-5D VAS					
6 weeks	52	73 (15)	51	63 (18)	0.004 [c]
6 months	53	89 (70–95)	54	80 (74–90)	0.2 [b]
1 year	52	85 (71–95)	52	88 (76–90)	0.6 [b]
2 year	48	85 (70–95)	45	90 (77–95)	0.6 [b]

[a] For not normally distributed data values are given as median (IQR) in parentheses and for normally distributed data as mean (SD).
[b] Nonparametric (Mann–Whitney U) test.
[c] 2-sided t-test for independent samples.

a Maisonneuve fracture pattern had better outcome scores with a median AOFAS at 100 in the Maisonneuve patients group compared with 95 in all other injuries (IQR 95–100 vs. 85–100, p = 0.001), while patients with trimalleolar fractures did worse, with a median AOFAS at 92 compared with 99 in other injuries (IQR 85–97 vs. 90–100, p = 0.03) (Table 3, see Supplementary data). The ability to plantar- and dorsiflex the ankle was similar between the groups. At 2 years, the mean difference between injured and uninjured ankle in plantar and dorsiflexion was ≤ 5° (Table 4, see Supplementary data). Per-protocol analyses supported the intention-to-treat findings.

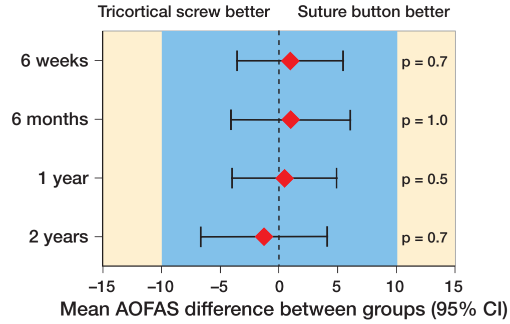

Figure 3. AOFAS equivalence diagram. Blue area indicates margins of equivalence defined as the between-group difference of 10 points. Results at all time intervals are equivalent since the 95% CI lies wholly inside the margins.

Radiological results

At 2 years, 30 patients in the SB group and 27 patients in the TS group had radiological signs of ankle OA (RR 1.1, CI 0.7–1.7). When analyzing for advanced OA, there was a difference between the groups at 2 years: 8 patients in the SB group and 1 patient in the TS group had advanced OA (RR 8, CI 1–60). The groups displayed similar results when analyzing presence of talar osteophytes at 2 years: 12 in the SB group and 7 in the TS group (p = 0.3). At 2 years, 0 patients in the SB group and 5 patients in the TS group had complete synostosis (p = 0.03) (Figure 4, see Supplementary data). When stratifying the complete cohort at 2 years according to fracture pattern, patients with a Maisonneuve fracture had less OA (15 vs. 42, RR 0.7, CI 0.4–1.0), patients with a trimalleolar fracture had more OA (19 vs. 38, RR 1.6, CI 1.2–2.1).

The tibiofibular distance measured on CT scans postoperatively and after 1 and 2 years was similar between the groups. At 2 years, the mean difference in tibiofibular distance was ≤ 1 mm for anterior, central, and posterior measurement in both groups (Table 5). When applying a tibiofibular difference of < 2 mm between injured and uninjured ankle as a criterion for acceptable reduction the groups had similar results at all controls; 19 patients in the SB group and 16 patients in the TS group had an anterior difference > 2 mm postoperatively (RR 1.2, CI 0.7–2.1) (Table 6, see Supplementary data). After 2 years, 35 of 45 patients still had their TS implanted; 10 screws were broken.

Complications and reoperations

10 patients in the SB group and 17 patients in the TS group had ≥ 1 reoperation (p = 0.2) (Table 7, see Supplementary data). 5 patients in the SB group and 11 patients in the TS group had their implants removed because of local irritation alone (p = 0.2). 3 patients in the SB group and 3 patients in the SS group required early reoperation (< 3 weeks) after CT postoperatively revealed unacceptable reduction of the fracture or of the syndesmosis (3 syndesmosis malreductions, 1 fibula malreduction, 2 medial malleolus malreduction). 2 patients (male, age 50 and female, age 52 years) suffered a low-energy tibia fracture through the suture button canal (Fig-

Table 5. Radiological results: difference measured in mm in tibiofibular distance at level of syndesmosis (1 cm proximal to the ankle joint) between injured and uninjured side. Values are mean (SD) or median (IQR) unless otherwise specified

Factor	n	SB difference	n	TS difference	Mean between-group difference (95% CI)	p-value [a]
Difference in anterior distance						
≤ 2 weeks	54	0.1 (1.9)	56	0.7 (1.8)	–0.5 (–1.2 to 0.2)	0.1
1 year	54	1.1 (2.0)	50	0.7 (1.8)	0.3 (–0.4 to 1.1)	0.4
2 years	46	0.9 (1.9)	45	0.7 (1.6)	0.2 (–0.5 to 1.0)	0.5
Difference in central distance						
≤ 2 weeks	54	0.1 (1.2)	56	–0.7 (1.1)	0.2 (–0.2 to 0.6)	0.3
1 year	54	1.2 (1.9)	50	0.9 (1.4)	0.3 (–0.3 to 1.0)	0.3
2 years	46	1.4 (0.0–2.0)	45	1.0 (0.0–1.0)	0.7 (0.0 to 1.4)	0.2 [b]
Difference in posterior distance						
≤ 2 weeks	54	–0.4 (2.2)	56	–0.6 (2.1)	0.2 (–0.6 to 1.0)	0.7
1 year	54	0.1 (1.8)	50	0.4 (1.8)	–0.3 (–1.0 to 0.4)	0.5
2 years	46	0.0 (2.3)	45	0.3 (2.0)	–0.4 (–1.2 to 0.5)	0.4

[a] Levene's test was used to assess equality of the variances. Statistical analysis was conducted using the 2-sided t-test for independent samples in normally distributed data; otherwise the Mann–Whitney U-test was used.
[b] The Mann–Whitney U-test was used.

ures 5, 6, see Supplementary data). The male patient presented 6 months postoperatively with a healed tibia fracture with 13° varus deformity. Since this patient had no complaints the fracture was not addressed surgically. The female patient presented initially with a large posterior malleolar fracture. She presented with pain while walking 4 months after her initial injury. She had suffered a tibia fracture and was reoperated on with open reduction and internal fixation. A dual energy X-ray absorptiometry (DEXA scan) showed osteoporosis.

Discussion

The main findings in this study are equivalent clinical results in patients treated with either an SB or an TS 2 years after acute syndesmotic injury. The mean AOFAS difference between the groups was overlapping and inside the margins of the 95% CI at all controls. The rate of appropriate syndesmotic reduction, reoperations, and rate of OA was similar between our groups. In the SB group, 2 patients experienced fractures through the suture button canal. 5 patients in the TS group had synostosis after 2 years. Fracture pattern affected clinical outcome.

The clinical results are in contrast to earlier studies reporting better results for SB fixation (Shimozono et al. 2018). An explanation for this discrepancy could be the different mechanical properties between the screw options for fixation. The dynamic properties of syndesmotic implants in vivo are unknown, but there are mechanical studies on the subject. Fixation of the syndesmosis with several 3.5 mm tricortical SS or a 4.5 mm quadricortical SS locks the fibula in the incisura, while the TS has in a cadaver study displayed more dynamic properties (Clanton et al. 2017). This may explain why Andersen et al. (2018) found a quadricortical SS to be inferior to an SB, while Kortekangas et al. (2015) found no difference when comparing an TS with an SB.

The first SBs available required a suture knot on the lateral side, with irritation and a reported removal rate of 6% (Andersen et al. 2018). We used a knotless SB to potentially lower this rate. Despite this, our removal rate was 9%. Changing to a knotless SB did not affect the removal rate. This could be due to other factors, such as irritation from the fibula plate, present in almost half of the SB patients. 6 patients required early reoperation, based on postoperative CT scans. We advocate a low threshold for obtaining postoperative CT scans after syndesmotic reduction (Garner et al. 2015, Barbosa et al. 2020).

