Chronic instability of *the anterior syndesmosis* of the ankle

Annechien Beumer

Chronic instability of the anterior syndesmosis of the ankle

Biomechanical, kinematical, radiological and clinical aspects

Thesis

Annechien Beumer

To my parents Ria Beumer-Sonneveld and Jaap Beumer,
for their love, support and encouragement to be everything I wanted to be.

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Thesis

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There is no doubt that Genius lasts longer than Beauty.
That accounts for the fact that we all take such pains to over-educate ourselves.
Oscar Wilde; The picture of Dorian Gray.

Contents

Chapter 1

Introduction

This thesis is concerned with chronic anterior instability of the tibiofibular syndesmosis of the ankle. The ankle plays a fundamental role in locomotion. It consists of the talocrural and distal tibiofibular joint. The latter is a syndesmosis, a fibrous joint with ample intervening fibrous connective tissue. The syndesmosis consists of the anterior inferior tibiofibular ligament (ATiFL, also known as the anterior syndesmosis), the interosseous ligament (IL), and the posterior inferior tibiofibular and transverse ligaments (PTiFL and TL), also known as the posterior syndesmosis). Some authors recognize the transverse ligament as a separate entity.

Injuries of the tibiofibular syndesmosis can occur in isolation or in combination with osseous or ligamentous ankle injuries. This thesis focuses on syndesmotic injuries without ankle fractures. To stress that no ankle fracture is present they are called 'isolated syndesmotic injuries', even though concomitant ligamentous or soft tissue injuries and tibiofibular avulsion fractures may be present. In this thesis the emphasis will be put on chronic anterior syndesmotic instability, but other syndesmotic injuries will be mentioned too.

Unless defined otherwise, syndesmotic rupture is defined as: 'a complete rupture or avulsion of one of more syndesmotic ligaments'. Partial tears are also referred to as sprains. In clinical practice the extent of the ligamentous injury is not always evident. The incidence of syndesmotic injury appears to be low as these injuries are not easily recognized and clinicians lack familiarity with this type of injury (Vertullo 2002, Gerber et al. 1998). When acute syndesmotic injuries are not recognized, or insufficiently treated, the complaints may become chronic. Adequate treatment is complicated because no consensus exists on the optimal physical examination, additional investigations or therapy of syndesmotic injuries.

The aim of this thesis is to provide more insight into chronic isolated instability of the distal anterior tibiofibular syndesmosis in order to optimize recognition, examination and treatment of these injuries. The studies performed for this purpose comprised biomechanic and kinematic, as well as clinical and radiological investigations.

Incidence

Ankle sprains are among the most common injuries of the locomotor system (Fallat et al. 1998). Estimates for The Netherlands were around 45000 ankle sprains in the year 2002 (Verhagen 2004). In the majority of ankle sprains the lateral collateral ligaments are involved, less frequently the deltoid ligament is (Fallat et al. 1998, Broström 1964). Syndesmotic injuries are reported to comprise 1 to 11% of all ankle sprains (Hopkinson et al.1990, Cedell 1975). In populations actively involved in high-level or high impact sporting activities, the incidence may be higher than 30% of all ankle sprains (Crim 2003, Gerber et al. 1998). Even higher incidences (50% direct and 36.2% indirect signs of syndesmotic injury) were reported in a study using arthrography (Weissman and Lazis 1980). In a retrospective study using MRI to assess injuries to the ankle joint in 90 severe ankle sprains Brown et al. (2004) found a syndesmotic injury in 63% (24% acute; 38% chronic). Most of the above mentioned studies describe sprains and ruptures of syndesmotic ligaments.

Gerber et al. (1998) described that the true incidence in the general population is higher than reported since syndesmotic sprains are probably under-diagnosed. It has not been reported in the literature why syndesmotic injuries are less frequent than lateral ankle sprains, but one reasons may be the rare trauma mechanism and another the fact that the syndesmotic ligaments are stronger than the lateral collateral ankle ligaments.

Long-term complications

Patients with a syndesmotic sprain or rupture are known to have a longer period of recovery than those with lateral ankle sprains (Ogilvie-Harris et al. 1994, Boytim et al. 1991, Hopkinson et al. 1990). Furthermore, these patients may have remaining long-term complaints as well (Boytim et al. 1991, Hopkinson et al. 1990). These problems may be due to impingement of scar tissue of the injured posterior tibiofibular ligament (Ogilvie-Harris et al. 1994) or intra articular adhesions (Pritsch et al. 1993). Furthermore, calcifications in the syndesmotic area and tibiofibular synostoses have been described. Fibular stress fractures have been reported to develop above such a synostosis (Kottmeier et al. 1992, Whiteside et al. 1978).

Syndesmotic injuries may result in chronic instability (Nussbaum et al. 2001, Kelikian and Kelikian 1985, Bonnin 1965, Mullins and Sallis 1958, Outland 1943, Alldredge 1940). When instability can be objectively documented with clinical and radiographic criteria it is defined as mechanic instability. Based on clinical symptoms only, such as the subjective sensation of the ankle giving way or feelings of instability on an uneven surface, instability can be referred to as functional (Freeman 1965). In the syndesmosis mechanic instability can be the result of wide-ning of the ankle mortise. If this condition is not recognized or left untreated permanent disability or an abduction deformity of the ankle with lateral subluxation of the talus may result (Bonnin 1965, Alldredge 1940). Osteoarthritis of the ankle joint will then develop (Figure 1). Thus, early recognition and treatment of syndesmotic injuries is of the utmost importance for a normal painless ankle with a functional gait.

Figure 1
Osteoarthritis of the ankle joint because mortise widening was not recognized or left untreated.

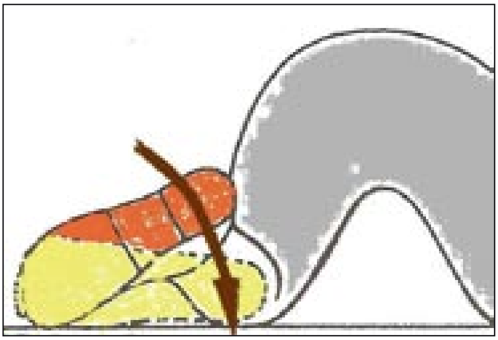

Figure 2
Syndesmotic injuries due to external rotation of ankle and foot can be the result from a direct impact put on the posterolateral aspect of the leg of a fallen rodeo bull rider or football player who is 'sitting' on the knees (Slawski and West 1997, Boytim et al. 1991).

Trauma mechanism

Pronation-abduction, pronation-eversion, supination-eversion, external rotation, supination-abduction and dorsiflexion have been described as trauma mechanisms that may result in (an isolated) syndesmotic injury (Orthner 1989, Pankovich 1979, Frick 1978, Weber 1966, Lauge-Hansen 1950). In clinical studies inversion is also mentioned as traumamechanism (Hopkinson et al. 1990).

Lauge-Hansen (1949), called the isolated syndesmotic injury 'a ligamentous ankle fracture'. He also described this as a stage-1 supination-eversion (external rotation) fracture, or a stage-2 supination-abduction, pronation-abduction or pronation-eversion fracture if the deltoid ligament was injured (Lauge-Hansen 1950). Syndesmotic injuries due to external rotation of ankle and foot are the most described (Ward et al. 1994, Taylor et al. 1992, Boytim et al. 1991, Fritschy 1989, Pankovich 1978, Mullins and Sallis 1958, Outland 1943). These injuries are often the result of trauma sustained during high-level and high-contact sports and have been described to result from straddling a gate while slalom skiing (Crim 2003, Fritschy 1989), or from a direct impact put on the posterolateral aspect of the leg of a fallen rodeo bull rider or football player who is 'sitting' on the knees (Figure 2; Slawski and West 1997, Boytim et al. 1991).

Classification

According to Kelikian and Kelikian (1985) there are 3 types of syndesmotic injuries without ankle fractures. The most common, and the most difficult to recognize, is the anterior syndesmotic diastasis (Figure 3), an injury resulting from external rotation of the talus. This disruption of the syndesmosis proceeds from front to back and may show associated injuries. An avulsion of the posterolateral margin of the tibia, the 'lipping fracture', is often seen. The intact posterior tibiofibular ligament can act as a hinge, resulting in an 'open book' injury. A partial or fully ruptured deltoid ligament may also be seen with this type of injury. The chronic form of anterior syndesmotic diastasis is similar to the chronic isolated anterior instability of the tibiofibular syndesmosis that is subject of this thesis.

The second type in the Kelikians' classification is complete tibiofibular diastasis (Figure 4), defined by a rupture of all 4 syndesmotic ligaments. It results from external rotation or abduction. This diastasis is often associated with a fracture of the medial malleolus or a rupture of the deltoid ligament. The least common form of diastasis is intercalary diastasis; a diastasis seen in children resulting from rupture of the interosseous membrane combined with a metaphyseal fracture of the fibula and a physeal fracture of the tibia. In this diastasis the syndesmotic ligaments remain intact (Figure 5).

Edwards and DeLee (1984) suggested another classification of adult ankle diastasis without fracture based on only 6 patients.

Medical History

A patient's medical history may give the first clue that leads the clinician to the diagnosis of chronic anterior instability of the distal tibiofibular syndesmosis. At first the trauma mechanism described can raise suspicion for this particular type of injury. Furthermore patients may indicate that in the acute stage they had noticed a swelling located at the level of the syndesmosis. The level of the swelling is important for diagnosis because this swelling is located at or above the anterior tibiofibular ligament (Miller et al. 1995, Boytim et al 1991, Karl and Wrazidlo 1987, Frick 1978, Kelikian and Kelikian 1985). It is thus more proximal and anterior and therefore different, and maybe less obvious, than the swelling seen in the more common lateral collateral ligament injuries (Gerber et al. 1998). Such a swelling is called a 'high ankle sprain' (Teitz and Harrington 1998) and may last into the chronic stage. In the acute stage patients complain of pain over the anterior syndesmosis and often the deltoid area. Sometimes the posterior syndesmosis is painful also. In the chronic stage patients experience pain during and after exercise and on dorsiflexion. Other symptoms found in the chronic stage include stiffness and feelings of instability, especially on rough or uneven ground (Grass et al. 2000, Taylor et al. 1992, Mullins and Sallis 1958). Most patients show a longer period of recovery than those with ordinary lateral ankle sprains (Ogilvie-Harris et al. 1994, Taylor et al. 1992, Boytim et al. 1991, Hopkinson et al. 1990, Katznelson et al. 1983, Whiteside et al. 1978).

Summarizing recurrent 'high' swelling, stiffness, feelings of instability or the sensation of giving way and pain over the syndesmosis at palpation and during dorsiflexion are commonly

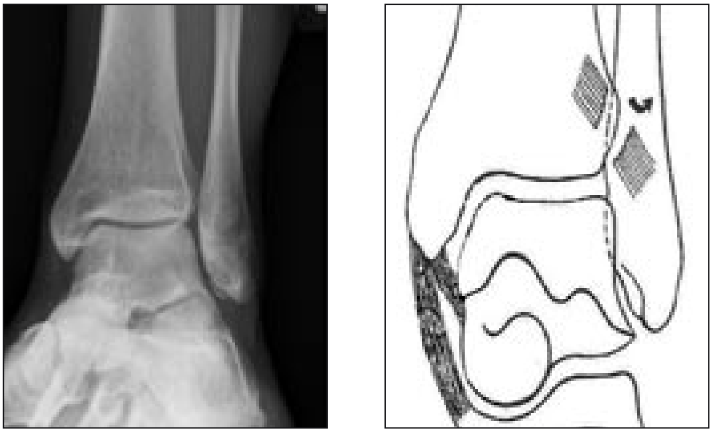

Figure 3
Anterior tibiofibular diastasis

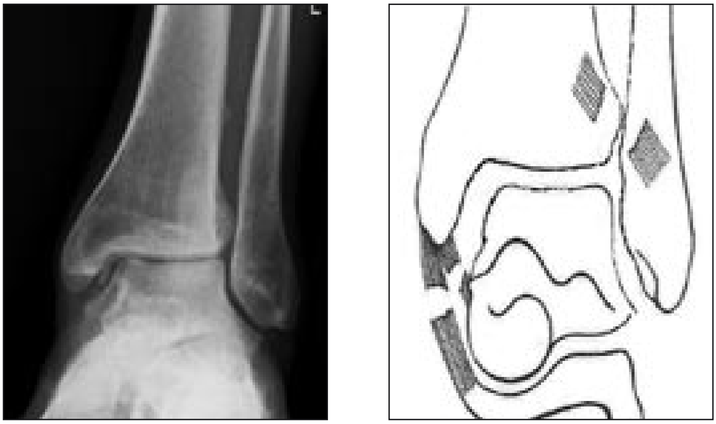

Figure 4
Complete tibiofibular diastasis

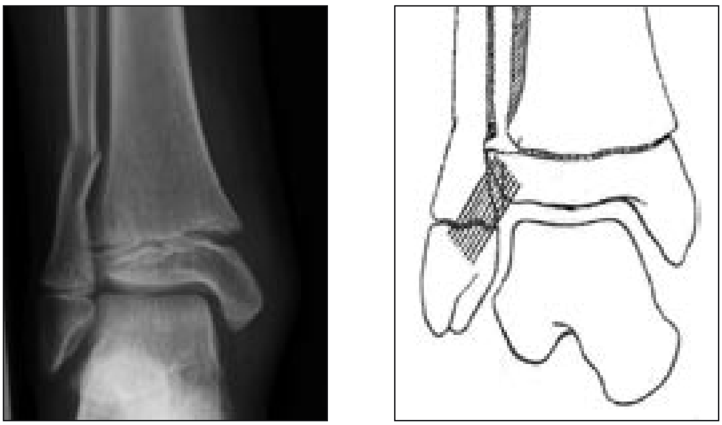

Figure 5
Intercalary diastasis

found in patients with a chronic injury of the distal syndesmosis.

Physical Examination

Although the medical history may suggest a syndesmotic injury, it is important to perform a comprehensive examination of the entire ankle and foot to prevent another concomitant or adjacent injury being missed. At examination, patients with chronic syndesmotic injuries may still show symptoms of a 'high' ankle sprain. Pain is usually found over the anterior tibiofibular ligament. It may extend cranially along the interosseous membrane. Less frequently the patient may have pain around the lateral and medial malleolus. When assessing the range of motion, a minor limitation in dorsiflexion is often found. Dorsiflexion and eversion are usually painful (Ward 1994, Dittmer and Huf 1987, Ruf et al. 1987, Frick 1978). As part of the clinical examination four clinical syndesmotic stress tests have been described:

The first is the *Cotton test* which was originally used to diagnose Pott's ankle fracture. It is performed by stabilizing the distal tibia and applying lateral force to the foot, creating a lateral translation of the foot, which is indicative of syndesmotic instability (Cotton 1910). The same phenomenon has also been described by Mullins and Sallis (1958). Their test is performed by 'rocking' the talus in the ankle mortise from side to side in order to diagnose the syndesmotic instability. A positive test has a characteristic feeling of a click in the ankle mortise. In the German literature Jäger and Wirth (1978) have later described the same phenomenon. The experience of Mullins and Sallis was that in some cases in the chronic stage the rocking could be diminished by compression of the mortise.