Trauma is the most common cause of ankle OA (Saltzman et al. 2005). The rate of radiologic OA after 2 years was high in this study. The reason for this could be the use of CT, which is more sensitive than radiographs when assessing OA. Most of the patients (48 of 57) displayed only minor signs of OA. The rate of advanced OA in 9 patients is in line with previous studies (Lübbeke et al. 2012, Ray et al. 2019). The observation period of 2 years is short and the study population is underpowered to conclude on the differences in advanced OA between the groups. More patients had complete synostosis in the TS group, supporting the findings by Hinds et al. (2014) that SS fixation is a risk factor for synostosis development. 2 patients treated with SB suffered a non-traumatic fracture through the suture button canal. This specific complication and its incidence have not been reported in the literature. We suggest a syndesmotic screw as a better alternative in patients with poor bone quality.

A weakness in the study is our choice of outcome score. The ideal outcome score should be validated for the injury in question, have high reliability, and be available in the language of the patients examined. Our primary outcome, the AOFAS, is not validated; it is criticized for low precision, and for producing skewed data due to ceiling effects (Veltman et al. 2017). Even so, the AOFAS was chosen because of its widespread use. We decided to add the MOXFQ, since it was available in Norwegian. It is validated for hallux valgus surgery, not ankle fractures, hence its properties for ankle fractures are not known. After initiation of our trial, a comparison of 3 different PROMs available in Norwegian were published, recommending the Self-Reported Foot and Ankle Score (SEFAS) for evaluating patients with ankle fractures (Garratt et al. 2018). Another weakness is the lack of standardization in the syndesmosis fixation and several surgeons treating the patients. This could be a source of uncontrolled variability between the groups. On the other hand, it makes our results transferable to the day-to-day practice of fracture surgery.

The primary strengths of this study are the randomized prospective design with blinded scoring of clinical outcome measures, comparable groups at baseline, a high follow-up rate, and CT evaluation 2 years after treatment. In addition, all hospitals participating in the study used both implants as standard treatments before initiation of the trial, minimizing problems with the learning curve associated with new treatments. The procedure was performed by the on-call team, providing generalizability. Our outcome scores after 2 years are in line with scores from similar studies (Wikeroy et al. 2010, Laflamme et al. 2015, Andersen et al. 2018), supporting previous data on outcomes after syndesmotic injury.

Interpretation

In this RCT comparing a knotless SB and an TS we found no clinically relevant differences regarding outcome scores between the groups. TS is an inexpensive alternative to SB when treating acute syndesmotic injury.

Supplementary data

Tables 3, 4, 6, 7 and Figures 4–6 are available as supplementary data in the online version of this article, http://dx.doi.org/10.1080/17453674.2020.1818175

BWR, JEM, MRA, and WF planned and designed the study. BWR, IKS, JEM, FF, MRA, and WF were active in inclusion, treatment, and follow-up. SBJ and BWR did analysis of the radiologic examinations. BWR and MRA did statistical analysis with feedback from IKS, JEM, FF, and WF. BWR designed the tables and wrote the first draft of the paper; all authors revised the paper and tables.

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Andersen M R, Frihagen F, Madsen J E, Figved W. High complication rate after syndesmotic screw removal. Injury 2015; 46(11): 2283-7.

Andersen M R, Frihagen F, Hellund J C, Madsen J E, Figved W. randomized trial comparing suture button with single syndesmotic screw for syndesmosis injury. J Bone Joint Surg Am 2018; 100(1): 2-12.

Andersen M R, Diep L M, Frihagen F, Hellund J C, Madsen J E, Figved W. Importance of syndesmotic reduction on clinical outcome after syndesmosis injuries. J Orthop Trauma 2019; 33(8): 397-403.

Barbosa P, Bonnaire F, Kojima K. AO surgery reference: Syndesmosis injury. https://surgeryreference.aofoundation.org/orthopedic-trauma/adult-trauma/malleoli/suprasyndesmotic-simple-fibular- fracture-medial-injury-posterior-fracture/orif?searchurl =%2fSearchResults#fixation; 2020.

Clanton T O, Whitlow S R, Williams B T, Liechti D J, Backus J D, Dornan G J, et al. Biomechanical comparison of 3 current ankle syndesmosis repair techniques. Foot Ankle Int 2017; 38(2): 200-7.

Dawson J, Doll H, Coffey J, Jenkinson C, Oxford and Birmingham Foot and Ankle Clinical Research Group. Responsiveness and minimally important change for the Manchester–Oxford foot questionnaire (MOXFQ) compared with AOFAS and SF-36 assessments following surgery for hallux valgus. Osteoarthritis Cartilage 2007; 15(8): 918-31.

Dawson J, Boller I, Doll H, Lavis G, Sharp R, Cooke P, et al. The MOXFQ patient-reported questionnaire: assessment of data quality, reliability and validity in relation to foot and ankle surgery. Foot 2011; 21(2): 92-102.

Garner M R, Fabricant P D, Schottel P C, Berkes M B, Shaffer A D, Ni A, et al. Standard perioperative imaging modalities are unreliable in assessing articular congruity of ankle fractures. J Orthop Trauma 2015; 29(4): e161-5.

Garratt A M, Naumann M G, Sigurdsen U, Utvåg S E, Stavem K. Evaluation of three patient reported outcome measures following operative fixation of closed ankle fractures. BMC Musculoskelet Disord 2018; 19: 134.

Hinds R M, Lazaro L E, Burket J C, Lorich D G. Risk factors for posttraumatic synostosis and outcomes following operative treatment of ankle fractures. Foot Ankle Int 2014; 35(2): 141-7.

Kortekangas T, Savola O, Flinkkila T, Lepojarvi S, Nortunen S, Ohtonen P, et al. A prospective randomized study comparing TightRope and syndesmotic screw fixation for accuracy and maintenance of syndesmotic reduction assessed with bilateral computed tomography. Injury 2015; 46(6): 1119-26.

Laflamme M, Belzile E L, Bédard L, van den Bekerom M P J, Glazebrook M, Pelet S. A prospective randomized multicenter trial comparing clinical outcomes of patients treated surgically with a static or dynamic implant for acute ankle syndesmosis rupture. J Orthop Trauma; 2015; 29(5): 216-23.

Lübbeke A, Salvo D, Stern R, Hoffmeyer P, Holzer N, Assal M. Risk factors for post-traumatic osteoarthritis of the ankle: an eighteen-year follow-up study. Int Orthop 2012; 36(7): 1403-10.

McKenzie A C, Hesselholt K E, Larsen M S, Schmal H. A systematic review and meta-analysis on treatment of ankle fractures with syndesmotic rupture: suture-button fixation versus cortical screw fixation. J Foot Ankle Surg 2019; 58(5): 946-53.

Morley D, Jenkinson C, Doll H, Lavis G, Sharp R, Cooke P, et al. The Manchester–Oxford Foot Questionnaire (MOXFQ): development and validation of a summary index score. Bone Joint Res 2013; 2(4): 66-9.

Norman G R, Sloan J A, Wyrwich K W. Interpretation of changes in health-related quality of life: the remarkable universality of half a standard deviation. Med Care 2003; 41(5): 582-92.

Olerud C, Molander H. A scoring scale for symptom evaluation after ankle fracture. Arch Orthop Trauma Surg 1984; 103(3): 190-4.

Patel S, Malhotra K, Cullen N P, Singh D, Goldberg A J, Welck M J. Defining reference values for the normal tibiofibular syndesmosis in adults using weight-bearing CT. Bone Joint J 2019; 101-B(3): 348-52.

Piaggio G, Elbourne DR, Pocock S J, Evans S J W, Altman D G, CONSORT Group. Reporting of noninferiority and equivalence randomized trials: extension of the CONSORT 2010 statement. JAMA 2012;3 08(24): 2594-604.

Ramsey D C, Friess D M. Cost-effectiveness analysis of syndesmotic screw versus suture button fixation in tibiofibular syndesmotic injuries. J Orthop Trauma 2018; 32(6): e198-e203.

Ray R, Koohnejad N, Clement N D, Keenan G F. Ankle fractures with syndesmotic stabilization are associated with a high rate of secondary osteoarthritis. Foot Ankle Surg 2019; 25(2): 180-5.

Riedel M D, Miller C P, Kwon Y. Augmenting suture-button fixation for Maisonneuve injuries with fibular shortening: technique tip. Foot Ankle Int 2017; 38(10): 1146-51.

Saltzman C L, Salamon M L, Blanchard G M, Huff T, Hayes A, Buckwalter J A, et al. Epidemiology of ankle arthritis: report of a consecutive series of 639 patients from a tertiary orthopedic center. Iowa Orthop J 2005; 25: 44-6.

Schepers T, Van Lieshout E M, de Vries M R, Van der Elst M. Complications of syndesmotic screw removal. Foot Ankle Int 2012; 32(11): 1040-4.

Shimozono Y, Hurley E T, Myerson C L, Murawski C D, Kennedy J G. Suture button versus syndesmotic screw for syndesmosis injuries: a meta-analysis of randomized controlled trials. Am J Sports Med 2018; 100(1): 363546518804804.

Veltman E S, Hofstad C J, Witteveen A G H. Are current foot- and ankle outcome measures appropriate for the evaluation of treatment for osteoarthritis of the ankle: evaluation of ceiling effects in foot- and ankle outcome measures. J Foot Ankle Surg 2017; 23(3): 168-72.

Wikeroy A K, Hoiness P R, Andreassen G S, Hellund J C, Madsen J E. No difference in functional and radiographic results 8.4 years after quadricortical compared with tricortical syndesmosis fixation in ankle fractures. J Orthop Trauma 2010; 24(1): 17-23.

III

The Impact of Posterior Malleolar Fixation on Syndesmotic Stability

ABSTRACT

Background: Trans-syndesmotic fixation with suture buttons (SBs), posterior malleolar fixation with screws, and anterior inferior tibiofibular ligament (AITFL) augmentation using suture tape (ST) have all been suggested as potential treatments in the setting of a posterior malleolar fracture (PMF). However, there is no consensus on the optimal treatment for PMFs.

Purpose: The purpose of this study was to determine which combination of 1) trans-syndesmotic SBs, 2) posterior malleolar screws, and 3) AITFL augmentation using ST best restored native tibiofibular and ankle joint kinematics following 25% and 50% PMF.

Study Design: Controlled Laboratory Study.

Methods: Twenty cadaveric lower leg specimens were divided into two groups (25% or 50% PMF) and underwent biomechanical testing using a 6-degrees-of-freedom robotic arm in 7 states: 1) Intact, 2) syndesmosis injury with PMF, 3) trans-syndesmotic SBs, 4) trans-syndesmotic SBs + AITFL augmentation, 5) trans-syndesmotic SBs + AITFL augmentation + posterior malleolar screws, 6) posterior malleolar screws + AITFL augmentation, 7) posterior malleolar screws. Four biomechanical tests were performed at neutral and 30 degrees of plantarflexion: 1) External rotation, 2) internal rotation, 3) posterior drawer, 4) lateral drawer. The position of the tibia, fibula, and talus were recorded using a 5-camera motion capture system.

Results: With external rotation, posterior malleolar screws with AITFL augmentation resulted in best stability of the fibula and ankle joint. With internal rotation, all repairs that included posterior malleolar screws stabilized the fibula and ankle joint. Posterior and lateral drawer resulted in only small differences between the intact and injured states. No differences were found in the efficacy of treatments between 25% and 50% PMFs.

Conclusion: Posterior malleolar screws resulted in higher syndesmotic stability compared to trans-syndesmotic SBs. AITFL augmentation provided additional external rotational stability when combined with posterior malleolar screws. Trans-syndesmotic SBs did not provide any additional stability and tended to translate the fibula medially.

Clinical relevance: Posterior malleolar fixation with AITFL augmentation using ST may be the preferred surgical method when treating patients with acute ankle injury involving an unstable syndesmosis and a PMF of 25% or larger.

Key terms: Posterior malleolar fracture, syndesmosis injury, suture button, syndesmotic stability

What is known about the subject: The posterior inferior tibiofibular ligament (PITFL) attaches to the posterior malleolus and provides significant stability to the syndesmosis. It has been suggested that fixation of the PMF may restore the tension of the intact PITFL and stabilize the syndesmosis without need for trans-syndesmotic fixation. Nevertheless, trans-syndesmotic fixation has remained the gold standard of treatment for syndesmotic instability.

What this study adds to existing knowledge: This study is a laboratory study which compares tibiofibular and ankle joint kinematics following trans-syndesmotic fixation with SBs and posterior malleolar fixation with screws of an ankle injury involving an unstable syndesmosis and a PMF of 25% or 50%. The study suggests an advantage to posterior malleolar fixation. AITFL augmentation using ST provided additional external rotational stability.

INTRODUCTION

Ankle fractures involve the posterior malleolus in 7-44% of cases and are associated with worse functional outcome compared to ankle fractures without a PMF.[8,13] The posterior inferior tibiofibular ligament (PITFL) attaches to the posterior malleolus and provides significant stability to the syndesmosis.[6] A posterior malleolar fracture (PMF) may therefore result in syndesmotic instability even when the PITFL remains intact.[10] Furthermore, fixation of the PMF may restore the tension of the intact PITFL and stabilize the syndesmosis without need for trans-syndesmotic fixation.[10] This concept has been supported by clinical studies.[3,17,21] Nevertheless, trans-syndesmotic fixation has remained the gold standard of treatment for syndesmotic instability.[1]

Presently, suture buttons (SBs) are frequently used for trans-syndesmotic fixation. Compared to syndesmotic screws, they allow for physiologic motion of the syndesmosis with reduced need for implant removal, and improved functional result has been reported.[30] However, concerns regarding inadequate syndesmotic stability with increased rotation and sagittal motion of the fibula have generated interest for anterior inferior tibiofibular ligament (AITFL) augmentation.[5,31-33,36] Improved stability has been demonstrated with syndesmotic fixation and AITFL augmentation compared to syndesmotic fixation alone in biomechanical studies.[31,36] In the presence of a PMF, fixation of the posterior malleolus combined with AITFL augmentation may be an appealing alternative.

The aim of this biomechanical study was to compare syndesmotic stability after posterior malleolar fixation with screws and after trans-syndesmotic fixation with SBs. The two surgical methods were compared individually and with AITFL augmentation. It was hypothesized that there was no difference in syndesmotic stability between the two methods.

MATERIALS AND METHODS

Specimen Preparation

Twenty unpaired cadaveric lower leg specimens, all male with mean age 55 years (range, 23 to 64) and no known history of foot or ankle injury, surgery, or pathology, were obtained for this study. Specimens with obvious deformity or poor bone quality were excluded. The cadaveric specimens used in this study were donated to registered tissue banks for the purpose of medical research and acquired by our institution. Institutional review board approval was not required because de-identified cadaveric specimens are exempt from review at our institution.

The specimens were stored at -20°C and thawed at room temperature, once for dissection and once for testing. During dissection, all skin, subcutaneous tissue, and muscles were removed proximal to the foot, leaving syndesmotic ligaments, ankle ligaments, and joint capsule intact. The medial aspect of the proximal tibia was embedded in a semicircular mold of polymethyl methacrylate (PMMA, Fricke Dental, Streamwood, IL, USA) to preserve the proximal tibiofibular joint.

The foot was rigidly secured to a pedestal using a custom fixture equipped with a 6-axis universal force/torque sensor (ATI Industrial Automation, NC, USA). Two threaded rods and 2 wood screws were inserted into the calcaneus with the subtalar joint in neutral position, and nuts and washers secured the rods to the foot and fixture. Additionally, 2 K-wires were used to stabilize the anterior portion of the foot. The potted tibia was mounted to the end effector of a 6-degrees-of-freedom robotic arm (KR 60-3; KUKA Robotics, Augsburg, Germany) with neutral orientation of the tibia in the coronal, sagittal, and axial plane using previously validated methodology.[15]

Surgical Technique

Each specimen was tested in 7 states (Figure 1): 1) Intact, 2) syndesmosis injury with PMF, 3) trans-syndesmotic SBs, 4) trans-syndesmotic SBs + AITFL augmentation, 5) trans-syndesmotic SBs + AITFL augmentation + posterior malleolar screws, 6) posterior malleolar screws + AITFL augmentation, 7) posterior malleolar screws. The order of fixation with trans-syndesmotic SBs and posterior malleolar screws was randomized. All cuts and repairs were performed by an orthopaedic resident (IKS).