The second test is the *squeeze test*, in which the fibula is squeezed towards the tibia at the midpoint of the calf. This test is considered positive when the proximal compression produces pain distally in the area of the syndesmosis (Teitz and Harrington 1998, Hopkinson et al. 1990). The same test is performed in a slightly different fashion by Kiter and Bozkurt (2005). Before these publications pain at compression of the mortise had been reported on as the test of Frick in the German literature (Frick 1987).

The *external rotation test* is performed by applying an external rotation stress to the involved foot and ankle with the knee held in 90° of flexion and the ankle in a neutral position. A positive test produces pain over the anterior or posterior tibiofibular ligaments and the interosseous membrane. This test can be performed in the acute and chronic stage (Boytim et al.1991, Ogilvie-Harris et al. 1994).

The final stress test described is *the fibula translation* test which is considered positive when anteroposterior translation of the fibula with respect to the tibia is possible (Ogilvie-Harris et al.1994). Pain at passive dorsiflexion (Ward 1994) and pain at palpation of the tibiofibular ligament (Taylor et al. 1992) have also been described as additional syndesmotic tests.

In retrospective studies, the squeeze test (Hopkinson et al. 1990), the external rotation test (Boytim et al. 1991) and the palpation test (Taylor et al. 1992) were used to assess syndesmotic injury: the tests were able to differentiate between individuals that would have a prolonged reco-very time after a sprain and those that would not. The patients with a prolonged recovery time were diagnosed as having a syndesmotic injury. This diagnosis, however, was not confirmed by radio-logical examinations or arthroscopy. In a prospective study, Alonso et al. (1998) assessed the inter-rater reliability of these 3 tests and a modification of the dorsiflexion test as well as the ability of these tests to predict prolonged recovery time. The results of the external rotation test showed the best inter-rater reliability, while the squeeze test showed moderate inter-rater reliability and the dorsiflexion-compression test and the palpation test showed only fair inter-rater reliability.

Differential Diagnosis

The differential diagnosis of chronic syndesmotic instability comprises a number of pathological changes which may include lateral ankle instability. Ogilvie-Harris et al. (1994) described scarring of the posterior tibiofibular ligament and disruption of the interosseous ligament as well as chondral damage. Others described impingement by osteophytes (Raikin and Cooke, 1999) or a thickened distal fascicle of the anterior tibiofibular ligament (Basset et al. 1990). Other possible diagnoses include the medial impingement syndrome (Mosier-LaClaire et al. 2000), adhesions in the tibiofibular syndesmosis (Pritsch et al. 1993), osteochondral fractures, loose bodies, as well as a generalized synovitis of the talocrural joint, the sinus tarsi syndrome, subtalar joint problems and tension neuropathy of the superior peroneal nerve resulting in an entrapment syndrome (Johnston and Howell 1999). However, as clinical examination alone is not sufficient to diagnose chronic anterior syndesmotic instability, additional investigations are necessary.

Diagnostic Imaging

Radiography: If the syndesmosis is completely disrupted and the fibula (sub)luxated,diastasis may be seen on plain anterior-posterior (AP) ankle or mortise (M) radiographs (Pavlov et al. 1999, Edwards and De Lee 1984). When no diastasis is visible abduction or external rotation stress examinations are described to rule out a diastasis that has been spontaneously reduced (Kelikian and Kelikian 1985). Other subtle changes in syndesmotic width, such as found with anterior syndesmotic injuries, cannot be measured reliably and are often not noted (Xenos et al. 1995, Edwards and De Lee 1984, McDade 1975).

Two parameters to assess ankle and syndesmotic integrity measured on AP and M views of the ankle are frequently used in the literature. The first parameter, the tibiofibular overlap, is measured as a horizontal distance between the medial border of the fibula and the lateral border of the anterior tibial tubercle (Pettrone et al. 1983). This distance is considered to be normal when it measures approximately 6 mm or more (or 42% fibular width) on the AP and 1 mm or more on the M view according to Harper and Keller (1989). The tibiofibular clear space (TFCS), is the second parameter. It is described as the distance between either the posterolateral border or anterolateral border, or the incisure of the tibia, and the medial border of the fibula (Harper and Keller 1989, Leeds and Ehrlich 1984, Sclafani 1985, Pettrone et al. 1983). Harper and Keller (1989) found that the tibiofibular clear space should be less than 6 mm, as measured between the posterolateral border and the medial border of the fibula on AP and M views. Others have reported that TFCS varies more than 1 mm between males and females (Ostrum et al. 1995). Using Harper and Keller's (1989) definition, Pneumaticos et al. (2002) stated that TFCS did not change significantly with rotation and is therefore reproducible and reliable in evaluating the integrity of the distal tibiofibular joint. When assessed for single occasion examinations TFCS has been found to have the highest inter-observer reliability (Brage et al 1997). No studies however, have been published that assessed the use of these radiologic parameters with regard to inter-observer reliability in repeated ankle radiography, which is mandatory in clinical practice.

Two other radiologic parameters are the superior and medial clear space. These parameters are used in the radiological assessment of syndesmotic ankle injuries because syndesmotic injuries are often accompanied by deltoid ligament injuries (Frick 1978, Broström 1964, Lauge-Hansen 1950). The superior clear space is measured between the talar dome and the tibial plafond (Joy et al. 1974). The medial clear space is measured as the distance between the medial talar facet and the medial malleolus. As the articular surfaces are oblique, similar borders, such as the anterior edge of the medial malleolus and the anterior talus should be used to avoid inaccurate measurements (Leeds and Ehrlich 1984, Sclafani 1985, Joy et al. 1974). It has been reported that the medial clear space should not exceed the superior clear space on the AP view or exceed 4 mm on the M view (Pettrone et al. 1983). There has been no scientific validation however, for these statements in the literature.

Arthrography: Traditionally arthrography of the ankle was performed if plain radiographs did not reveal any abnormalities in acute or chronic ankle injuries (Wrazidlo et al. 1988, Karl and Wrazidlo 1987, Kelikian and Kelikian 1985, Luning et al 1969, Frick 1978, Sanders 1977). Wrazidlo et al. (1988) describe a sensitivity of 90% and a specificity of 67% when compared to intraoperative findings for an isolated rupture of the anterior tibiofibular syndesmosis.

In the case of an acute rupture of the anterior tibiofibular ligament, extra-articular leakage of contrast solution ventral to this ligament is seen. In the lateral view the ventral aspect of the contour of the distal fibula is covered by contrast medium (Sanders 1977). This contrast material extends anteriorly at the level of the syndesmotic injury or craniolaterally between tibia and fibula for more than 2 cm, in 'a flame like fashion' (Karl and Wrazidlo 1987) when a tear is present in the synovial recess of the syndesmosis. In the intact situation this recess extends 6-10 mm proximally (Weissman and Lazis 1980). A tear in the synovial recess of the syndesmosis closes about a week after the injury (Sanders 1977), but an expanded diverticulum may persist at the tear site. It has been reported that the synovial recess of the syndesmosis can appear to have become duplicated if an old injury exists (Kelikian and Kelikian 1985). Others describe this phenomenon as a normal finding (Weissman und Lazis 1980). According to these authors the presence of syndesmotic injuries can be determined by direct and indirect signs at arthrography. Direct signs were defined as contrast accumulation at the anterior and/or posterior tibiofibular ligament as well as the 'fil-ling' of the triangular contour of the distal fibula between these two ligaments. Indirect signs were defined as anterior displacement of the fibula, fractures of the medial malleolus, posterior tibial lip fractures, and avulsion fractures of the fibula at the level of the tibiofibular joint. In an arthrography study of 139 acute ankle injuries they found as much as 50 % direct and 36.2 % indirect signs of syndesmotic injury. Currently conventional arthrography is not routinely performed anymore as it has been superseded by CT and MRI. These examinations, however, may involve arthrography also.

Radionuclide Imaging: Several authors (Frater et al. 2002, Marymont et al. 1986) have assessed the value of bone-scintigraphy in ankles 1-5 weeks after a sprain. Trauma to the syndesmosis was indicated by focal activity at the syndesmosis or at the posterior edge of the tibial plafond consistent with avulsion of the posterior tibiofibular ligament, while interosseous membrane injury resulted in a linear area of increased activity at the distal lateral tibial border. This area was found to extend along the lateral aspect of the distal tibia above the region of the damaged anterior tibiofibular ligament. In patients with chronic complaints after syndesmotic sprains, increased activity in the region of the syndesmosis was found (Ogilvie-Harris et al. 1994). Thus positive scintigraphy may indicate syndesmotic injury. The type of injury (impingement, fibrosis, instability), however, cannot be assessed with scinti-graphy.

Ultrasound: Acute ruptures of the anterior tibiofibular ligament can be diagnosed sonographically, when a dehiscence of the ligament ends or an interruption of the parallel fibers in combination with a hypo-echogenic zone (edema, haematoma) are visualized. If some straight, parallel fibers are seen, the diagnosis is an incomplete rupture (Milz et al. 1998). The normal interosseous membrane can be recognized by a thin hyperechoic line, nearly equal to bone cortex. The acutely injured interosseous membrane can be distinguished by an abnormally hypoechoic and poorly defined discontinuous line (Durkee et al. 2003).

When compared to MRI (0.2 Tesla with fixed extremity coil, T1- and T2-weighted sequences), ultra high frequency ultrasound imaging (13-Mhz scanner, 0.118 mm axial and 0.15 mm lateral resolution) was reported to have a sensitivity of 66%, a specificity of 91%, a positive predictive value of 86%, and a negative predictive value of 77% in acute ruptures of the anterior tibiofibular ligament (Milz et al. 1998).

In a prospective trial, Krappel et al. (1997) compared the diagnostic value of ultrasound imaging with clinical examination in the diagnosis of injuries of the anterior syndesmosis (basic standard machine with 7.5 MHz piece), with arthrography as the gold standard. Based on clinical examination they suspected a syndesmotic injury when swelling over the syndesmosis, a positive squeeze,- and external rotation test were present and lateral instability absent. A positive predictive value of 40% was found for clinical examination when compared to arthrography findings. When the increase in tibiofibular width between maximal plantar,- and dorsiflexion was measured with ultrasound they describe a specificity similar to that of arthrography in experienced hands. However, ultrasound imaging relies heavily on the experience of the examiner and to date ultrasound is not performed routinely in syndesmotic injuries.

Computer tomography: CT has been used to describe the normal anatomy of the anterior and posterior facet of the fibular incisure of the tibia, as well as the angle between facets, the depth of the incisure and the amount of tibiofibular overlap (Ebraheim et al. 1998). To compare the projection of the injured syndesmosis on radiographs with CT (GE 9800 high speed, slice thickness not described). Ebraheim et al. (1997) placed plastic spacers in the distal tibiofibular interval of cadaveric lower limbs after the anterior and posterior tibiofibular ligament as well as the interosseous ligament and distal 5 cm of the interosseous membrane had been sectioned. Spacers with successive 1-mm increments and a maximum thickness of 4 mm were placed in the syndesmosis. They assessed if widening of the syndesmosis could be observed on the radiograph or with CT. Widening was defined by a TFCS > 6 mm or/and a TFO < 6 mm. Widening when spacers smaller than 2 mm were used, could not reliably be recognized with CT or radiography (Ebraheim et al. 1997). CT scanning was found to be more sensitive than radiography for detecting syndesmotic injuries if the spacers were between 2 and 4 mm thick. This is in accordance with the statement made by Harper (1993) that CT is the better method to assess the syndesmotic interval after ankle fractures because of the inherent inaccuracy of radiography.

Magnetic resonance imaging: MRI can be used to assess acute and chronic ligamentous injuries, because it can accurately show a (complete) ligamentous tear and determine the proximity of the torn ligament ends. It can also display increased signal intensity and an abnormal course or contour of the ligament as well as concurrent injuries of the joint (Helgason and Chandnani 1998). In a MRI (0.3 Tesla, T1-weighted sequences) study of cadaveric ankles and healthy volunteers, full dorsiflexion of the ankle and an axial imaging plane was found to be optimal for visualization of the anterior tibiofibular, posterior and transverse tibiofibular ligament as well as for an overview of the deltoid ligament (Muhle et al. 1998, Schneck et al. 1992). When a coronal imaging plane was used, they visualized the naviculotibial, tibiospring and calcaneotibial ligament as well as the posterior talotibial part of the deltoid ligament in full dorsiflexion, and the fibulocalcaneal and naviculotibial as well as the anterior talotibial part of the deltoid ligament in full plantarflexion (Schneck et al. 1992, Pankovich and Shivaram 1979).

Vogl et al. (1997) studied acute ankle injuries with a 1.5 Tesla unit with extremity coil and the feet placed in neutral or dorsiflexion. They have described the anterior tibiofibular ligament in the intact situation as a short band-like structure with low signal intensity in plain T1- and T2-weighted sequences with transverse slice orientation. The intact posterior tibiofibular ligament was described as a triangular structure with a fan-like shape that shows signal inhomogeneties in plain T1- and T2-weighted sequences. No contrast enhancement was seen in transverse T1-weighted sequences in the normal situation. They defined sprained syndesmotic ligaments as having a normal contour and shape, but irregularly increased internal signal intensities in T1- and T2-weigthed sequences, as well as intermediately marked enhancement in the T1- weighted post contrast sequences. Ruptures were defined by an absent ligament, an abnormal course, a wavy irregular contour, as well as by increased signal intensity on the T1- and T2-weighted sequences and marked enhancement in the T1- weighted contrast sequence after contrast. Although others have reported otherwise (Bartoníček 2003, Kapandji 1985), they considered joint fluid in the tibiofibular space and the prolapse of interspace fat as important secondary signs of rupture of the anterior tibiofibular tibiofibular ligament also.