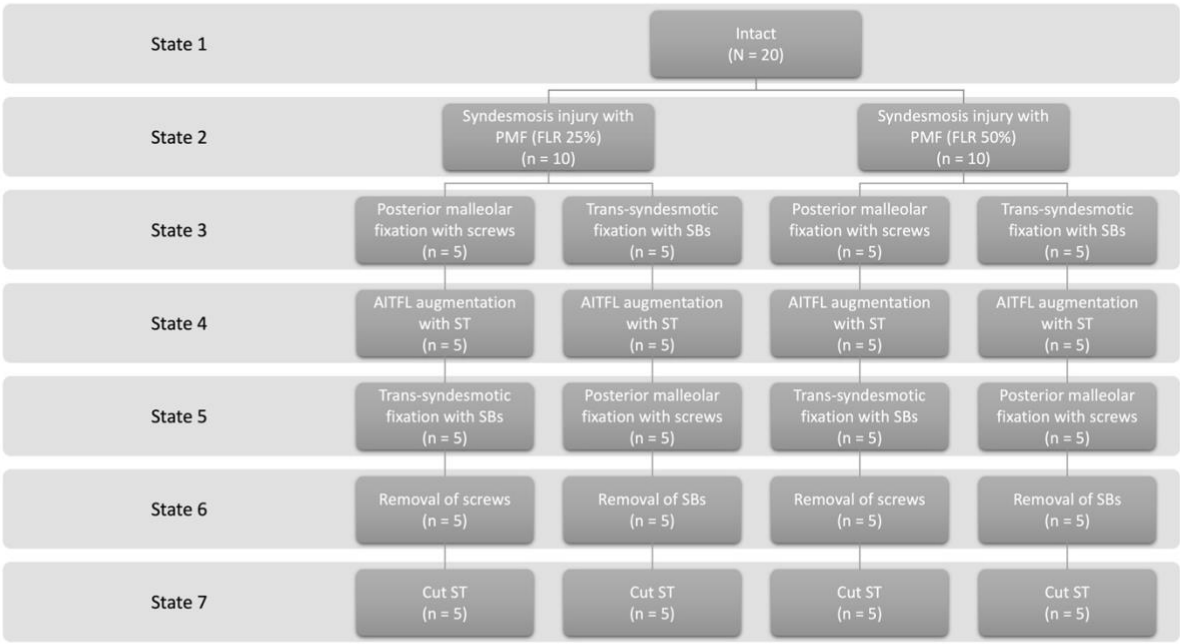

Figure 1: The flowchart demonstrates the steps that were made to achieve each of the 7 test states.

<u>Syndesmosis Injury with PMF</u>

A syndesmosis injury, including sectioned AITFL, interosseous tibiofibular ligament (ITFL), and interosseous membrane (IOM), and a PMF with the intact PITFL attached was created in each specimen. This injury pattern is often seen in Weber C fractures and results in syndesmotic instability. The fibula was left intact, simulating a rigid fixation of the Weber C fracture. Additionally, the deltoid ligament was left intact, simulating an ideal ligament repair. These choices were made to study the repair of the PMF and syndesmosis without confounding variables resulting from repair of the commonly associated fibula fracture and deltoid ligament injury.

A 3D printed cutting guide was made to create a PMF classified as Mason type 2A (Mason),[18] a posterolateral fragment frequently seen in Weber C injuries (Figure 2a and 2b).[38] In previous reports, 70% of Mason type 2A fractures have been associated with syndesmotic instability.[14] The fracture was located posterolateral with an axial angle of 21 degrees at the level of the tibial plafond and a sagittal angle of 17.5 degrees, measurements previously reported on CT scans of PMFs.[11,38] Additionally, each specimen was randomly assigned to a fragment length ratio of either 25% or 50%, with 10 ankles in each group.[37] The width of the tibia in relation to the total width of the tibia and fibula was digitally measured on CT scans of 24 paired uninjured lower legs, on axial views at the level of the tibial plafond, and was found to be mean 71% (SD = 3%). Therefore, the medial-to-lateral position of the guide for the fracture to exit in the fibular notch was set to 71% of the tibia/fibula width. The anteroposterior (AP) length and medial-to-lateral width of each specimen were measured with manual calipers at the level of the tibial plafond.

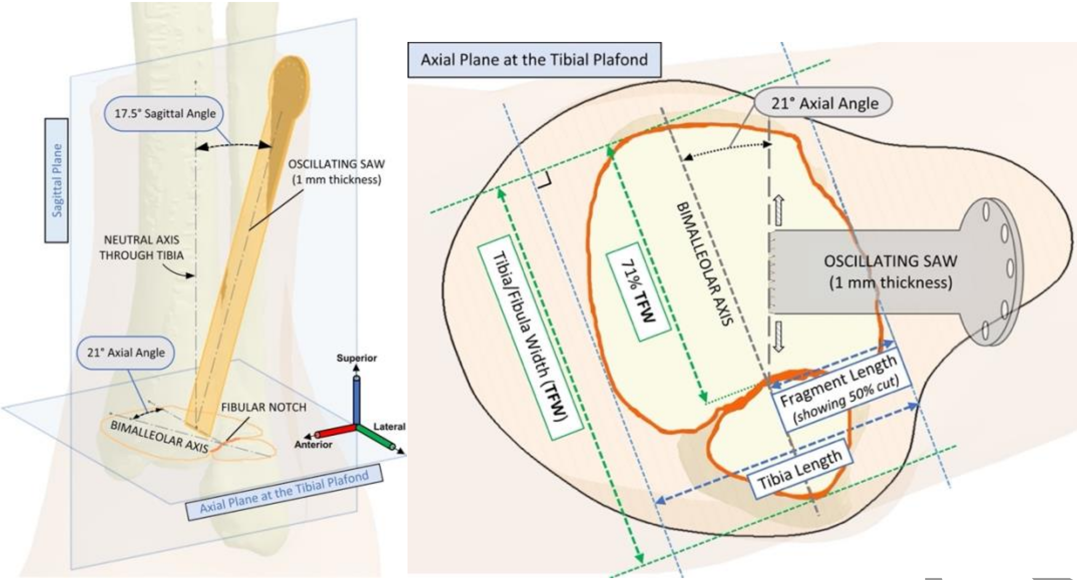

Figure 2a and 2b: The figures illustrate the creation of the PMF in a left ankle using an oscillating saw. Figure 2a demonstrates the anterolateral view of the distal tibia and fibula and Figure 2b demonstrates the axial plane of the distal tibia and fibula at the level of the tibial plafond seen from a superior view. The fracture was located posterolateral with an axial angle of 21 degrees at the level of the tibial plafond and a sagittal angle of 17.5 degrees. Additionally, each specimen was assigned to a fragment length ratio (fragment length/tibia length) of either 25% or 50%. The medial-to-lateral position of the guide for the fracture to exit in the fibular notch was set to 71% of the tibia/fibula width.

The 3D printed cutting guide was fixed to the medial aspect of the tibia using K-wires (Figure 3). Using this guide, creation of the PMF was started proximally with a 13 mm wide oscillating saw. The fracture was completed with an osteotome into the ankle joint after the guide had been removed (Figure 4). Thereafter, the AITFL and ITFL (distal 5 cm) were sectioned with a scalpel. Care was taken to leave the PITFL intact and attached to both the fibula and posterior malleolar fragment.

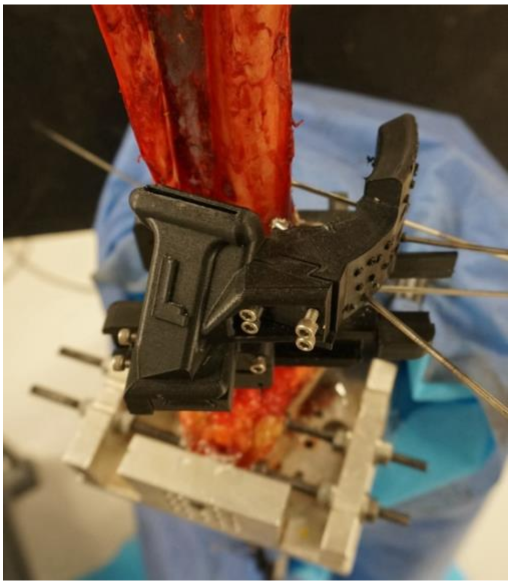

Figure 3: The figure demonstrates the cutting guide fixed to the tibia using K-wires.

Figure 4: The figure demonstrates the ankle with a 50% PMF.

After completed testing, the tibiotalar joint was disarticulated and the actual size of the posterior malleolar fragment was measured with manual calipers. The fragment size was reported as the AP distance of the fragment in relation to the AP distance of the tibial plafond at the fibular incisura.