With these criteria sensitivity ranged from 93 - 100% and specificity from 96 - 100% for different MRI sequences when compared to intraoperative findings or clinical follow-up examinations when a non-operative treatment was given (Vogl et al. 1997). Brown et al. (2004) retrospectively assessed the MRI findings (1.5 Tesla, extremity coil, T1- and T2-weigthed sequences) found after a MRI database was searched for the words ‘ankle sprain’. Injury to the ATiFL was determined as acute when edema around the ligament was seen and chronic when disruption or thickening of the ligament without edema was seen. They found in 24% of the scans signs of acute and in 38% signs of chronic syndesmotic injuries. This was associated with 38% bone bruises, 46% tibiofibular joint incongruency, 14% osteoarthritis and an increased height of the tibiofibular recess (1.2/1.4 mm in acute/chronic syndesmotic injury versus 0.5 mm in normal ankles). This is a different value for normal synovial recess height than that given by others who describe that this recess extends 6-10 mm proximally in the intact situation (Lee et al. 1998, Weissman and Lazis 1980). Brown et al. also found 83% injuries of the anterior talofibular ligament. In contrast with these findings Uys and Rijke (2002) found an inverse correlation between the presence of lateral collateral ligament injuries and syndesmotic injuries when graded lateral stress radiography was compared with MRI (1.5 Tesla, wrap-around surface coil, T1- and T2-weigthed sequences) in acute ankle injuries.

In a bit confusing publication MRI of the bony syndesmotic anatomy was described by Mavi et al. in 2002 and in a rather similar publication by the same group of authors (Yildirim et al.) in 2003. In patients with acute ankle injuries Takao et al. (2003) found that MRI (1.5 Tesla with extremity coil, transverse T1- and T2-weigthed sequences) has a sensitivity, specificity and accuracy of above 90 % for anterior tibiofibular and 100 % for posterior tibiofibular ligament injuries when compared to arthroscopy. Nearly the same results and nearly the same patients were described in a later publication by the same group of authors (Oae et al. 2003).

In the evaluation of intra-articular structures with MRI the presence of joint fluid is of aid. In the acute stage a torn ligament or torn capsule may be demonstrated with haemarthros or excess joint fluid as contrast agent. The same effect can be achieved in MR arthrography with the use of an intra-articular injection of contrast material. MR arthrography may be particularly useful in the evaluation of sub-acute or chronic injury in which excess joint fluid is absent (Shakhapur and Grainger 2001, Trattnig et al. 1999, Lee et al. 1998). Lee et al. describe findings after scanning in a coronal, sagittal, axial and oblique axial plane. The oblique axial planes were orientated parallel with and perpendicular to the long axis of the calcaneus. More recently another axial oblique plane has been described. To appreciate the syndesmotic ligaments in their full length in order to be able to assess their integrity the syndesmotic ligaments are best scanned in an oblique axial plane parallel with their course (Beumer et al. 2005, Hermans and Beumer 2002).

Although the use of ultrasound and MRI has been described to detect acute syndesmotic injuries and MRI has been shown to be most useful in assessing other chronic ligamentous injuries, to date no study has been published about the use of ultrasound, CT or MRI to differentiate between normal ankles and those with chronic syndesmotic injuries.

Arthroscopy and assessment of the syndesmosis during operative treatment

Several authors have mentioned arthroscopy as a useful technique to diagnose syndesmotic injuries (Takao et al. 2003, Ogilvie-Harris et al.1994). According to Ogilvie-Harris arthroscopy in chronic syndesmotic injuries shows scarring of the interosseous ligament, which has been torn from the fibula and prolapsed into the joint. Furthermore, a rupture of the transverse ligament and a chondral fracture of the posterolateral tibia plafond were described.

During arthoscopic assessment, instability of the syndesmosis can be demonstrated with the probe in the medial or lateral portal. In normal ankles a maximum of 1.6 mm lateral displacement of the fibula from plantarflexion to dorsiflexion has been described using radiostereometry (Lundberg et al. 1989). Several authors have stated that instability is present when more than 2 mm movement between fibula and tibia can be seen at arthroscopic examination (Takao et al. 2003, Ogilvie-Harris et al.1994). A stress test of the distal tibiofibular joint by moving the ankle from internal rotation to external rotation under arthroscopy as well as an abnormal course or an avulsion of the ligament is used to identify an acutely torn anterior tibiofibular ligament by Takao et al. (2003).

During operative treatment of ankle fractures external rotation stress imaging or lateral translation of the fibula by traction with a hook in the coronal plane (Hahn and Colton 2000), or an elevator placed in the interosseous area between tibia and fibula (Mizel 2003) have been recommended to assess syndesmotic integrity. Caudal-Couto et al. (2004) demonstrated that larger displacements of the fibula can be found when traction with the hook is performed in the sagittal plane. However, no quantitative data regarding how much displacement may be considered to be normal have been given in the literature.

Treatment

No consensus exists in the literature concerning the therapy indicated for the different types of syndesmotic injury. For acute isolated ruptures of the syndesmosis, treatment ranges from 'functional' to immobilization in a plaster or operative treatment. The latter treatment may involve placement of a syndesmotic set screw, staple, hook or endobutton, with or without suturing of the torn ligament. This would then be followed by 6 to 8 weeks of immobilization in a below knee plaster (Thornes et al, 2003, Miller et al 1995, Ward 1994, Dittmer and Huf 1987, Ruf et al. 1987, Cedell and Wiberg 1962, Mullins and Sallis 1958, Outland 1943).

Different operations have been described in the literature to treat chronic syndesmotic injuries. Good results have been reported for treating impingement by shaving scar tissue from the syndesmosis (Ogilvie-Harris et al. 1994). For treatment of instability, permanent placement of a syndesmotic set screw (Mullins and Sallis 1958) or reconstruction of the syndesmosis are possible treatment options available. Several methods have been described to reconstruct the anterior syndesmosis. Different types of tenodeses are performed with use of the extensor tendon of the fifth or fourth toe, the peroneus longus or plantaris tendon, fascia lata or dura mater (Grass et al.2000, Jäger and Wirth 1995, Podesva 1985, Kelikian and Kelikian 1985). Some cases of late syndesmotic reconstruction after ankle fracture have been performed by removal of scar tissue both medial and lateral in the talocrural joint, followed by reconstruction of the anterior syndesmosis with use of a cuff of firm fibrous tissue and placement of a syndesmotic screw (Harper 2001, Beals and Manoli 1998).

Most, if not all, syndesmotic reconstructions are protected with a syndesmotic screw. A number of studies found no difference in syndesmotic fixation between 1 or 2, 3.5 or 4.5 mm screws and fixation through 3 or 4 cortices (Hahn and Colton 2000, Thompson and Geesink 2000, Burns et al. 1993). Olerud (1985) advised to place the screw with the ankle in plantarflexion to avoid loss of dorsiflexion due to overtightening. However, a study by Tornetta et al. (2001) showed that syndesmotic compression did not diminish dorsiflexion. It is common practice however, to remove the screw before weight bearing (Needleman et al. 1989). Finally, arthrodesis of the syndesmosis has been proposed as a salvage procedure for long standing instability (Grath 1960, Outland 1943).

Aims of this thesis:

A thorough knowledge as well as a clear understanding of the function of an ankle with instability, in comparison to an uninjured stable ankle is essential for proper diagnosis and management of chronic anterior syndesmotic instability. This thesis focuses on chronic instability of the anterior part of the distal tibiofibular syndesmosis, and studies have been performed to obtain more insight in the diagnosis and treatment of this type of instability.

The aims of these studies were: 1. To describe the kinematics of the distal tibiofibular syndesmosis both in the intact and in the injured situation (Chapters 3, 6, 8, 13). 2. To display if chronic instability of the anterior distal tibiofibular syndesmosis exists and can be objectivated (Chapters 6, 7, 9, 13). 3. To assess the optimal way to diagnose syndesmotic injuries with physical examination as well as with additional investigations (Chapters 4, 5, 7, 10). 4. To describe the experiences with a 'new' anatomical type of surgical reconstruction for chronic anterior tibiofibular instability and to assess the effect of this treatment in a prospective study (Chapters 11 and 13). 5. To optimize the postoperative treatment after reconstruction of the syndesmosis (Chapter 12). 6. To formulate treatment guidelines for chronic (and acute) anterior instability of the distal tibiofibular syndesmosis (Chapter 14).

To achieve these aims 11 different studies have been performed in collaboration with the department of Biomedical Physics and Technology and the Laboratory for Experimental Radiology of the Erasmus University Medical Centre Rotterdam and the department of Orthopaedic Surgery of the Leiden University Medical Centre, Leiden, The Netherlands, as well as the Orthopaedic Biomechanics Laboratory of the University of Maryland, Baltimore, USA and the department of Orthopaedic Surgery of the University Hospital of Umeå, Sweden.

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Chapter 2

Development and anatomy of the ankle and the distal tibiofibular syndesmosis

The most significant functional change in the anatomy of foot and ankle occurred during the development from reptiles into mammals. This involved the superposition of the talus over the calcaneus with subsequent development of the subtalar joint complex and the ability for inversion, eversion, pronation and supination. As a result the fibula lost most of its weight bearing function and the tibiofibular syndesmosis developed. These characteristic features had evolved to varying degrees by the end of the Cretaceous period, 65 to 70 million years ago (Conroy et al. 1983).

Embryology

The lower limbs can be seen in the fourth week of development when the embryo is 6 mm long as small elevations, known as limb buds. The legs grow from these buds which are situated caudally in the Wolffian ridge, a thickening of mesoderm covered by ectoderm. The ectoderm gives rise to the skin and its derivative parts such as nails, hair, sebaceous glands and sweat glands, while the bones, muscles, tendons and ligaments originate from the mesoderm. In addition, nerves and blood vessels grow out of the trunk into the limb itself.

At five weeks of gestation the human embryo has grown to 10-12 mm enabling thighs, legs and feet to be distinguished. The skeletal elements (future bones) are first made of condensed mesenchym. During the sixth and seventh week of development, chondrification has taken place in tibia, fibula, talus, calcaneus, cuboid, cuneiforms and the second to the fifth metatarsal (Böhm 1929). Ossification then starts distally in the distal phalanges at the end of the seventh week. The calcaneus ossifies in the third fetal month followed by talus and cuboid. At birth the primary ossification centers of talus, calcaneus and cuboid are present (Tachdjian 1972).

At the beginning of their development (second month) the feet are positioned in equinus and adduction. In this phase, the talus and calcaneus are situated next to each other and the foot is as flat as a board. The thigh and knee are in marked external rotation and the dorsal aspect of the foot is turned laterally. Furthermore the foot is in such an equine position, that it is in a straight line with and in the same plane as the lower leg (the later frontal plane). At the end of the embryonic period (9 wks; 23mm), the feet have rotated more than 90° into supination, but remain in equinus. The calcaneus has moved from lateral to the talus to a position posterior to the talus and the beginning of a transverse arch is seen. At ten weeks of gestation (35 mm) the supination is unchanged but the equinus has declined. At the beginning of the fourth month the foot has become perpendicular to the leg. It is then in midsupination with slight varus at the metatarsus. The soles of the feet are facing each other, the 'praying feet' position. Thereafter the foot begins to rotate into pronation and the forefoot loses its primitive adducted position in relation to the hindfoot. The ankle and foot gradually assume the position that they will have at birth (Tachdjian 1972, Böhm 1929).

It has been postulated that a differential growth of the distal end of the tibia and the fibula contributes to the migration of the talus and calcaneus during their development (Victoria-Diaz 1979). Further, this author suggests that during development there is first a fibular phase (20-30 mm embryo length) during which fibular development puts the calcaneus and foot in the embryological position, followed by a tibial phase (31-50 mm embryo length) that brings the talus and foot into their fetal position. If the latter phase is interrupted the foot will remain in its embryologic position with a resultant equino-varus-adduction position of talus and calcaneus. This is also known as clubfoot. Apart from clubfoot, congenital diastasis of the tibiofibular joint has been described in combination with hypoplasia of the first ray of the foot, tarsal bone anomalies and hand anomalies such as syndactyly or split hand-foot complex also known as lobster claw deformity. It has been postulated that congenital diastasis of the tibiofibular joint is a form of tibial hypoplasia (Choi et al. 2004).

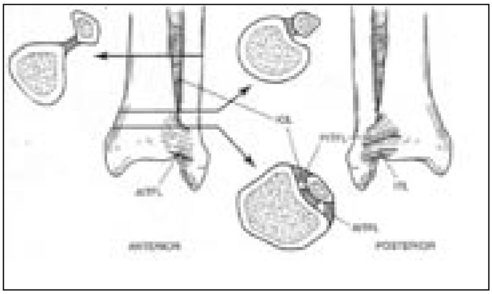

Figure 1.
Schematic drawing of distal tibiofibular syndesmosis with ATiFL, IL, PTiFL and TL.

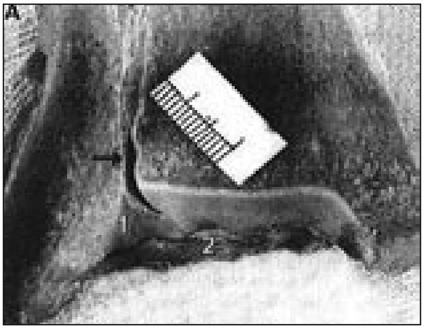

Figure 2.
Coronal section trough distal tibiofibular syndesmosis. Anteriorly the inferior level of the IL is bordered by fatty tissue which is lined with a synovial plica from the talocrural joint space. The medial aspect of the plica is not attached to the tibia, allowing an interosseous diverticulum from the ankle joint between the plica laterally and the tibia medially. Posteriorly the TL is visible.
(Bartonícek J. Anatomy of the tibiofibular syndesmosis and its clinical relevance. Surg Radiol Anat 2003; 25: 379-86).

Anatomy of the distal tibiofibular syndesmosis

The connection between tibia and fibula is formed by three structures, namely the superior tibiofibular joint, the interosseous membrane and the distal tibiofibular joint. The proximal and distal tibiofibular joints are syndesmoses, which are fibrous joints with intervening fibrous connective tissue. The superior tibiofibular articulation is a diarthrodial joint connected by the anterior and the posterior superior tibiofibular ligament (Kapandji 1985). A fibrous sheet, the crural interosseous membrane connects the shafts of tibia and fibula. This membrane consists of interlacing fibers which run about 15 degrees obliquely downward from the interosseous ridge of the tibia to the margin of the fibula (Lutz 1941). The membrane has 2 apertures that allow nerves and vessels to pass through the compartments. The anterior tibial vessel and nerve pass through the larger superior oval opening, just beneath the superior tibiofibular joint. The perforating branch of the peroneal artery passes through the smaller aperture, just above the inferior tibiofibular syndesmosis (Kelikian and Kelikian 1985).

The distal tibiofibular syndesmosis consists of four ligaments: the anterior inferior tibiofibular ligament, the posterior inferior tibiofibular ligament, the transverse ligament and the interosseous ligament, which is the most distal part of the interosseous membrane (Bartoníček 2003, Kelikian and Kelikian 1985, Grath 1960, Lutz 1941).

The anterior inferior tibiofibular ligament (ATiFL): The ATiFL (Figure 1) is a strong, shiny ligament, maximal 2 cm in width and almost 0.5 cm thick. It consists of 3 bundles, separated by 2 mm wide gaps that slightly converge in the laterodistal direction (Bartoníček 2003). The superficial anterior fibers are 2 to 3 cm long, the deeper posterior fibers somewhat shorter (Broström 1964). They run obliquely downward from the anterior

Figure 3.
Plastinated axial section through distal tibiofibular syndesmosis. The talocrural joint space and interosseous diverticulum have been filled with a green dyed polymer.
A transverse section from anterior to posterior through the syndesmosis shows the ATiFL bordered posteriorly by a triangular strip of fibrofatty tissue. Slightly more posteriorly a zone with direct contact between cartilage surfaces of tibia and fibula is seen.The dyed polymere can be seen in the diverticulum that extends along the entire syndesmosis. Just anterior of PTiFL the diverticulum narrows and gives room for the fatty tissue with the synovial plica laterally.

tibial tubercle to the anteromedial aspect of the fibular malleolus with an angle of about 30-50 degrees. Its distal margin protrudes over the lateral tibiofibular joint space (Kapandji 1985). The ATiFL is located outside the ankle joint capsule, but in 20% of people a separate bundle may be seen intraarticularly (Stoller 1998).

The posterior inferior tibiofibular (PTiFL) and the transverse (TL) ligament: The PTiFL (Figure 1) has a trapezoid shape. It is more compact and runs more horizontal than the ATiFL. It is on average 18 mm width and 0.6 mm thick. Superiorly there is an almost continuous transition into the interosseous membrane (Bartoníček 2003). The distal margin of the PTiFL is formed by a more anterior and transverse bundle (Figure 2), which is recognized by some authors as a separate entity known as the transverse ligament (Broström 1964), and serves as a labrum to the tibia (Stoller 1998).

The interosseous ligament (IL): The tibiofibular interosseous ligament is a strong pyramid shaped thickening of the fibers of the interosseous membrane. These fibers form a network that runs from 5 to 1.5 cm proximal to the tibiotalar joint space in a laterodistal direction from the tibia (Bartoníček 2003, Lutz 1941). Only a few fascicles on the dorsal aspect of the ligament are described as running transversely or in the reverse direction. The posterior edge of the IL almost continuously passes into the PTiFL. The anterior surface of IL is divided from the ATiFL by a small gap. Bartoníček (2003) has described the perforating branch of the fibular (peroneal) artery running in a postero-anterior direction through the upper part of the IL (Bartoníček 2003), while the Kelikians (1985) consider the passage of this artery as the division between the IM and the IL.

At the inferior level the IL is bordered by fatty tissue which is lined with a synovial fold (or plica) from the talocrural joint space. This fold protrudes into the talocrural joint during plantarflexion and is suspended in the tibiofibular joint in dorsiflexion (Kapandji 1985). The medial aspect of the plica is not attached to the tibia, allowing an interosseous diverticulum from the ankle joint between the plica laterally and the tibia medially. The height of the interosseous diverticulum has been found to range between 12 and 15 mm in non-injured specimens. A transverse section from anterior to posterior through the syndesmosis shows the ATiFL posteriorly bordered by a triangular strip of fibrofatty tissue. This may be followed by a zone with direct contact between 1 mm thick cartilage surfaces of tibia and fibula. The cartilage can be between 2 and 9 mm high, the tibial cartilage is always larger than the fibular cartilage. The zone of direct contact is not always present (Bartoníček 2003), there may also be a cartilaginous lining (Bartoníček 2003, Kapandji 1985, Lanz and Wachsmuth 1959). More posteriorly the fatty tissue with the synovial plica and interosseous diverticulum are seen anteriorly of the PTiFL (figure 3).

The afferent (sensory) innervation (propriocepsis) of the syndesmosis is from all major nerves passing this joint: the tibial, saphenus, sural and deep peroneal nerve.

The deltoid ligament: Although the deltoid ligament is not part of the distal tibiofibular syndesmosis it is functionally closely associated with it. The deltoid ligament originates from the medial malleolus and is covered posteriorly by the tendons of tibialis posterior and flexor digitorum longus. The medial malleolus consists of a slender and long anterior and a broader posterior colliculus, which are separated by the intercollicular groove (Pankovich and Shivaram 1979). The deltoid ligament consists of superficial and deep layers. In general, the superficial layer originates primarily from the anterior colliculus and inserts on the navicular bone, the spring (plantar calcaneo-navicular) ligament, the sustentaculum tali and the medial tubercle of the talus, whereas the deep layer runs from the intercollicular groove and the posterior colliculus to the medial surface of the talus.

Three separate bands can be discerned in the superficial layer of the deltoid ligament. The triangular *naviculotibial ligament* fans from the anterior colliculus and inserts on the dorso-medial surface of the navicular bone and along the dorso-medial surface of the spring ligament. It is the largest, widest and weakest part of the deltoid ligament. The middle, and strongest, *calcaneotibial ligament* runs from the mid-portion of the medial surface of the anterior colliculus to the medial border of the sustentaculum tali of the calcaneus. The calcaneotibial ligament covers the deep anterior talotibial ligament and the naviculo-tibial ligament. It has a course perpendicular to these ligaments. The *superficial talotibial ligament* originates from the posterior part of the medial surface of the anterior colliculus and a small part of the adjacent posterior colliculus. The superficial talotibial ligament has a postero-distal direction and inserts anteriorly on the medial tubercle of the processus posterior tali.

The deep layer of the deltoid ligament consists of two bands that are nearly intraarticular structures. The small and short *deep anterior talotibial ligament* runs in a distal and anterior direction from anterior colliculus and the intercollicular groove to insert on the medial surface of the talus near its neck. The deep anterior talotibial ligament is continuous with the *deep posterior talotibial ligament*, which is a strong, thick ligament originating from the intercollicular groove and the medial surface of the posterior colliculus. The deep posterior talotibial ligament extends posteriorly, laterally and distally to insert on the medial surface of the talus, from the medial talar tubercle to the edge of the posterior third of the talar trochlea (Pankovich and Shivaram 1979).

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Chapter 3

A biomechanical evaluation of the tibiofibular and tibiotalar ligaments of the ankle

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Abstract

The purpose of this ex vivo biomechanical study was to determine the strength and stiffness of the anterior and posterior syndesmotic tibiofibular ligaments and the posterior tibiotalar component of the deltoid ligament. Injuries to these ligaments are a prevalent clinical problem, yet little is known about their mechanical behavior. Ten fresh-frozen cadaver lower extremities (average age at death, 72 ± 8 years) were harvested.

The anterior and posterior tibiofibular ligaments and the posterior tibiotalar component of the deltoid were isolated and prepared as bone–ligament–bone complexes for tensile testing to determine strength, stiffness, and mode of failure. The posterior tibiofibular ligament exhibited greater strength, but not significantly so (p < .05), than the anterior tibiofibular ligament and the posterior tibiotalar component of the deltoid ligament. There were no significant differences in stiffness between the three ligaments tested. The dominant mode of failure for the anterior tibiofibular ligament was ligament substance rupture, primarily near its fibular insertion, whereas the failure modes of the posterior tibiofibular ligament were evenly split between substance ruptures and fibular avulsions.

The posterior tibiotalar component of the deltoid ligament ruptured most often near the talar insertion. The tibiofibular ligaments showed greater strength than the lateral collateral and deltoid ligaments, as mentioned in literature. The greater strength of the tibiofibular ligaments relative to the lateral collateral and deltoid ligaments suggests that these ligaments play an important role in ankle constraint.

***Keywords:** Ankle; Syndesmosis; Ligaments Mechanical Behavior; Biomechanics; Tibiotalar*

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Table 1: Strength stiffness and failure mode of ankle ligaments

Ligament	Strength (N)a	Stiffness (N/mm)[a]	Substance Ruptures (n/site)	Bony Avulsions (n/site)
Anterior tibiofibular	499 ± 105	78 ± 12 7	(5 fibular)	3 (fibula)
Posterior tibiofibular	708 ± 91	101 ± 16 5	(3 fibular)	5 (fibula)
Posterior tibiotalar component of the deltoid ligament	446 ± 51	115 ± 15 9	(6 talar)	1 (talus)

[a]Mean ± SEM, n = 10

Introduction

Ankle sprains are among the most common injuries,[2] and they usually involve the lateral collateral ligaments[6]; less commonly, the deltoid ligament is affected.[5] Although syndesmotic (anterior and/or posterior tibio-fibular) ligament injuries are most often seen in combination with ankle fractures, they can also be isolated.[3] Syndesmotic sprains comprise 1–11% of all ankle sprains[2]; however, in populations actively involved in sporting activities, the incidence may be considerably higher.[1,7] The low incidence of isolated syndesmotic injuries relative to other ankle sprains may be attributed to the strength of the ligaments or to the fact that the external rotation, abduction, and/or dorsiflexion mechanism required to injure the syndesmosis[10] may occur less frequently than the inversion mechanism associated with other ankle sprains.[4] Some investigators have also suggested that tibiofibular ligament sprains may be underrecognized.[6]

Despite the low incidence, tibiofibular ligament sprains are clinically important because they have a longer recovery time compared to all other ankle sprains.[1,7] This may be as much as twice that of other ankle sprains,[7] and they may develop subsequent chronic ankle instability.[6] Determination of the biomechanical characteristics of normal tibiofibular ligaments would provide the basic information needed to understand the ligament's normal function and to establish a standard with which potential ligament repairs can be compared.

The goal of the current study was to determine the mechanical response and failure mode of the anterior and posterior tibiofibular ligaments and of the posterior tibiotalar component of the deltoid ligament.

Materials and methods

Ten (six male, four female) fresh-frozen cadaver lower extremities (mean age at death, 72 ± 8 years) were obtained from the Maryland State Anatomy Board and sectioned through the knee. Macroscopic examination was performed, and conventional AP and lateral radiographs revealed no major ankle pathology or previous surgery. The legs were wrapped in salinesoaked towels and stored in sealed bags at –20°C.

Specimens were allowed to thaw at room temperature (20°C) for 24 hours before testing. On the lateral side, the tibia was split in a frontal plane to produce two bone–ligament–bone complexes, one with the anterior tibiofibular ligament and the other with the posterior tibiofibular ligament, including the transverse ligament, but both attached to the fibula. From the medial side of each specimen, a bone–ligament–bone complex was obtained consisting of the medial malleolus, posterior tibiotalar component of the deltoid ligament (as defined elsewhere[9]), and talus. The bony portions of each complex were potted in pieces of polyvinyl chloride pipe using a common epoxy resin (Fastray, Bosworth, Skokie, IL). Each specimen was mounted on a servohydraulic testing machine (Instron, Canton, MA) so that the load was applied along the longitudinal axis of the ligament fibers. The test specimens were kept moist by frequent irrigation with saline solution, preloaded to 10 N, and then elongated at a rate of 0.5 mm/s until failure occurred. Mode of failure (bone avulsion or ligament rupture) and site of failure (fibula or tibia for syndesmosis, talus or tibia for tibiotalar) were noted. Force and elongation data were recorded at 10 Hz. Strength was defined as the peak load, and stiffness was measured as the slope of the force-versus-elongation curve between 30 N and one-half peak load.

A one-way, repeated measures analyses of variance (ANOVA) was used to check for an effect of subject or ligament on the parameters of interest, namely strength and stiffness. Differences among the parameters of interest were checked for significance using a Tukey's multiple comparison test. Significance was set at $p < .05$, unless otherwise specified.

Results

The posterior tibiofibular ligament exhibited, on average, greater strength than the anterior tibiofibular and the posterior tibiotalar component of the deltoid ligament (Table 1), but the differences between ligament strengths were not significant ($p = .06$, $\beta = .60$). There was no significant difference in ligament stiffness between the three ligaments tested ($p = .26$, $\beta = .90$). The dominant mode of failure for the anterior tibiofibular ligament was ligament rupture, primarily near its fibular insertion (Table 1), whereas that for the posterior tibiofibular ligament was rupture or fibular avulsion. The posterior tibiotalar component of the deltoid ligament ruptured most often through its substance near the talar insertion.

Discussion

According to Pankovich and Shivaram,[9] the deltoid ligament consists of two components: 1) the superficial part, which has three bands (the tibionavicular, the tibiocalcaneal, and the superficial tibiotalar ligaments); and 2) the deep part, which consists of the deep anterior and posterior tibiotalar ligaments. The superficial tibiocalcaneal and the deep anterior tibiotalar ligaments blend with each other and may be confused during dissection.

Therefore, we chose to test only the posterior tibiotalar component of the deltoid ligament. Furthermore, this component is the largest (and, presumably, the mechanically most important), and ruptures have been reported in patients with syndesmotic injuries.[3,14]

Regardless of whether the incidence rate of syndesmotic sprains is a function of ligament strength or frequency of injury mechanism, the strength of the syndesmotic ligaments suggests that these ligaments play an important role in stabilizing the ankle. Therefore, one might assume that, once injured, these ligaments need treatment.

The ligament strength results are generally supported by the data reported by Sauer et al.,[11] the only study we found that reported the mechanical properties of the syndesmotic ligaments. In that study, which used cadavers more than 50 years old at death, the posterior tibiofibular ligament was found to be the stiffest and strongest (averages: 45 N/mm and 617 N, respectively), followed by the anterior tibiofibular ligament (averages: 38 N/mm and 627 N, respectively) and then the entire deltoid ligament (averages: 31 N/mm and 431 N, respectively). However, the ligament stiffness values in our study were considerably greater than those reported by Sauer et al.[11] The difference could be attributed to the differences in elongation rates between the studies.

Sauer et al.[11] used an elongation rate of 0.13 mm/s, whereas we used a rate of 0.5 mm/s. Because both rates are slow and may be considered quasistatic, it is doubtful that the minimal difference between the rates would account for the magnitude of the difference in ligament stiffness. Although details regarding their testing setup are scant,[11] it appears grips were used to hold the bone blocks. In our study, we decided to pot the bone blocks in epoxy to prevent grip slippage. If grip slippage during testing occurred in the study by Sauer et al.,[11] it would account for their lower stiffness values.

In our study, the strength values for the posterior tibiotalar component of the deltoid ligament were similar to those reported by Siegler et al.[12] It should be noted that those investigators tested the tibionavicular, tibiospring, and posterior tibiotalar component of the deltoid ligament separately. To optimize loading in the direction of the fibers of the posterior tibiotalar component of the deltoid ligament and to avoid using different bones as anchors, we did not separate the deltoid ligament into different bone–ligament–bone complexes, but chose to test the posterior tibiotalar component of the deltoid ligament only. The fact that Siegler et al.[12] used multiple anchoring parts and loading not exactly along the ligament line could account for their report of bone avulsions. None were observed in our study.