Trans-Syndesmotic Fixation with SBs:

Trans-syndesmotic fixation consisted of 2 SBs (TightRope®, Arthrex Inc., Naples, FL, USA) inserted from lateral to medial according to the manufacturer's technique guide. Two SBs have been recommended in the treatment of Maisonneuve fractures.[7] The SB tunnels were predrilled before the PMF was completed, to avoid malreduction of the syndesmosis. The first tunnel was placed parallel and 2 cm proximal to the tibial plafond, directed 30 degrees anterior to the coronal plane. The second tunnel was placed 1 cm proximal to the first, divergently angled 15 degrees posterior to the trajectory line of the first tunnel. The angles were verified using a goniometer. After the PMF was completed, the syndesmosis was reduced with manual compression before the SBs were inserted and tensioned appropriately.[23]

Posterior Malleolar Fixation with Screws:

Before the PMF was completed with the osteotome, two 1.6 mm K-wires were inserted into the posterior malleolus perpendicular to the fracture plane, and the screw holes were drilled with a 2.6 mm cannulated drill bit. This was to avoid malreduction of the fragment. After completion of the PMF, the posterior malleolar fragment was fixed with 2 partially threaded cannulated screws with diameter 4.0 mm and length 36 mm placed from posterior to anterior using standard AO technique.

AITFL Augmentation with ST:

AITFL augmentation was performed using a suture tape (ST) with bone anchors (*Internal*Brace™, Arthrex Inc., Naples, FL, USA) inserted according to the manufacturer's technique guide. At Chaput's tubercle, the hole was placed within the footprint of the AITFL and angled slightly cephalad and medially, away from the tibiotalar and tibiofibular joint. During drilling, care was taken to not interfere with the posterior malleolar screws. The hole was tapped before insertion of a 4.75-mm BioComposite suture anchor (SwiveLock®, Arthrex Inc., Naples, FL, USA) loaded with a ST (FiberTape®, Arthrex Inc., Naples, FL, USA). The tunnel through the fibula was started within the AITFL footprint at the Wagstaffe's tubercle, drilled horizontally and parallel to the long axis of the fibula. The hole was tapped, and a 3.5-mm BioComposite suture anchor (SwiveLock®, Arthrex Inc., Naples, FL, USA) was inserted with appropriate tension of the ST by adding just under the length of the suture anchor when pulling it through the eyelid.

Biomechanical Testing:

Biomechanical testing consisted of 4 tests under a constant 100-N axial compression load, each performed at neutral and 30 degrees of plantarflexion: 1) 5 Nm external rotation, 2) 5 Nm internal rotation, 3) 88 N posterior drawer, 4) 88 N lateral drawer. Additionally, each specimen was tested with only the compressive load at neutral ankle orientation to measure the tibiofibular position at rest.

Motion Capture:

A system of 5 Miqus motion capture cameras (Qualysis AB, Göteborg, Sweden) was used to track the motion of 3D-printed reflective marker clusters drilled into each bone (Figure 5). A coordinate measuring machine (Romer Absolute Arm, Hexagon Metrology, North Kingstown, RI, USA) was used to locate anatomic landmarks on the tibia, fibula, and foot to establish joint coordinate systems, as described in the SimVitro software (SimVITRO, Cleveland, OH, USA). The location of each marker cluster was relayed to the anatomic coordinate frame by digitizing the location of the markers with the same coordinate measuring machine. Sagittal translation, rotation, and coronal translation of the fibula in addition to talar motion in relation to the tibia were recorded.

Figure 5: The figure demonstrates a cadaveric lower leg specimen mounted to the end effector of the robotic arm. Marker clusters have been drilled into each of the bones.

Statistical Analysis:

Separate random-intercepts linear mixed-effects (LME) models were used to compare experimental conditions for each combination of fragment size, robotic test, and measurement type. For each LME model, 6 possible covariance structures were considered to reflect the repeated measures experimental design (zero within-group covariance, autoregressive, compound symmetry, exponential, spherical and unstructured). The covariance structure resulting in the smallest Bayesian Information Criterion (BIC), while also producing acceptable residual diagnostics, was chosen as the final model.[4] Estimated marginal means were reported and Tukey's method was used to make all pairwise comparisons among the states. Residual diagnostics were inspected to ensure model fit and that assumptions were met. Tukey adjusted p-values less that 0.05 were considered statistically significant. The statistical software R version 4.0.3 was used for all plots and analyses.[16,25,26]

Statistical power was considered prior to experimental testing. For a 2-tailed repeated measures comparison of external rotation of the fibula between posterior malleolar fixation with screws and trans-syndesmotic fixation with SBs, and assuming an alpha level of 0.05, 10 specimens were sufficient to detect an effect size of Cohen's d = 1.0 with 80% statistical power. This is comparable to previously reported effect sizes in the biomechanical literature.[5,31] In total, 20 specimens were included in this study, with 10 specimens in each of the two fragment size groups.

RESULTS

Specimens

Only 8 specimens were included in the group with 50% PMFs because 2 specimens were considered as outliers and excluded due to abnormal testing that was not consistent with the rest of the group.

Fragment characteristics

The measured mean size of the posterior malleolar fragment was 26% (SD = 4) in the 25% PMF group and 44% (SD = 6) in the 50% PMF group.

Compressive load at neutral ankle orientation

With both 25% and 50% PMFs, compressive load at neutral ankle orientation resulted in <1.2 mm fibular translation and <1.7 degrees fibular rotation in the injured and repaired states compared to the intact state.

External rotation test

At neutral ankle orientation, the 25% PMFs demonstrated mean 5.5 mm posterior translation, 4.7 degrees external rotation, and 0.6 mm medial translation of the fibula, and 7.1 degrees external rotation of the talus compared to the intact state, which were all statistically significant (Supplemental file: Table 1). All states, except SBs only, significantly reduced posterior translation of the fibula towards normal, and all states with ST were not significantly different from the intact state (Figure 6a). Additionally, all states, except SBs only, significantly reduced external rotation of the fibula towards normal, and screws + ST and screws + ST + SBs were not significantly different from the intact state. Screws only and screws + ST significantly reduced medial translation of the fibula towards normal and were not significantly different from the intact state; however, the differences between all states were small. Finally, all states, except SBs only, significantly reduced external rotation of the talus towards normal; however, only screws + ST and screws + ST + SBs were not significantly different from the intact state (Figure 6b).

Comparable results, but with smaller magnitudes, were found with 25% PMFs and 30 degrees of plantarflexion (1.9 mm posterior translation, 1.8 degrees external rotation, and 0.5 mm medial translation of the fibula, and 1.9 degrees external rotation of the talus. $p<.001$, $p<.001$, $p=.002$, and $p<.001$, respectively). Best restoration of posterior translation of the fibula was seen in states with ST, external rotation of the fibula with screws + ST, and medial translation of the fibula with screws only. Best restoration of external rotation of the talus was seen with screws + ST and screws + ST + SBs.

The 50% PMFs at neutral ankle orientation demonstrated similar results, but with greater magnitudes than the 25% PMFs (7.0 mm posterior translation, 5.5 degrees external rotation, and 0.9 mm medial translation of the fibula, and 6.6 degrees external rotation of the talus, $p<.001$ for all comparisons).

Internal rotation test

At neutral ankle orientation, the 25% PMFs demonstrated mean 1.8 mm anterior translation of the fibula, 1.2 degrees internal rotation of the fibula, and 1.8 degrees internal rotation of the talus, which were all statistically significant from the intact state (Supplemental file: Table 2). No significant difference in fibular translation was found in the coronal plane. All states with screws were significantly different from the injured state and comparable to the intact state when looking at anterior translation of the fibula (Figure 6c), internal rotation of the fibula, and internal rotation of the talus (Figure 6d). Small differences were found in coronal translation, although a significant medial translation of the fibula was seen with SBs only and screws + ST + SBs compared to the intact and injured states. No significant difference was found between screws only and screws + ST in any of the motions.

Comparable results, and with greater magnitudes, were found with 25% PMFs and 30 degrees of plantarflexion (1.9 mm anterior translation of the fibula, 2.0 degrees internal rotation of the fibula, and 2.8 degrees internal rotation of the talus, $p<.001$ for all comparisons). Best restoration of anterior translation and internal rotation of the fibula and the talus were found in states with screws, and small differences in coronal translation were found with a significant medial translation of the fibula with screws + ST + SBs compared to the intact (0.4 mm, $p=.048$) and injured (0.5 mm, $p<.001$) states.