With regard to the mode and site of failure of the posterior tibiotalar component of the deltoid ligament, our results differ from those reported in the literature. We found the rate of substance ruptures to be 90%, whereas Siegler et al.[12] reported 30–100% substance tears, depending on the ligament component tested. All deltoid ligaments tested by Nigg et al.[8] failed in the ligament substance. Nigg et al.[8] tested the deltoid ligaments in their entirety. It is difficult to determine whether the higher incidence of lateral ankle sprains compared with syndesmotic sprains is related to the frequency of occurrence of a given mechanism of injury or to the damage tolerance of the ligaments in question. Some investigators have suggested that syndesmotic sprains are consistent with activities associated with higher energy levels. Gerber et al.6 reported a syndesmotic sprain incidence rate of more than 30% for participants in high-impact sports, whereas that for participants in low-impact sports was less than 5%. A report that isolated syndesmotic injuries are rare relative to those associated with a fracture3 also suggests that a high-energy mechanism of injury is necessary. These assumptions are supported by our finding that the posterior tibiotalar component of the deltoid ligament and the tibiofibular ligaments were stronger than the lateral collateral ankle ligaments.[8,12,13]

Measurements in the anterior and posterior tibiofibular ligaments during ankle movements have shown that strain during dorsiflexion increases in both ligaments, but strain during external rotation increases in the anterior tibiofibular ligament and decreases in the posterior tibiofibular ligament.[4] Strain in the anterior talofibular ligament increases when the ankle is moved into greater degrees of plantarflexion, internal rotation, and inversion, whereas strain in the calcaneofibular ligament increases during dorsiflexion and inversion. The fact that the various ligaments are strained differently depending on the direction in which the ankle is moved suggests that different mechanisms of injury exist for the various ligaments.

We tested the anterior and posterior tibiofibular ligaments and the posterior tibiotalar component of the deltoid ligament. The interosseous ligament was not tested because preparing this ligament would have weakened the other tibiofibular bone–ligament–bone complexes.

Conclusion

We found that the posterior tibiofibular ligament failed at a greater load (but not significantly so) than the other ligaments tested and that stiffness among the three ligaments was similar.

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Chapter 4

The influence of ankle positioning on the radiography of the distal tibial tubercles

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Abstract

Three embalmed human lower legs, with the anterior and posterior tubercles of the distal tibia marked with needles, were radiographed in four positions of rotation to describe the projection and the configuration of the distal tibial tubercles and the tibiofibular syndesmosis, since the distal tibial tubercles are often described incorrectly in the literature. The anterior and posterior tubercles have distinct features that can be recognized in different positions of rotation. The anterior tubercle has an angular shape with its maximum dimension approximately 1 cm above the joint line. The posterior tubercle is a rounded structure in continuity with the posterior lip of the tibia, projecting caudally from the anterior tubercle superimposed on the talus. It was shown that the tibiofibular clear space (TFCS) and the tibiofibular overlap (TFO) differ considerably with rotation and that neither the TFCS nor the TFO depicts a constant syndesmotic interval. Both change considerably with varying rotational projections. To achieve uniformity it is recommended that the TFCS be measured as the distance between the medial border of the fibula and the floor of the incisura, and the TFO as the distance between medial border of the fibula and the anterior tubercle, both on the anteroposterior radiograph.

Influence du positionnement de la cheville sur la radiographie des tubercules de l'extrémité distale du tibia

Résumé

Trois membres inférieurs de cadavres humains embaumés dont les tubercules antérieur et postérieur de l'extrémité distale du tibia, limitant l'incisure fibulaire, avaient étémarqués avec des aiguilles, ont étéradiographiés dans quatre positions de rotation pour décrire les projections et la configuration de ces tubercules de l'extrémitédistale du tibia et la syndesmose tibio-fibulaire, car ces tubercules de l'extrémité distale du tibia sont souvent décrits incorrectement dans la littérature. Les tubercules antérieur et postérieur ont un aspect distinct qui doit être reconnu sur les clichés en différentes positions de rotation. Le tubercule antérieur a une forme angulaire dont la dimension est maximum environ 1 cm au-dessus de l'interligne articulaire. Le tubercule postérieur est une structure arrondie, en continuitéavec le rebord postérieur du tibia, se projetant plus distalement que le tubercule antérieur et se superposant au talus.

Nous avons montréque l'espace clair tibio-fibulaire et l'empiètement tibio-fibulaire différent considérablement avec la rotation et que ni l'un, ni l'autre ne représente un intervalle syndesmotique constant. Tous deux changent considérablement en fonction de la rotation. Pour obtenir une uniformisation des radiographies, nous recommandons que l'espace clair tibio-fibulaire soit mesuré entre le bord médial de la fibula et le fond de l'incisure et que l'empie` tement tibio-fibulaire représente la distance séparant le bord médial de la fibula et le tubercule antérieur, tous deux sur les radiographies de face.

Keywords
Ankle radiography • Syndesmosis • Tibiofibular clear space • Tibiofibular overlap • Topo-graphy

Introduction

Radiographs are frequently used to diagnose osseous or ligamentous injury after ankle trauma. The most common radiographs are the antero-posterior (AP) view[14], in which the X-ray beam is directed at the center of the ankle in line with the foot, the mortise (M) view thatis taken in about 15° of internal rotation of the foot[6], and the lateral (LAT) view that is taken mediolateral with the beam perpendicular to the cassette and centered 1–2 cm proximal to the medial malleolar tip[1]. Various authors have looked into the question whether the AP, the M view, or both are necessary in the evaluation of ankle trauma. It has been stated that an ankle fracture can be classified reliably with the M and LAT views[3]. The AP view is more useful for the evaluation of the position of implants in the medial malleolus because the medial and lateral talar joint surfaces are not parallel[7]. The 50° external rotation view has been found to be most useful for assessment of the posterior malleolus[5], usually known as the posterior tibial lip.

To assess the syndesmosis on ankle radiographs, two parameters are commonly used. These are the tibiofibular clear space (TFCS) and the tibiofibular overlap (TFO), for which discrimination between the anterior and posterior distal tibial tubercles is necessary. The same holds true in the preoperative planning of ankle fracture surgery, since the approaches to an anterior or posterior distal tibial tubercle fracture are essentially different[8]. Thus the ability to discriminate correctly between the anterior and posterior distal tibial tubercle is essential in the evaluation and treatment of ankle injuries. The existing literature on ankle radiography, however, is not clear or consistent in describing the distal tibial tubercles or in measuring the TFCS and the TFO [2, 4, 10, 11, 13, 15, 17].

The aim of this study was to describe the appearance of the distal tibial tubercles on ankle radiographs in different positions of ankle rotation in order to identify these tubercles.

Materials and methods

Three embalmed human lower legs, which showed no evidence of ankle disease or osteoarthrosis macroscopically or radiologically, were amputated through the knee. All soft tissues with the exception of the interosseous membrane and the ligaments and capsules of the ankle and foot were removed. Each specimen was mounted on a testing device that allowed full rotation about the longitudinal central axis of the tibia. This axis and the bimalleolar axis were placed parallel to the ground surface with the use of a malleolar clamp which had two levels, and then calibrated as zero position using an electronic inclinometer (Cybex EDI 320, Lumex, Ronkonkoma, N.Y. 11779) attached to the testing device (Fig. 1). This zero position is equivalent to the M view in ankle radiography [6], and was chosen because it is only dependent on the tibial and fibular anatomy, and not influenced by foot position, as the AP position is.

The ankle was accurately rotated 15° and 25° externally and 10° internally from this zero position. The 15° externally rotated position correlates with the standard AP ankle radiograph. All three ankles were radiographed in each of the four positions described.

While the inclinometer was kept in place, the anterior and posterior tubercles were marked with needles placed in the soft tissues on the medial side of the tubercle in the coronal plane perpendicular to the joint surface, projecting upward at the anterior tubercle and downward at the posterior tubercle, and all radiographs were repeated. In this way two sets of radiographs, one with and one without the tubercles marked for each position of rotation, were made from each ankle. On the basis of these sets, the projection and configuration of the tubercles was described.

Results

The radiographs, with corresponding drawings, are shown in Fig. 2. On the basis of their shape and appearance, one can differentiate between the anterior and posterior tubercles in any position of rotation of the ankle. Furthermore the approximate position of rotation can be deduced from the appearance of the tubercles.

25° external rotation from the zero position

In a radiograph made in 25° more external rotation than the M view (Fig. 2a) the anterior tubercle is very prominent. Its angular shape is clearly visible 1 cm above the level of the horizontal ankle joint line. In addition the lack of superimposition on the talus clearly distinguishes the anterior tubercle. The profile of the posterior tubercle meets that of the floor of the fibular notch. This is shown in the transverse drawing where the deepest and most medial part of the incisura lies in the sagittal plane with the edge of the posterior tubercle. Additional features that characterize this as a radiograph taken in external rotation are the superimposition of the talus and the distal fibula, and the open medial tibiotalar joint space.

15° external rotation from the zero position (AP radiograph)

In the projection corresponding to an AP ankle radiograph (Fig. 2b) the anterior tubercle is smaller, but, as a result of its angular profile and its more cranial position, is still easily distinguishable from the posterior tubercle.

The round shape of the posterior malleolus and the posterior tubercle projects over the talus. As the floor of the incisura is now the most medial feature of the tibiofibular joint, it is visible as a separate structure on the radiograph. The lateral talus projects free from, but close to the distal fibula; the medial tibiotalar joint space is slightly less visible than on the former projection.

Zero position (M view)

In the zero position corresponding to the M view (Fig. 2c) the tubercles have similar dimensions, as shown on the transverse drawing. Therefore, the tubercles are less easy to distinguish in this projection. Their form and position, however, can still differentiate them. The anterior tubercle projects maximally 1 cm above the joint line and the posterior tubercle lies slightly caudally.

The incisura can be recognized easily as the deepest point of the tibiofibular articulation, the medial tibiotalar joint space cannot be evaluated but the lateral fibulotalar joint space opens up.

10° internal rotation from the zero position

Finally, 10° more internal rotation from the zero position (Fig. 2d) shows a small anterior tubercle projecting laterally from the incisura, which is still the most medial point and thus visible on the radiograph. The posterior tubercle is very prominent. The medial tibiotalar joint space is no longer visible and the lateral fibulotalar joint space projects completely opened.

On the basis of the above the following characteristics can be described: The anterior distal tibial tubercle has an acute, or angular profile. The most prominent part is projected approximately 1 cm above the tibial plafond.

The posterior tubercle extends caudally to the anterior tubercle, has a smooth curvature and is in continuity with the posterior malleolus, which is superimposed on the talus in every position of rotation. The anterior tubercle increases and the posterior tubercle decreases in size with external rotation, while the opposite is true for internal rotation. As shown on the radiographs and the drawings the point of intersection between the medial fibular and lateral tibial cortex is projected marginally more distally for each increment in internal rotation.

Discussion

Radiographic evaluation of the ankle and its syndesmosis should be done by an experienced observer on radiographs of an accurately positioned ankle [2]. It may be argued that CT scanning can offer a better assessment of syndesmotic displacement. However, whereas plain radiographs are universally available and relatively inexpensive, CT scanning may be difficult to access in many trauma units around the world, or be beyond the economic resources available. The ionizing radiation exposure of CT scanning, in addition to the standardized screening views recommended above, can be avoided in many cases by simple observations on plain radiographs as described here and may not be justifiable.

An accurate interpretation of the normal radiographic appearances is a conditio sine qua non for the appreciation of the pathoanatomy of injury of all regions, including the ankle.

For the radiographic evaluation of the ankle and the syndesmosis, recognition of the distal tibial tubercles is essential. Unfortunately, the distal tibial tubercles often are not denominated correctly in the literature. Furthermore the effect of inaccurate positioning of the ankle on the projections of the tubercles or on the evaluation of the syndesmosis has not been evaluated. Pettrone et al. [15] showed a correct and clear image of the projection of the tubercles on the AP ankle radiograph but failed to do the same for the M view. Ebraheim et al. [4], discussing tibiofibular diastasis, showed a what they described as an AP view with a very prominent posterior tubercle, indicating internal rotation, and an M view with a very prominent anterior tubercle, indicating an AP or external rotation view. Brage et al.[2] referred to a schematic figure of an AP radiograph, depicting the appearance of the tubercles in external rotation for measurements on AP and M radiographs, without explaining the differences in radiological appearance of the tubercles on the M view. Further, Resnick and Niwayama [16], in their classical book on skeletal radiology, labeled an ankle radiograph, which is clearly made in internal rotation as shown by the shapes of the posterior tubercle and of the medial malleolus, as "AP view". McDade[12] stated that the anterior tubercle always casts the more lateral shadow over the fibula and that the posterior tubercle is always the more medial. In the present study, it has been shown that this is only true on the AP view.

A correct description of the tubercles has been offered by Sclafani[17], who showed the outline of the tubercles on the AP and M view. Harper [9] confirmed this with a demonstration of the profiles of the tubercles by using pieces of thin steel wire in one cadaveric specimen. She commented on the different projection of the tubercles due to lateral displacement and rotational abnormalities of the fibula. Nevertheless, the changing radiographic appearances of the tubercles in different positions of rotation of the leg have not been mentioned by either of these authors.

Much confusion exists regarding how to assess syndesmotic integrity radiographically. Most authors use the TFCS and the TFO. The existing literature, however, is not clear or consistent in measuring the TFCS and the TFO. The majority of authors[4, 10, 11, 13] consider the TFCS to be the distance between the medial side of the fibula and the incisura on both the AP and M views. Exceptions are Pettrone et al.[15] and Brage et al.[2], who consider the TFCS as the distance between the medial side of the fibula and the posterior distal tibial tubercle on the AP view, and Sclafani [17] who considers the TFCS as the distance between the medial side of the fibula and the posterior tubercle on the AP, and as the distance between the medial side of the fibula and the anterior tubercle on the M view. The TFO is generally measured as the distance between the medial side of the fibula and the anterior tubercle on both AP and M views[2, 4, 10, 13, 15]. Thus, different authors measure these parameters differently. One reason could very well be the inability to differentiate between the anterior and posterior distal tibial tubercles in different projections.

Furthermore, the transverse drawings in Fig. 2 show that neither the TFCS nor the TFO, as stated in any of the aforementioned definitions, depicts a "constant" syndesmotic interval, and that each changes considerably in size and appearance with varying rotational projections. These findings lead to confusion when TFCS and TFO are measured on both the AP and M views.

To achieve uniformity, we therefore recommend that the TFCS be measured as the distance between the medial border of the fibula and the floor of the incisura, and the TFO as the distance between medial border of the fibula and the anterior tubercle. As the anterior distal tibial tubercle is largest on the AP view and because the tubercles are difficult to discriminate from each other 1 cm above the joint line on the M view, the TFO should be measured on the AP view only. To avoid misunderstanding, and excessive radiography, the TFCS could be measured on the same radiograph.

On the basis of this study, it is possible to discriminate between the anterior and posterior distal tibial tubercles. The effect of improper positioning of the ankle on quantitative measurement of the TFCS and the TFO should be the subject of further study.

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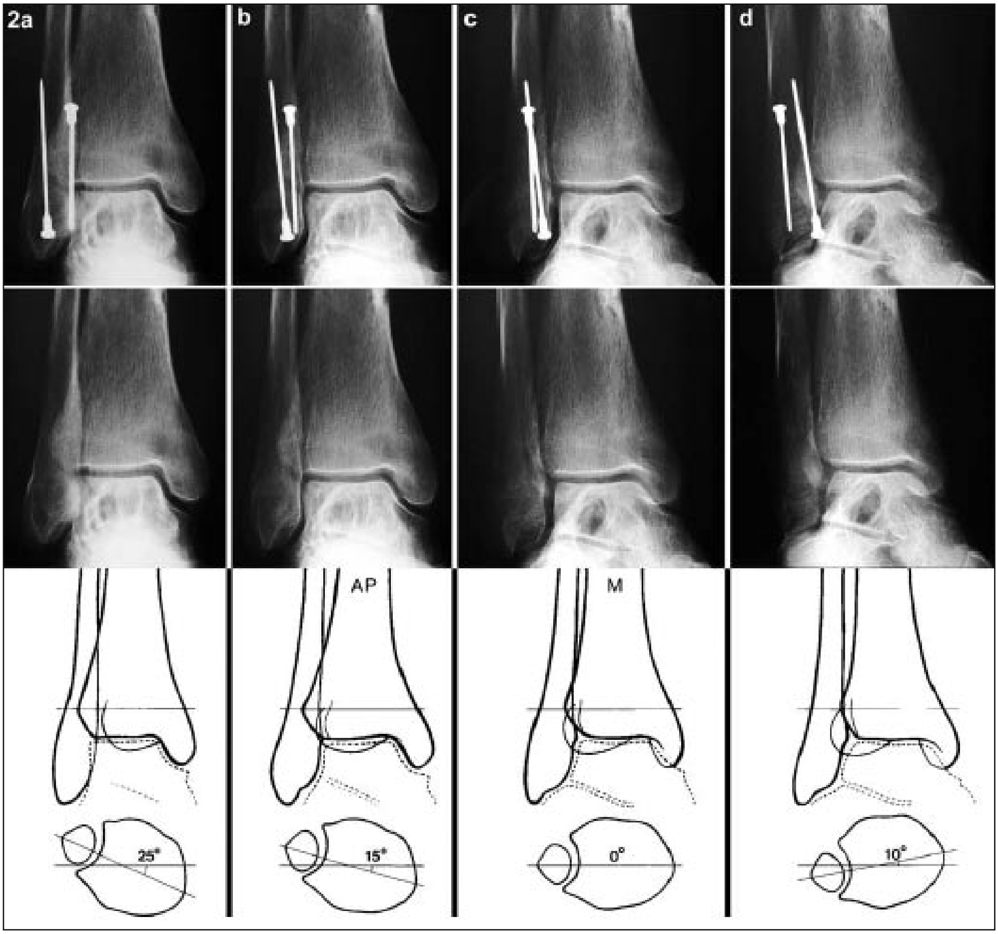
Fig. 1
Lower leg in the testing device with inclinometer and malleolar clamp

Fig. 2a–d
The ankle joint in four positions of rotation.
a *25° external rotation from the zero position.*
b *15° external rotation from the zero position (AP radiograph).*
c *Zero position (M view).*
d *10° internal rotation from the zero position. Top row, radiographs with the anterior distal tibial tubercle marked with a needle pointing upward, and the posterior distal tibial tubercle marked with a needle pointing downward; second row, plain radiographs; third row, schematic drawing of plain radiographs; the anterior tubercle is depicted with a thick line,the posterior tubercle with a thin line; bottom row, schematic drawing of a transverse section through the lower leg, 1 cm above the tibial plafond.*



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Chapter 5

Radiographic measurement of the distal tibiofibular syndesmosis has limited use

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Radiographs of 20 plastinated human cadaveric lower legs were obtained in 12 positions of rotation to determine the optimal parameter for reliable assessment of syndesmotic and ankle integrity, and to assess the effect of positioning of the ankle on this parameter. Three observers measured eight parameters twice after four repetitions of ankle positioning.

Intraclass correlation coefficients and reproducibility were assessed. Some tibiofibular overlap was present in all radiographs in any position of rotation. The medial clear space was smaller than or equal to the superior clear space in all radiographs. Intraclass correlation coefficients of the other parameters were too weak for reliable quantitative measurements, as was shown with a mixed model analysis of variance.

This resulted from the inability to reproduce ankle positioning, even under optimal laboratory circumstances.

This study shows that no optimal radiographic parameter exists to assess syndesmotic integrity. Tibiofibular overlap and medial and superior clear space are the most useful, because one-sided traumatic absence of tibiofibular overlap may be an indication of syndesmotic injury, and a medial clear space larger than a superior clear space is indicative of deltoid injury. Additional quantitative measurement of all syndesmotic parameters with repeated radiographs of the ankle cannot be done reliably and therefore are of little value.

Injuries of the distal tibiofibular syndesmosis occur either isolated, or in combination with ankle fractures. If the syndesmosis is completely disrupted, diastasis can be seen on plain AP ankle or mortise radiographs.[10] More subtle changes in syndesmotic width however, often are not appreciated and cannot be quantified reliably.[9]

Several parameters to assess ankle and syndesmotic integrity, measured on AP and mortise views of the ankle, have been described.[6,7,11–13] These measurements often are used as tools in treatment decision-making. The tibiofibular clear space is described as the distance between the posterolateral border, the anterolateral border or the incisura fibularis of the tibia, and the medial border of the fibula.[6,8,11–13] The tibiofibular overlap is measured as the horizontal distance between the medial border of the fibula and the lateral border of the anterior tibial tubercle.[6,11–13]

The medial clear space is described as the widest distance between the medial border of the talus and the lateral border of the medial malleolus on the AP view.[7,8,13] Medial clear space is said not to exceed the superior clear space, which is measured between the talar dome and the tibial

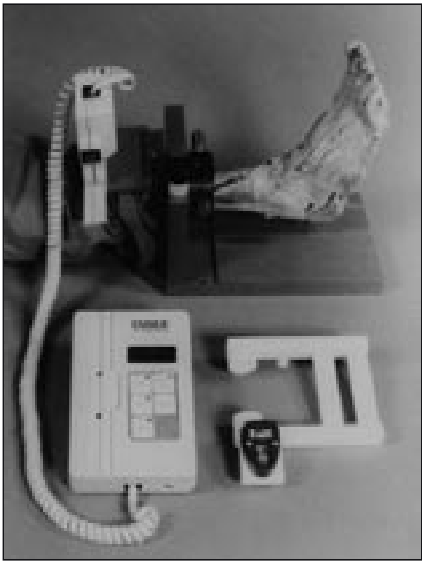

Fig 1.
A testing device with a malleolar clamp with two levels and electronic inclinometer is shown.

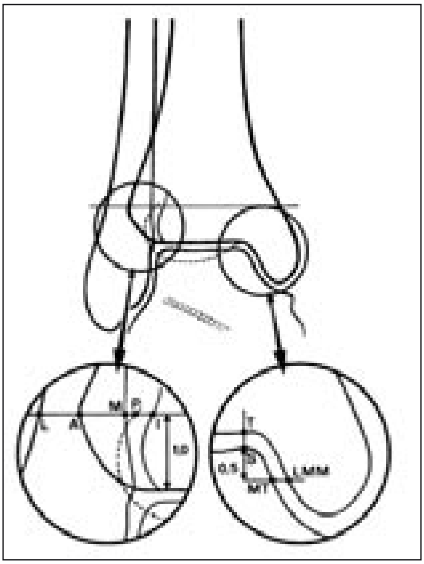

Fig 2. A schematic drawing of the ankle shows landmarks used for measurement of the different radiologic parameters. L = Lateral border of fibula; M = Medial border of fibula: A = Anterior tibial tubercle: P = Posterior tibial tubercle; I = Floor of incisura fibularis: T = Tibial plafond S = Superior point of medial talus; MT = Medial side of talus, LMM = Lateral side of medial malleolus

plafond.[7] However, there is no scientific validation for this statement.

Because it is not known yet which parameter should be used to determine syndesmotic and ankle integrity, no consensus exists in the literature regarding how to measure the aforementioned parameters, and reproducibility of those parameters has not been assessed.

The current study examined the aforementioned parameters, measured in every way described in the literature and in various radiographic positions to determine the effect of incorrect positioning of the ankle on the parameters, to determine which has the highest reproducibility and should be used to determine syndesmotic and ankle integrity.

Materials and methods

For this study 20 plastinated human cadaver lower legs (10 right, 10 left) were used. Plastination is a process during which biologic tissues are impregnated by curable polymers resulting in dry, odorless, and durable specimens with intact gross and microscopic anatomy.[14]

Each specimen was mounted on a testing device that allowed full rotation of the leg around its longitudinal axis, while the ankle was kept in a slightly plantar flexed position comparable to common clinical practice, and to avoid widening of the mortise caused by forced dorsiflexion. With the use of a malleolar clamp with two levels, the axis of the tibia and the bimalleolar axis were fixed in the 0 position in the horizontal plane (Fig 1). This 0 position, made with the beam perpendicular to the line centered through the malleoli, correlates with the mortise view on ankle radiographs, whereas the 15° external rotation position correlates with the AP view.4,10 Twelve radiographs were made by rotating the leg accurately from the 0 position, in increments of 5°, to 30° external, and to 25° internal rotation, using an electronic inclinometer (Cybex EDI 320, Lumex Inc, Ronkokoma, NY) attached to the testing device. Because most ankle radiographs are made with the subject bearing no weight, no loads were applied to the tibial plateau. Distances were measured 1 cm above, and parallel to, the tibial plafond for each of the following parameters: the distance between the medial side of the fibula and the anterior tibial tubercle, the distance between the medial side of the fibula and the posterior tibial tubercle, the distance between the floor of the incisura fibularis and the anterior tubercle of the tibia, the distance between the floor of the incisura fibularis and the posterior tubercle, the width of the fibula, and the distance between the medial side of the fibula and the floor of the incisura fibularis. All projections of the tubercles medial to the fibula were given a negative value. The superior tibiotalar clear space was measured as the distance between the tibial plafond and the highest point of the medial talar dome; the medial tibiotalar clear space was measured 0.5 cm beneath it on a line parallel to the superior talar joint surface (Fig 2). The latter was measured this way as it was hypothesized more standardized readings would be given than with measuring the maximum width, as suggested by Leeds and Ehrlich.8 On two occasions three observers measured these parameters using the same ruler with 1-mm discrimination. To determine mean and range, 8640 readings were made for six of the parameters, and 960 each for medial clear space and superior clear space, as the latter two could not be measured in extreme internal and external rotation.

To determine reproducibility of placement of the specimens, three investigators each did positioning five times. This multiple (replicate) positioning increased the total amount of readings to 15,360.

Statistical Analysis

The results were analyzed using mixed-model ANOVA (PROC MIXED of SAS version 6.12 SAS, Cary, NC). Variability in the readings was thought to derive from ankle, positioning (nested within ankle: ankle*position), interobserver, and intraobserver and residual (mainly consisting of intraobserver and pure error).

Each of these sources was a certain proportion of the total variance, and together they added up to the total variance of the readings. If there were no replicate positionings per ankle, the position-

Table 1. Mean Values (Range) in mm of the Syndesmotic Radiographic Parameters in the Most Common Positions of Rotation

Position	MFPT	MFAT	MFINC	INCPT	INCAT
25° external rotation	–2.1 (–6–4)	11.4 (5–15)	2.3 (0–5)	0.2 (–1–3)	13.4 (7–18)
20° external rotation	–2.1 (–5–3)	10.0 (5–14)	2.4 (1–4)	0.3 (–2–11)	12.2 (0–16)
15° external rotation AP view	–1.8 (–4–4)	8.7 (3–13)	2.5 (1–4)	0.9 (–0.5–11.5)	10.9 (0–16)
10° external rotation	–1.2 (–4–7)	7.3 (0–12)	2.3 (0–4)	0.9 (–1–4)	9.8 (1–15)
5° external rotation	0.4 (–4.5–6)	5.8 (–2–16)	2.3 (1–4.5)	1.9 (–1.5–14)	8.0 (0–15)
0° Mortise view	0.3 (–4–7)	4.2 (–3–10)	2.2 (0–4)	2.5 (0–13)	6.4 (0–12.5)
5° internal rotation	1.0 (–3–7)	2.9 (–3–9)	2.2 (1–4.5)	3.2 (0–11)	5.1 (0–14)
10° internal rotation	1.8 (–3–6)	1.5 (–3–10)	2.2 (–1–4)	4.0 (0–16)	3.8 (0–10)

MFPT = medial fibula-posterior tibial tubercle
MFAT = medial fibula-anterior tibial tubercle
MFINC = medial fibula-incisura fibularis
INCPT = incisura fibularis-posterior tibial tubercle
INCAT = incisura fibularis-anterior tibial tubercle

ing component was added and therefore was included in the ankle component whereas the total variance did not change.

This caused the ankle component in the total variance to become too great and reproducibility too small. Therefore, total variance was reduced to a between-ankle and a within-ankle component using replicate positioning. The within-ankle component was additionally reduced to a positioning component (necessary for taking a radiograph) and a reading component. The reading component may consist of interobserver and intraobserver variability.

These variabilities can be distinguished from one another if there are several observers and several replicate readings by each observer. In this way more realistic intraclass correlation coefficients and reproducibilities can be calculated. The intraclass correlation coefficient measures how accurately ankles can be distinguished from each other using the readings. The intraclass correlation coefficient is defined as the between-ankle variance (ankle component) as a proportion of the total variance, therefore it is a dimensionless number between 0 and 1 (the nearer to 1, the better). Reproducibility measures the maximum absolute difference between two replicate readings (taken under reproducible conditions) that can be attributed to chance with 95% probability, (the maximum absolute difference that is exceeded with a probability of 5%). It is defined as 1.96 times the square root of twice the within-ankle variance (the sum of positioning, interobserver and intraobserver components). It has the same dimension (mm) as the readings and can be interpreted clinically (the smaller, the better).