The 50% PMFs at neutral ankle orientation demonstrated comparable results as the 25% fragments (1.8 mm anterior translation of the fibula, 1.6 degrees internal rotation of the fibula, and 1.8 degrees internal rotation of the talus, $p<.001$ for all comparisons). All states with screws significantly returned internal rotation of the talus to the intact state; however, anterior translation of the fibula was not significantly different from the intact state only with screws + ST and screws + ST + SBs (screws only: -0.6 mm, $p=.011$; screws + ST: -0.6 mm, $p=.060$;

screws + ST + SBs: -0.5 mm, p=.210). Furthermore, screws + ST and SBs + ST returned internal rotation of the fibula closest to the intact state (screws + ST: -0.7 degrees, p=.077; SBs + ST: 0.5 degrees, p=.382). A significant medial translation of the fibula was seen in all states with SBs compared to the intact (SBs only: 1.0 mm, p=.023; SBs + ST: 1.0 mm, p=.033; screws + ST + SBs: 1.1 mm, p=.011) and injured (SBs only: 1.1 mm, p=.011; SBs + ST: 1.0 mm, p=.016; screws + ST + SBs: 1.2 mm, p=.005) states (Figure 6e).

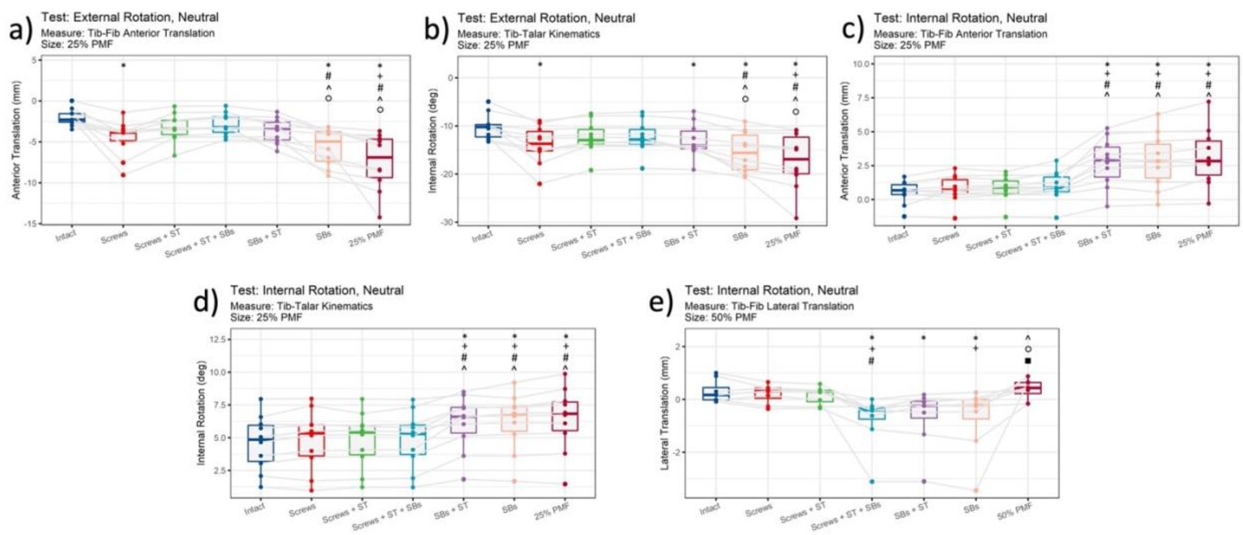

Figure 6a-e: Box plot graphs demonstrating a) anterior translation of the fibula in relation to the tibia during the external rotation test with neutral ankle orientation and 25% PMF, b) internal rotation of the talus in relation to the tibia during the external rotation test with neutral ankle orientation and 25% PMF, c) anterior translation rotation of the fibula in relation to the tibia during the internal rotation test with neutral ankle orientation and 25% PMF, d) internal rotation of the talus in relation to the tibia during the internal rotation test with neutral ankle orientation and 25% PMF, and e) lateral translation of the fibula in relation to the tibia during the internal rotation test with neutral ankle orientation and 50% PMF.

** Significant difference compared to intact state.*

+ Significant difference compared to screws.

 # Significant difference compared to screws + ST.

^ Significant difference compared to screws + ST + SBs.

○ Significant difference compared to SBs + ST.

▪ Significant difference compared to SBs.

Posterior drawer test

With 25% PMFs, minor differences were seen between the states with posterior drawer, both in neutral and 30 degrees of plantarflexion. Although some states were significantly different statistically, the differences were ≤1 mm and ≤2 degrees, and likely to be clinically irrelevant. Greater magnitudes were seen with 50% PMFs with a statistically significant posterior translation of the fibula, external rotation of the fibula, and posterior translation of the talus compared to the intact state (Supplemental file: Table 3). Screws + ST and screws + ST + SBs returned posterior translation of the fibula to the intact state. None of the repairs returned external rotation of the fibula or posterior translation of the talus to the intact state. States with SBs resulted in a significant medial translation of the fibula compared to the intact state.

Lateral drawer test

With both 25% and 50% PMFs, minor differences were seen between the states with neutral ankle orientation and lateral drawer. Although some states were significantly different statistically, the differences were ≤1.2 mm and ≤2 degrees, and likely to be clinically irrelevant.

With 25% PMFs and 30 degrees of plantarflexion, greater magnitudes were seen (Supplemental file: Table 4). The injured state demonstrated significant anterior translation of the fibula compared to the intact state, and states with screws significantly returned the anterior translation and were not different from the intact state. Also, the injured state demonstrated a significant lateral translation of the talus compared to intact state that was reduced in states with screws. SBs only and screws + ST + SBs resulted in a significant medial translation of the fibula compared to the intact and injured states. Small differences were seen in rotation of the fibula.

DISCUSSION

In contradiction to our hypothesis, posterior malleolar fixation with screws resulted in higher syndesmotic and ankle stability compared to trans-syndesmotic fixation with SBs. Overall, the stability with SBs only was poor. Posterior malleolar screw fixation with AITFL augmentation restored syndesmotic and ankle kinematics during external rotation of the foot better than posterior malleolar screw fixation alone. Minor differences were found in the efficacy of treatments between 25% and 50% PMFs. These findings suggest that posterior malleolar fixation with AITFL augmentation provides the most stable situation in syndesmosis injuries.

Syndesmosis malreduction has been reported to be the most important negative predictor of outcome after ankle fracture,[35] and is associated with osteoarthritis and worse functional result.[2,28] With sequential sectioning of the syndesmosis and deltoid ligament, Hunt et al.[12] found a significant increase and a posterolateral shift of tibiotalar contact pressure after the ITFL and transverse ligament had been sectioned. Only 1 mm of talar translation may decrease tibiotalar contact area by up to 42% and predispose to posttraumatic osteoarthritis.[27] Consequently, reduction and stabilization of the syndesmosis is key to achieving the optimal clinical outcome.

Traditionally, syndesmosis injuries have been treated with trans-syndesmotic screw fixation. Due to a high risk of malreduction and need for implant removal, trans-syndesmotic fixation using SB has become increasingly popular, allowing for more physiologic motion of the syndesmosis and better functional outcome compared to screw fixation.[30] However, even though SBs have shown tibiotalar contact pressure that is closer to the intact state compared to screws,[22] both 1 and 2 SBs have demonstrated inadequate stabilization of the fibula in the sagittal and axial plane compared to the intact state.[5,22,33] These findings were supported in the present study, where SBs only demonstrated increased posterior translation and external rotation of the fibula in the external rotation test and increased anterior translation and internal rotation of the fibula in the internal rotation test. Although it is unknown how much syndesmotic stability is required for anatomic syndesmosis healing, inadequate stability may lead to increased scarring, pain, and reduced ankle function.

More recently, AITFL augmentation has been suggested to restore anatomic restraint of the syndesmosis which may increase resistance to sagittal fibular translation and rotation while still maintaining a dynamic construct.[31,32,36] In a partial syndesmosis injury model with intact PITFL, SB with ST augmentation and ST only demonstrated syndesmotic stability that was comparable to the intact state with dorsiflexion, inversion, and external rotation of the foot.[31] Contrary, SB only was significantly different from the intact state. Although a complete syndesmosis injury was created in the present study, all states with ST demonstrated highest syndesmotic stability in the external rotation test in terms of posterior fibular translation. Additionally, screws + ST and screws + ST + SBs were not significantly different from the intact state in terms of external rotation of the fibula and the talus. Our results are consistent with the previous literature,[31,32,36] demonstrating that AITFL augmentation may provide additional syndesmotic stability with external rotation of the foot.

Recent studies have suggested that posterior malleolar fixation may restore the tension of the PITFL and thereby stabilize the syndesmosis, obviating the need for trans-syndesmotic fixation. Gardner et al.[10] created an injury simulating a PER Stage 4 injury in 10 cadaveric specimens, including a 5 mm thick posterior malleolar fragment and cut deltoid ligament, AITFL, and IOM. The specimens had either PMF fixation with a screw or trans-syndesmotic fixation with a 3.5 mm tricortical screw. With external rotation of the foot, posterior malleolar fixation restored 70% of the ankle stiffness compared to 40% with trans-syndesmotic fixation. Clinical studies have reported a reduced need for syndesmotic fixation after posterior malleolar fixation.[3,17,21] Miller et al.[21] reported that 2% of the patients had syndesmotic instability after fixation of the PMF compared to 27% without PMF fixation. Baumbach et al.[3] reported that only 25% of the patients required trans-syndesmotic fixation after posterior malleolar plate fixation compared to 61% after AP screws and 63% after no fixation, with no impact of fragment size (smaller or larger than 25%) in each group. Mean fragment sizes in the respective groups were 24.7%, 30.3%, and 15.6% of the tibial plafond. Additionally, plate fixation had a significantly better reduction compared to AP screws and no fixation. Other studies have reported comparable radiographic syndesmosis reduction and functional score with posterior malleolar fixation and syndesmotic fixation.[19,20] Even though the results after posterior malleolar fixation have been promising, trans-syndesmotic fixation has remained the gold standard for treating these injuries.[1]

In this study, compressive load at neutral ankle orientation resulted in only small changes in fibula motion in the injured and repaired states, indicating that none of the procedures pulled the fibula away from its natural resting position. In the internal rotation test, posterior malleolar screw fixation alone returned translation and rotation of the fibula and talus to the intact state. However, in the external rotation test, screws only were not sufficient. Of note, we found that trans-syndesmotic fixation with SBs only did not restore fibular or talar motion, neither with external nor internal rotation of the foot. In fact, SBs tended to translate the fibula medially, thereby compressing or over reducing the syndesmosis. Overreduction with SBs has also been reported in previous studies[29]; however, since the SBs may sag over time, the clinical implication of overreduction is unknown.[24] Augmentation with ST ensured syndesmosis integrity by anatomical restoration of 2 of the 3 syndesmotic ligaments: the PITFL and AITFL with posterior malleolar screws and ST, or the ITFL/IOM and AITFL with SBs and ST, respectively. In the external rotation test, ST provided additional stability to both screws and SBs; however, best stability was seen with screws and ST. In the internal rotation test, no additional stability was provided by ST with 25% PMFs, neither with screws nor SBs. With 50% PMFs, screws and ST was the only fixation that was not significantly different from the intact state, although all states with screws provided stability that was closer to the intact state. The low number of specimens with 50% PMFs may explain why screws only and screws with ST and SB did not return the motions to the intact state. Interestingly, restoration of all 3 syndesmotic ligaments, including posterior malleolar screws for PITFL, ST for AITFL, and SBs for ITFL/IOM, did not provide additional stability to the syndesmosis or ankle joint compared to posterior malleolar screws and ST.

The impact of the PMF on the syndesmosis has been explored to a limited extent. In a biomechanical study, Fitzpatrick et al.[9] reported posterior and lateral displacement of the fibula in the incisura after PMFs had been fixed in malreduction. This demonstrates the importance of anatomic reduction of the PMF for syndesmosis reduction. Jayatilaka et al.[14] showed that the PITFL insertion is broad, extending up to 58 mm proximal to the tibiotalar joint and blending with the posterior tibial tendon sheath medially. They also found that syndesmotic instability was present more frequently in Mason type 2A compared to 2B fractures, indicating that a portion of the PITFL surrounding the fragment must be avulsed from the tibia for syndesmotic instability to occur in type 2A fractures. In the present study, only the PITFL that was attached to the posterior malleolar fragment was left intact, resulting in syndesmotic instability in all specimens regardless of fragment size. In agreement with Jayatilaka et al.,[14] this suggests that the size of the PMF may be irrelevant when evaluating syndesmotic stability.

Furthermore, fixation of the fragment significantly improved syndesmotic stability in all specimens, suggesting that only a portion of the PITFL needs to be reattached to the tibia to restore syndesmotic stability. Therefore, we recommend posterior malleolar screw fixation (or a posterior plate[34]) for all PMFs with fragment length ratio of 25% or larger to restore PITFL tension and subsequently syndesmotic and ankle joint stability.

We acknowledge the limitations of the present study. This is a time zero cadaveric study where the ankle injury and surgical treatment do not directly translate to clinical practice, and the rehabilitation and tissue healing is not considered. All soft tissues, except ligaments, were removed to facilitate accurate and reproducible injuries and repairs. A standardized injury model with intact fibula and deltoid ligament was created to limit the number of confounding variables. Another limitation is that the fragment length ratio was used to create 25% and 50% PMFs. The correlation between fragment length ratio and fragment size measured on lateral plain radiographs has, to our knowledge, not been examined previously. However, fragment size on axial CT scans, calculated as a percentage of fragment involvement in relation to the fibula incisura, has been demonstrated to be in poor agreement with fragment size on lateral plain radiographs.[39] This implies that the size of the PMFs in the present study was not directly transferable to lateral plain radiographs. However, due to low inter- and intraobserver reproducibility reported on lateral plain radiographs,[39] other measurements for determining surgical indication should be considered in the future. Furthermore, the present study was designed to examine how to best stabilize the syndesmosis with presence of a PMF. As both fragments had a fragment length ratio of at least 25%, no conclusions can be drawn for PMFs with a fragment length ratio smaller than 25%. Cyclic testing over time was not included in the test protocol, and the durability of the constructs could not be examined.

In conclusion, posterior malleolar screws resulted in higher syndesmotic stability compared to trans-syndesmotic SBs. AITFL augmentation provided additional external rotational stability when combined with posterior malleolar screws. Trans-syndesmotic SBs did not provide any additional stability and tended to translate the fibula medially. Posterior malleolar fixation with AITFL augmentation using ST may be the preferred surgical method when treating patients with acute ankle injury involving an unstable syndesmosis and a PMF of 25% or larger.

References

1. AO Surgery reference. http://www.aofoundation.org. Accessed 19 April 2022.
2. Andersen MR, Diep LM, Frihagen F, et al. The importance of syndesmotic reduction on clinical outcome after syndesmosis injuries. *J Orthop Trauma.* 2019.
3. Baumbach SF, Herterich V, Damblemont A, et al. Open reduction and internal fixation of the posterior malleolus fragment frequently restores syndesmotic stability. *Injury.* 2019;50(2):564-570.
4. Burnham K, Anderson D. Practical use of the information-theoretic approach. In: *Model selection and inference.* New York, NY: Springer; 1998:75-117.
5. Clanton TO, Whitlow SR, Williams BT, et al. Biomechanical Comparison of 3 Current Ankle Syndesmosis Repair Techniques. *Foot Ankle Int.* 2017;38(2):200-207.
6. Clanton TO, Williams BT, Backus JD, et al. Biomechanical Analysis of the Individual Ligament Contributions to Syndesmotic Stability. *Foot Ankle Int.* 2017;38(1):66-75.
7. Cottom JM, Hyer CF, Philbin TM, Berlet GC. Treatment of syndesmotic disruptions with the Arthrex Tightrope: a report of 25 cases. *Foot Ankle Int.* 2008;29(8):773-780.
8. Court-Brown CM, McBirnie J, Wilson G. Adult ankle fractures—an increasing problem? *Acta Orthop Scand.* 2009;69(1):43-47.
9. Fitzpatrick E, Goetz JE, Sittapairoj T, et al. Effect of Posterior Malleolus Fracture on Syndesmotic Reduction: A Cadaveric Study. *J Bone Joint Surg Am.* 2018;100(3):243-248.
10. Gardner MJ, Brodsky A, Briggs SM, Nielson JH, Lorich DG. Fixation of posterior malleolar fractures provides greater syndesmotic stability. *Clin Orthop Relat Res.* 2006;447:165-171.
11. Haraguchi N, Haruyama H, Toga H, Kato F. Pathoanatomy of posterior malleolar fractures of the ankle. *J Bone Joint Surg Am.* 2006;88(5):1085-1092.
12. Hunt KJ, Goeb Y, Behn AW, Criswell B, Chou L. Ankle Joint Contact Loads and Displacement With Progressive Syndesmotic Injury. *Foot Ankle Int.* 2015;36(9):1095-1103.
13. Jaskulka RA, Ittner G, Schedl R. Fractures of the posterior tibial margin: their role in the prognosis of malleolar fractures. *J Trauma.* 1989;29(11):1565-1570.