Results

Tibiofibular overlap of either the anterior or the posterior tubercle and the fibula was positive or 0 in every radiograph. The value of all syndesmotic parameters changed with rotation (Table 1). The distance between the medial side of the fibula and the posterior tibial tubercle was smallest in the maximum external rotation position, and increased with internal rotation. The contrary was found for the distance between the medial side of the fibula and the anterior tibial tubercle, which increased with external rotation. The distances between the floor of the incisura fibularis and the posterior tibial tubercle and between the floor of the incisura fibularis and the anterior tibial tubercle showed similar trends. This is a result of the anterior tubercle projecting

Table 2. Mean Values (Range) in mm of the Fibular Width and the Medial and Superior Clear Space in the Most Common Positions of Rotation

Position	MFLF	SCS	MCS
25° external rotation	13.9 (11–17)	4.0 (3–5.5)	3.0 (1.5–5)
20° external rotation	14.0 (11–17)	4.0 (2.5–5)	2.8 (2–5)
15° external rotation AP view	13.8 (8–18)	3.9 (2.5–5.5)	2.8 (2–5)
10° external rotation	13.9 (10–17)	3.9 (1.5–5)	2.7 (2–4)
5° external rotation	14.1 (11.5–18)	3.9 (2–5)	2.8 (1.5–5)
0° Mortise view	14.1 (12–17)	3.9 (2–5)	2.7 (1–4)
5° internal rotation	14.2 (12–16.5)	3.9 (2–5)	2.7 (1–4)
10° internal rotation	14.2 (10–17)	4.0 (3–5)	2.8 (1–4)

MFLF = medial fibula-lateral fibula
SCS = superior tibiotalar clear space
MCS = medial tibiotalar clear space

greatest in external rotation and the posterior tubercle projecting greatest in internal rotation.

The mean distance between the medial side of the fibula and the floor of the incisura fibularis in every position ranged from 2.2–2.5 mm. Unfortunately, the range per position was too great to consider this distance a useful parameter.

The value of the medial clear space and superior clear space changed considerably in the different positions of rotation (Table 2), but in any position of rotation the medial clear space was smaller than or equal to the superior clear space in all but two of 960 readings.

When the positioning component was not taken into account, reliable measurements (intraclass correlation coefficient ≥ 0.7) could be made for the distances between the medial side of the fibula and the anterior tibial tubercle, between the floor of the incisura fibularis and the anterior tibial tubercle and for the width of the fibula in every position from 30° to 5° external rotation. The distance between the medial side of the fibula and the posterior tibial tubercle could only be measured reliably in extreme internal rotation. In the AP position the distances between the medial side of the fibula and the anterior tibial tubercle, between the floor of the incisura fibularis and the anterior tibial tubercle, between the medial side of the fibula and the floor of the incisura fibularis, and the width of the fibula could be reliably measured. On the mortise view the width of the fibula was the only parameter that could be measured reliably. However, when the positioning component was taken into account, the width of the fibula remained the only parameter that could be measured reliably (Tables 3 and 4).

The reproducibilities of all parameters in all positions of rotation (Tables 5 and 6), with the exception of fibular width, neared or exceeded the mean values of those parameters (Tables 1 and 2). Therefore it is evident that none of the measurements can be used in clinical practice. The width of the fibula, the only parameter that could be measured reproducibly, has no clinical relevance.

Table 3. Intraclass Correlation Coefficients of Five Syndesmotic Radiographic Parameters

Position	MFPT	MFAT	MFINC	INCPT	INCAT
30°X					
1	0.00	**0.91**	0.46	0.00	**0.87**
2	0.00	0.57	0.36	0.00	0.52
25°X					
1	0.55	**0.94**	0.59	0.00	**0.96**
2	0.39	0.59	0.46	0.00	0.57
20°X					
1	0.11	**0.95**	0.68	0.00	**0.73**
2	0.08	0.59	0.53	0.00	0.43
15°X AP view					
1	0.20	**0.95**	**0.71**	0.54	0.69
2	0.14	0.59	0.55	0.39	0.41
10°X					
1	0.21	**0.75**	0.51	0.30	**0.82**
2	0.15	0.47	0.36	0.22	0.49
5°X					
1	0.36	**0.73**	0.57	0.43	**0.70**
2	0.25	0.46	0.44	0.31	0.42
0° Mortise view					
1	0.50	0.58	0.44	0.32	0.58
2	0.35	0.36	0.34	0.23	0.34
5°N					
1	0.33	0.41	0.14	0.34	0.33
2	0.23	0.26	0.11	0.25	0.20
10°N					
1	0.49	0.28	0.47	0.49	0.31
2	0.34	0.17	0.36	0.35	0.18
15°N					
1	0.53	0.33	0.45	0.50	0.33
2	0.37	0.21	0.35	0.36	0.20
20°N					
1	**0.81**	0.41	0.26	0.54	0.34
2	0.57	0.26	0.20	0.39	0.20
25°N					
1	**0.92**	0.34	0.49	**0.83**	0.19
2	0.65	0.21	0.38	0.60	0.11

X = external rotation
N = internal rotation
MFPT = medial fibula-posterior tibial tubercle
MFAT = medial fibula-anterior tibial tubercle
MFINC = medial fibula-incisura fibularis
INCPT = incisura fibularis-posterior tibial tubercle
INCAT = incisura fibularis-anterior tibial tubercle
Intraclass correlation coefficients equal or larger than 0.70 are highlighted. Interobserver variability is included in the total variance.
1. intraclass correlation coefficients of single radiograph measurements, with inclusion of the positioning component in the ankle component
2. intraclass correlation coefficients of repeated ankle radiography

Table 4. Intraclass Correlation Coefficients of Fibular Width and the Medial and Superior Clear Space in the Most Common Positions of Rotation

Position	MFLF	SCS	MCS
30°X			
1	**0.84**	—	—
2	**0.77**	—	—
25°C			
1	**0.91**	0.46	0.63
2	**0.83**	0.43	0.56
20°X			
1	**0.92**	0.53	0.68
2	**0.84**	0.49	0.61
15°X AP view			
1	**0.80**	0.49	0.55
2	**0.73**	0.45	0.49
10°X			
1	**0.80**	0.37	0.65
2	**0.73**	0.34	0.58
5°X			
1	**0.91**	0.47	0.65
2	**0.83**	0.43	0.58
0° Mortise view			
1	**0.84**	0.54	0.59
2	**0.77**	0.50	0.53
5°N			
1	**0.87**	0.49	0.52
2	**0.80**	0.45	0.46
10°N			
1	**0.90**	0.58	0.53
2	**0.82**	0.54	0.47
15°N			
1	**0.85**	—	—
2	**0.78**	—	—
20°N			
1	**0.89**	—	—
2	**0.81**	—	—
25°N			
1	**0.90**	—	—
2	**0.82**	—	—

X = external rotation
N = internal rotation
MFLF = medial fibula-lateral fibula
SCS = superior tibiotalar clear space
MCS = medial tibiotalar clear space
Intraclass correlation coefficients equal or larger than 0.70 are highlighted. Intraobserver variability is included in the total variance.
1. intraclass correlation coefficients of single radiograph measurements, with inclusion of the positioning component in the ankle component
2. intraclass correlation coefficients of repeated ankle radiography

Discussion

Our aims in this study were to find the optimal ankle position and parameter to assess syndesmotic integrity radiographically, as those measurements might be influenced by rotation and no consensus exists how to measure tibiofibular clear space and overlap. We radiographed 20 ankles in 12 different positions of rotation and measured tibiofibular overlap and clear space in every way described in the literature. This was followed by repeated positioning, radiography, and measurement of the parameters to assess reproducibility. This study showed that, even when done in optimal laboratory conditions, no reproducible ankle positioning is possible. Therefore the reliability of syndesmotic measurements in repeated ankle radiographs is questionable. This study was done using 20 plastinated cadaveric specimens. Plastination does not change macroscopic or microscopic anatomy, so results from this study should be comparable to results of unloaded ankle radiographs in the clinical setting.

Three observations important for clinical practice were made. First the overlap of the fibula with the tibia with respect to either the anterior (the distance between the medial side of the fibula and the anterior tibial tubercle) or the posterior tibial tubercle (the distance between the medial side of the fibula and the posterior tibial tubercle) was positive or 0 in every radiograph. This finding suggests that absence of overlap is abnormal, and indicates syndesmotic injury. This is in accordance with findings of Pneumaticos et al,[12] but now assessed in a larger series with repeated positioning, radiography, and measuring. However, bilateral nontraumatic absence of tibiofibular overlap can be seen in some people. Therefore unilateral absence of tibiofibular overlap after ankle injury should be considered as syndesmotic diastasis.

Second, the value of the medial clear space was smaller than or equal to the superior clear space in all but two of 960 measurements. These two exceptions are most likely attributable to measurement errors, because they were measured differently by the aberrant observer on the other occasion. The absolute values of medial clear space

Table 5. Reproducibility (mm) of Five Syndesmotic Radiographic Parameters

Position	MFPT	MFAT	MFINC	INCPT	INCAT
30°X					
1	3.4	1.7	1.5	1.1	2.3
2	—	3.8	1.7	—	4.5
25°X					
1	2.7	1.5	1.5	2.3	1.4
2	3.2	4.0	1.7	—	4.6
20°X					
1	3.4	1.3	1.1	4.1	3.7
2	3.4	3.8	1.3	—	5.4
15°X AP view					
1	3.0	1.5	0.9	4.6	4.5
2	3.1	4.2	1.1	5.3	6.2
10°X					
1	3.9	3.7	1.3	2.8	3.1
2	4.0	5.4	1.4	2.9	5.3
5°X					
1	4.8	4.1	1.3	4.7	4.3
2	5.1	5.9	1.5	5.1	6.0
0° Mortise view					
1	4.8	4.8	1.6	5.5	5.1
2	5.5	6.0	1.7	5.9	6.4
5°N					
1	5.8	5.5	3.0	5.6	6.3
2	6.2	6.2	3.0	6.0	6.9
10°N					
1	4.6	5.5	1.7	5.3	5.3
2	5.2	5.9	1.9	6.0	5.8
15°N					
1	4.2	4.5	1.7	4.7	5.4
2	4.9	4.9	1.9	5.3	5.9
20°N					
1	2.4	4.0	1.7	4.0	4.0
2	3.6	4.5	1.8	4.5	4.4
25°N					
1	1.7	3.9	1.4	2.6	4.5
2	3.7	4.3	1.5	4.0	4.7

X = external rotation
N = internal rotation
MFPT = medial fibula-posterior tibial tubercle
MFAT = medial fibula-anterior tibial tubercle
MFINC = medial fibula-incisura fibularis
INCPT = incisura fibularis-posterior tibial tubercle
INCAT = incisura fibularis-anterior tibial tubercle
1. reproducibilities of single radiograph measurements, with inclusion of the positioning component in the ankle component

Table 6. Reproducibility (mm) of Fibular Width, Medial Clear Space and Superior Clear Space

Position	MFLF	SCS	MCS
30°X			
1	1.8	—	—
2	2.2	—	—
25°X			
1	1.2	1.2	1.2
2	1.6	1.4	1.4
20°X			
1	1.2	1.2	1.2
2	1.7	1.4	1.4
15°X AP view			
1	1.9	1.3	1.2
2	2.2	1.4	1.3
10°X			
1	1.7	1.5	1.0
2	2.0	1.6	1.1
5°X			
1	1.2	1.4	1.1
2	1.6	1.6	1.3
0° Mortise view			
1	1.4	1.2	1.2
2	1.7	1.5	1.3
5°N			
1	1.2	1.3	1.3
2	1.5	1.2	1.4
10°N			
1	1.2	1.1	1.5
2	1.6	1.4	1.6
15°N			
1	1.4	—	—
2	1.6	—	—
20°N			
1	1.3	—	—
2	1.7	—	—
25°N			
1	1.3	—	—
2	1.7	—	—

X = external rotation
N = internal rotation
MFLF = medial fibula-lateral fibula
SCS = superior tibiotalar clear space
MCS = medial tibiotalar clear space
1. reproducibilities of single radiograph measurements, with inclusion of the positioning component in the ankle component
2. reproducibilities of repeated ankle radiography

and superior clear space changed considerably in the different positions of rotation. This observation is in contrast with findings of a less extensive study of Joy et al,[7] who stated that variations in rotation between 5° and 20° rotation do not alter measurements of the medial clear space or the superior clear space. Furthermore our study shows the combined measurement of medial clear space and superior clear space to be useful, as the medial clear space should not exceed the superior clear space in any projection of the nonweight-bearing ankle. If the medial clear space exceeds the superior clear space it is indicative of deltoid ligament injury, which is not uncommon with syndesmotic injury.

Finally, quantitative measurement of all syndesmotic parameters in repeated ankle radiographs may not be as useful as previously reported by other authors.[6,12] In our opinion the reason for this different finding is that none of the other authors took results of repeated ankle radiographs into account. Pneumaticos et al[12] stated that the tibiofibular clear space (measured as the distance between the medial side of the fibula and the posterior tibial tubercle) did not change significantly with rotation and therefore is reproducible and reliable in evaluating the integrity of the distal tibiofibular joint. Those authors however, did not address interobserver reliability and repeated ankle radiography. The current study shows that reliable measurements (intraclass correlation coefficient ≥ 0.7) can be made for the distance between the medial side of the fibula and the anterior tibial tubercle, the floor of the incisura fibularis and the anterior tibial tubercle and the width of the fibula in several positions, but that these measurements are not reliable for repeated ankle radiography. The finding of Pneumaticos et al[12] that the tibiofibular overlap (measured as the distance between the medial side of the fibula and the anterior tibial tubercle) never has a negative value is confirmed by our study.

Brage et al[1] showed excellent reliability for certain parameters measured on ankle radiographs, with reliability increasing with experience. The interobserver intraclass correlation coefficients from the current single radiograph measurements in our study were better than their results for the distance between the medial side of the fibula and the anterior tibial tubercle (their syndesmosis B or the tibiofibular overlap) in positions of 5° to 30° external rotation, comparable for the distance between the medial side of the fibula and the posterior tibial tubercle (their syndesmosis A or the tibiofibular clear space) on the AP view, and worse for the distance between the medial side of the fibula and the anterior tibial tubercle (their syndesmosis C) on the mortise view. The latter probably is attributable to the fact that in our study the ankles were accurately placed, so that a more precise mortise view was accomplished, with superimposition of the anterior and posterior tubercles, which made discrimination of the tubercles more difficult. Furthermore, the study by Brage et al[1] evaluated reliability for single extremity–single occasion radiographs without accounting for the effect of repositioning of the ankle. This essentially is different from the current study and from clinical practice. Also, serial radiographs are mandatory to evaluate a patient during treatment, or to compare the injured with the noninjured extremity.

Measurements of the distance between the medial side of the fibula and the anterior tibial tubercle (mortise view, 4.2 mm; AP view, 8.7 mm) were close to the values which Harper and Keller[6] found for the tibiofibular overlap (mortise view, 4.2 mm; AP view, 9.4mm) in these positions. There is a bigger difference between the distance between the medial side of the fibula and the floor of the incisura fibularis and their tibiofibular clear space.