14. Jayatilaka MLT, Philpott MDG, Fisher A, et al. Anatomy of the Insertion of the Posterior Inferior Tibiofibular Ligament and the Posterior Malleolar Fracture. *Foot Ankle Int.* 2019;40(11):1319-1324.
15. Larkins CG, Brady AW, Aman ZS, et al. Evaluation of the Intact Anterior Talofibular and Calcaneofibular Ligaments, Injuries, and Repairs With and Without Augmentation: A Biomechanical Robotic Study. *Am J Sports Med.* 2021;49(9):2432-2438.
16. Lenth R. emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.4.6. https://CRAN.R-project.org/package=emmeans.
17. Li M, Collier RC, Hill BW, Slinkard N, Ly TV. Comparing Different Surgical Techniques for Addressing the Posterior Malleolus in Supination External Rotation Ankle Fractures and the Need for Syndesmotic Screw Fixation. *J Foot Ankle Surg.* 2017;56(4):730-734.
18. Mason LW, Marlow WJ, Widnall J, Molloy AP. Pathoanatomy and Associated Injuries of Posterior Malleolus Fracture of the Ankle. *Foot Ankle Int.* 2017;38(11):1229-1235.
19. Miller AN, Carroll EA, Parker RJ, et al. Direct visualization for syndesmotic stabilization of ankle fractures. *Foot Ankle Int.* 2009;30(5):419-426.
20. Miller AN, Carroll EA, Parker RJ, Helfet DL, Lorich DG. Posterior malleolar stabilization of syndesmotic injuries is equivalent to screw fixation. *Clin Orthop Relat Res.* 2010;468(4):1129-1135.
21. Miller MA, McDonald TC, Graves ML, et al. Stability of the Syndesmosis After Posterior Malleolar Fracture Fixation. *Foot Ankle Int.* 2018;39(1):99-104.
22. Pang EQ, Bedigrew K, Palanca A, et al. Ankle joint contact loads and displacement in syndesmosis injuries repaired with Tightropes compared to screw fixation in a static model. *Injury.* 2019;50(11):1901-1907.
23. Park YH, Ahn JH, Choi GW, Kim HJ. Comparison of Clamp Reduction and Manual Reduction of Syndesmosis in Rotational Ankle Fractures: A Prospective Randomized Trial. *J Foot Ankle Surg.* 2018;57(1):19-22.
24. Peterson KS, Chapman WD, Hyer CF, Berlet GC. Maintenance of reduction with suture button fixation devices for ankle syndesmosis repair. *Foot Ankle Int.* 2015;36(6):679-684.
25. Pinheiro J, Bates D, DebRoy S, Sarkar D, R Core Team. nlme: Linear and Nonlinear Mixed Effects Models. https://CRAN.R-project.org/package=nlme. Accessed Feb 21, 2021.
26. R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing. https://www.R-project.org/. Accessed Feb 21, 2021.
27. Ramsey PL, Hamilton W. Changes in tibiotalar area of contact caused by lateral talar shift. *J Bone Joint Surg Am.* 1976;58(3):356-357.
28. Ray R, Koohnejad N, Clement ND, Keenan GF. Ankle fractures with syndesmotic stabilisation are associated with a high rate of secondary osteoarthritis. *Foot Ankle Surg.* 2019;25(2):180-185.
29. Schon JM, Mikula JD, Backus JD, et al. 3D Model Analysis of Ankle Flexion on Anatomic Reduction of a Syndesmotic Injury. *Foot Ankle Int.* 2017;38(4):436-442.
30. Shimozono Y, Hurley ET, Myerson CL, Murawski CD, Kennedy JG. Suture Button Versus Syndesmotic Screw for Syndesmosis Injuries: A Meta-analysis of Randomized Controlled Trials. *Am J Sports Med.* 2019;47(11):2764-2771.

31. Shoji H, Teramoto A, Suzuki D, et al. Suture-button fixation and anterior inferior tibiofibular ligament augmentation with suture-tape for syndesmosis injury: A biomechanical cadaveric study. *Clin Biomech (Bristol, Avon).* 2018;60:121-126.
32. Teramoto A, Shoji H, Sakakibara Y, et al. Suture-Button Fixation and Mini-Open Anterior Inferior Tibiofibular Ligament Augmentation Using Suture Tape for Tibiofibular Syndesmosis Injuries. *J Foot Ankle Surg.* 2018;57(1):159-161.
33. Teramoto A, Suzuki D, Kamiya T, et al. Comparison of different fixation methods of the suture-button implant for tibiofibular syndesmosis injuries. *Am J Sports Med.* 2011;39(10):2226-2232.
34. Wang X, Yin J, Zhang C, et al. Biomechanical Study of Screw Fixation and Plate Fixation of a Posterior Malleolar Fracture in a Simulation of the Normal Gait Cycle. *Foot Ankle Int.* 2017;38(10):1132-1138.
35. Weening B, Bhandari M. Predictors of functional outcome following transsyndesmotic screw fixation of ankle fractures. *J Orthop Trauma.* 2005;19(2):102-108.
36. Wood AR, Arshad SA, Kim H, Stewart D. Kinematic Analysis of Combined Suture-Button and Suture Anchor Augment Constructs for Ankle Syndesmosis Injuries. *Foot Ankle Int.* 2020;41(4):463-472.
37. Yao L, Zhang W, Yang G, et al. Morphologic characteristics of the posterior malleolus fragment: a 3-D computer tomography based study. *Arch Orthop Trauma Surg.* 2014;134(3):389-394.
38. Yi Y, Chun DI, Won SH, et al. Morphological characteristics of the posterior malleolar fragment according to ankle fracture patterns: a computed tomography-based study. *BMC Musculoskelet Disord.* 2018;19(1):51.
39. Zhang K, Jia X, Qiang M, et al. Quantitative Evaluation of Articular Involvement of Posterior Malleolus Associated with Operative Indication: A Comparative Study of Six Methods Based on Radiography and CT. *Biomed Res Int.* 2020;2020:6745626.

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Title of thesis: On the treatment of unstable ankle fractures

Page	Paragraph	Line	Original text	Revision type	Revised text
5	1	2	... department of orthopaedics at ...	Correction	... orthopaedic department at ...
16	1	1	The recent years ...	Correction	In recent years ...
20	1	1	... and deltoid ligament was cut.	Correction	... and deltoid ligament were cut.
20	1	2	… was cut isolated.	Correction	… were cut isolated.
21	2	4	… supination addiction …	Correction	… supination adduction …
28	2	4	The more recent years …	Correction	In more recent years …
43	2	5	… the 1. metatarsophalangeal …	Correction	… the first metatarsophalangeal …
50	Figure 16			Changed figure (incorrect figure copied from cited reference)	
50	Figure legend Figure 16		The whiskers represent the outliers within 1.5 times the IQR. Analysis with Mann-Whitney U-test.	Correction	The whiskers represent the minimum and maximum recorded score. SS = tricortical screw, SB = suture button.
50	Figure legend Figure 17		Figure by Ræder et al., Acta Orthopaedica 2020 (212).	Correction	Figure by LBW Ræder, thesis, University of Oslo 2021 (214). Reprinted with permission.
53	2	6	… neither Peeperkorn et al. (nail: 13%, plate: 29%) nor …	Correction	… either Peeperkorn et al. (nail: 13%, plate: 29%) or …
54	1	7	… reaming of then canal …	Correction	… reaming of the canal …
56	1	1	… have expressed concerns …	Correction	… have highlighted concerns …
56	2	3	… thereby increase fibular stability.	Correction	… thereby increasing fibular stability.
57	1	1	Both paper I and II …	Correction	Both papers I and II …
57	1	5	… methods that was the best …	Correction	… methods was the best …
58	3	6	… resulted in lost …	Correction	… resulted in loss …
59	1	7	… fractures in Norwegian.	Correction	… fractures in Norwegian language.