Harper and Keller[6] reported that measurement of the tibiofibular clear space could exclude syndesmotic diastasis, based on the radiographic evaluation of 12 accurately placed fresh cadaveric lower extremities. This only is true, however, if accurate positioning has been done. Therefore,

Harper[5] later stated that precise evaluation of the tibiofibular relationship should be done by CT to avoid misinterpretation of the tibiofibular width because of rotational deformities or translations of the fibula. In agreement with her, it was suspected that rotation attributable to positioning errors could be responsible for even weaker reproducibilities in repeated radiographs. This was confirmed with the calculation of more realistic intraclass correlation coefficients and reproducibility based on the replicate positioning.

Computed tomography scans can show the tibial tubercles the incisura fibularis and tibiofibula, as has been shown in cadaveric studies describing the normal aspect of the incisura fibularis,[2,5] but criteria how to distinguish the normal from the injured syndesmosis with CT have not been described, and reproducibility of CT for this purpose has not been assessed. Ebraheim et al[3] correlated radiographic and CT findings in seven patients with low fibular fractures, but they state that with CT the syndesmosis was found to be disrupted without describing the CT criteria for disruption. Furthermore this investigation may be difficult to access in many trauma units, or be beyond the economic resources available, whereas plain radiographs are universally available and relatively inexpensive.

Based on our observations, it is evident that no optimal radiographic parameter exists to assess syndesmotic integrity, because all parameters are dependent on the position of rotation. As precise positioning of the ankle is not possible, the aforementioned parameters are not reliable in repeated ankle radiography. Two parameters were found to be of some use. These are the tibiofibular overlap and the combination of the medial and superior clear space. Unilateral absence of tibiofibular overlap should raise the suspicion of a syndesmotic injury, and a medial clear space exceeding the superior clear space on a nonweight-bearing radiograph should raise the suspicion of deltoid ligament injury in any projection of a normal ankle. Quantitative measurement of all other syndesmotic parameters in repeated ankle radiographs may be of little value.

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Chapter 6

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

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Background Syndesmotic injuries of the ankle without fractures can result from external rotation, abduction and dorsiflexion injuries. Kinematic studies of these trauma mechanisms have not been performed.

We attempted to describe the kinematics of the tibiofibular joint in cadaveric specimens using radiostereometry after sequential ligament sectioning, and resulting from different trauma mechanisms and axial loading, in order to put forward treatment guidelines for the different types of syndesmotic injuries.

Methods We assessed the kinematics of the distal tibiofibular joint in fresh–frozen cadaveric specimens using radiostereometry in the intact situation, and after alternating and sequential sectioning of the distal tibiofibular and anterior deltoid ligaments. To assess which of the known trauma mechanisms would create the largest displacements at the syndesmosis, the ankle was brought into the following positions under an axial load that was comparable to body weight (750 N): neutral, dorsiflexion, external rotation, abduction, and a combination of external rotation and abduction.

Results In the neutral position, the largest displacements of the fibula consisted of external rotation and posterior translation. Loading of the ankle with 750 N did not apparently increase or decrease the displacements of the fibula, but gave a larger variety of displacements.

In every position, sectioning of a ligament resulted in some fibular displacement. Sectioning of the anterior tibiofibular ligament (ATiFL) invariably resulted in external rotation of the fibula. Additional sectioning of the anterior part of the deltoid ligament (AD) gave a larger variety of displacements. In general, sectioning of the posterior tibiofibular ligament (PTiFL) gave the smallest displacements. Combined sectioning of the ATiFL and the PTiFL resulted in a larger variety of displacements in the neutral position. Sectioning of the AD together with the ATiFL and PTiFL resulted in tibiofibular displacements in the neutral situation exceeding the maximum values found in the intact situation, the most important being fibular external rotation.

Interpretation Sectioning of the ATiFL results in mechanical instability of the syndesmosis. Of all trauma mechanisms, external rotation of the ankle resulted in the largest and most consistent displacements of the fibula relative to the tibia found at the syndesmosis.

Based on our findings and the current literature, we recommend that patients with isolated PTiFL or AD injuries should be trea-

ted functionally when no other injuries are present. Patients with acute complete ATiFL ruptures, or combined ATiFL and AD ruptures should be treated with immobilization in a plaster. Patients with combined ruptures of the ATiFL, AD and PTiFL need to be treated with a syndesmotic screw.

Testing device. The tibia is secured and the foot is attached to a plate, allowing full range of motion (example of maximal dorsiflexion).

The distal tibiofibular syndesmosis consists of an anterior part (the anterior inferior tibiofibular ligament; ATiFL), a posterior part (the posterior inferior tibiofibular ligament; PTiFL and a transverse ligament; TL) and in–between, the interosseous ligament (IL)—the most distal condensation of fibres of the interosseous membrane (Grath 1960).

According to Kelikian and Kelikian (1985), 3 types of syndesmotic injuries (or diastasis) without ankle fractures can be recognized.

Most commonly, the ATiFL is ruptured. This anterior syndesmotic diastasis is an "open book" injury resulting from external rotation of the fibula.

The ATiFL rupture may be combined with an injury of the deltoid ligament. Alternatively, a complete tibiofibular disruption of all 4 syndesmotic ligaments may result from abduction or external rotation. The third and least common variety is intercalary diastasis, which is seen in children. It results from a rupture of the interosseous membrane combined with a metaphyseal fracture of the fibula and a physeal fracture of the tibia. The above–mentioned injuries have also been recognized by others (Mullins and Sallis 1958, Rasmussen et al. 1982, Miller et al. 1995, Xenos et al. 1995). They are believed to result from external rotation, abduction and dorsiflexion injuries, or combinations of these (Lauge–Hansen 1950, Weber 1966, Frick 1978, Pankovich 1979, Colville et al. 1990). Kinematic studies—including those concentrating on these trauma mechanisms—are difficult to perform because displacements in the syndesmosis are usually small and are thus difficult to measure.

We assessed the kinematics of the tibiofibular joint in cadaveric specimens using radiostereometry (RSA) after sequential ligament sectioning and axial loading to simulate different trauma mechanisms, in order to put forward guidelines for the treatment of different types of syndesmotic injuries.

Material and methods

10 fresh–frozen lower legs, sectioned through the knee, with a mean age of 88 (81–102) years were used. Only intact specimens at macroscopic and radiographical examination (conventional anteriorposterior and lateral views) were included. All soft tissues from knee to tarso–metatarsal joints, except the interosseous membrane and the ligaments and joint capsules, were removed. 5 tantalum markers (0.8 mm) were placed in the distal tibia and fibula according to a standard scheme to achieve optimal spreading.

The specimens were mounted on a device that secured the tibia and allowed full range of motion (Figure). The foot was attached to a plate, with fixation at the calcaneus and forefoot. The longitudinal axis of the tibia was positioned parallel to the ground surface. Before RSA examinations started, the range of motion of the ankle and foot complex was determined with a goniometer attached to the device. The neutral position (i.e. the starting position of this study) was set as a plantigrade ankle position with the intermalleolair line parallel to the ground. This position, instead of the zero position for the forefoot (American Academy of Orthopaedic Surgeons 1965),

Table 1. The number of specimens in different positions and sectioning conditions

Position[a] and loading	Intact	Sectioning conditions[b] A	D	P	A+D	A+P	A+D+P
N	9	4	3	2	5	4	10
N loaded	10	4	3	2	5	5 1	0
ER	10	4	3	2	5	5	10
ER loaded	9	4	3	2	5	5	10
AB loaded	9	4	3	2	5	5	10
ER+AB loaded	9	4	3	1	5	5	10
DF loaded	7	4	3	2	5	5	10

a Positions:
N: Neutral,
ER: External rotation,
DF: Dorsiflexion.
AB: Abduction;
b Sectioning conditions:
A: ATiFL sectioned,
D: anterior part of deltoid ligament (AD) sectioned,
P: PTiFL sectioned.

was chosen to minimize positioning errors that could be the result of forefoot abnormalities.

RSA examinations were done, unloaded and under an axial load (L) that was comparable to body weight (750 N), in the following positions: neutral (N), maximal dorsiflexion (DF), maximal external rotation (ER), maximal abduction (AB) and a combination of the latter two (ER+AB), and for the following sectioning conditions: isolated sectioning of the ATiFL (A), isolated sectioning of the anterior deltoid ligament (D), isolated sectioning of the PTiFL and the transverse ligament (P), and combinations of these (Table 1). With a Vidar VXR–12 scanner (Vidar Systems Corp., Alleroed, Denmark), the radiographs were scanned at 150 d.p.i. and 8–bit gray scale resolution. They were digitally processed and analyzed (Valstar et al. 2000) using RSA–CMS software (Medis BV, Leiden, The Netherlands).

The motion of the fibula was expressed as translation and rotation of the fibula relative to the tibia. Positive directions for translations along the coordinate axes were lateral–medial, caudal–cranial, and posterior–anterior. Positive directions for rotations about the coordinate axes were plantar flexion, internal rotation, and adduction. Reliability of RSA depends on nonlinear marker distribution.

The geometrical interpretation of the distribution of the markers in 3–D space is expressed in the condition number (Söderkvist and Wedin 1993). In accordance with international recommendations, examinations were included in the study when the condition number was below 80–90 (Börlin et al. 2002). Descriptive statistics and confidence limits were calculated with Stata software (StataCorp LP, College Station, Texas, USA).

Results

The mean ranges of motion of the ankle and foot complex were: dorsiflexion 18° (15–20); plantarflexion > 30°; internal rotation 2° (0–5); external rotation 19° (15–25); abduction 3° (0–5) and adduction 19° (15–25). The mean condition numbers for tibia and fibula were 24 (15–39) and 15 (10–17).

No segment had to be excluded from analysis. The reproducibility, assessed by repeating 10 examinations of the intact situation and presented as SDs from zero, was 0.1 mm/0.2° (x–axis), 0.1 mm/0.3° (y–axis), 0.2 mm/ 0.1° (z–axis).

Displacements of the fibula with respect to the tibia (Tables 2–7)

All positions and conditions, except ER and some conditions of ER–L, resulted in an increase in tibiofibular width. ER and ER–L resulted in a decrease in width. Most positions and conditions resulted in cranial displacement of the fibula. Exceptions were found after P in most positions, as well as after P, A+D and A+D+P during N–L. DF–L and ER+AB–L resulted in posterior displacement of the fibula in all sectioning conditions. With the exception of P, larger posterior translations were found for ER and ER–L. All conditions of AB–L (except A+D) resulted in anterior translation. N–L resulted in a large variety of translations in all sectioning conditions. Displacements about the x–axis did not exceed 1 mm or 1° for any position

Table 2. Translation X:

Lateral–medial displacement of the fibula relative to the tibia after transection of the tibiofibular and deltoid ligaments in different positions and loading conditions (mean and SD; relative to the intactneutral unloaded situation).
Negative value = lateral displacement

	Translation X		
	Mean	SD	95% CII
Intact (n=10)			
N	–	–	
N loaded	–0.24	0.50	–0.63 to 0.14
ER	0.53	0.38	0.26 to 0.81
ER loaded	0.14	0.40	–0.16 to 0.45
AB loaded	–0.29	0.61	–0.76 to 0.18
ER+AB loaded	–0.04	0.80	–0.65 to 0.57
DF loaded	–0.81	0.73	–1.49 to –0.14
ATiFL sectioned (n=4)			
N	–0.01	–0.01	–0.16 to 0.14
N loaded	–0.52	–0.52	–1.10 to 0.06
ER	0.50	0.50	–0.06 to 1.06
ER loaded	–0.45	–0.45	–1.17 to 1.08
AB loaded	–0.42	–0.42	–1.03 to 0.20
ER+AB loaded	–0.26	–0.26	–0.86 to 0.33
DF loaded	–0.58	–0.58	–1.24 to 0.08
AD sectioned (n=3)			
N	–0.06	0.36	–0.95 to 0.82
N loaded	–0.57	0.63	–2.13 to 0.99
ER	0.00	0.80	–1.99 to 1.99
ER loaded	–0.27	0.35	–1.15 to 0.61
AB loaded	–1.09	0.70	–2.84 to 0.66
ER+AB loaded	–1.04	0.75	–2.91 to 0.82
DF loaded	–1.12	0.94	–3.44 to 1.21
PTiFL sectioned (n=2)			
N	–0.03	0.25	–2.25 to 2.18
N loaded	–0.58	0.18	–2.17 to 1.01
ER	0.50	0.80	–6.72 to 7.72
ER loaded	0.29	0.27	–2.43 to 2.49
AB loaded	–0.25	0.04	–4.86 to 4.36
ER+AB loaded	–0.34	–	–
DF loaded	–0.90	0.40	–4.51 to 2.72
ATiFL and AD sectioned (n=5)			
N	–0.05	0.34	0.22 to 0.54
N loaded	–0.16	0.73	–1.42 to 0.61
ER	0.67	0.36	0.16 to 0.88
ER loaded	0.27	0.28	–1.15 to 0.36
AB loaded	–0.13	0.70	–1.56 to 0.07
ER+AB loaded	0.14	0.57	–1.67 to 0.32
DF loaded	–0.58	0.20	–2.13 to 0.01
ATiFL and PTiFL sectioned (n=5)			
N	–0.05	0.34	–0.47 to 0.38
N loaded	–0.16	0.73	–1.32 to 1.00
ER	0.67	0.36	0.22 to 1.13
ER loaded	0.27	0.28	–0.08 to 0.61
AB loaded	–0.13	0.70	–1.00 to 0.73
ER+AB loaded	0.14	0.57	–0.76 to 1.05
DF loaded	–0.58	0.20	–0.83 to –0.33
ATiFL, AD and PTiFL sectioned (n=10)			
N	–0.08	0.68	–0.57 to 0.40
N loaded	–0.43	0.64	–0.89 to 0.03
ER	0.51	0.53	0.13 to 0.88
ER loaded	0.01	0.66	–0.46 to 0.48
AB loaded	–0.50	0.77	–1.05 to 0.05
ER+AB loaded	–0.32	0.78	–0.92 to 0.28
DF loaded	–0.69	0.71	–1.20 to –0.19

See Table 1 for abbreviations.

Table 3. Translation Y:

Caudal–cranial displacement of the fibula relative to the tibia after transection of the tibiofibular and deltoid ligaments in different positions and loading conditions (mean and SD; relative to the intact neutral unloaded situation).
Negative value = caudal displacement

	Translation Y		
	Mean	SD	95% CII
Intact (n=10)			
N	–	–	– –
N loaded	0.19	0.29	–0.29 to 0.41
ER	0.12	0.22	–0.30 to 0.28
ER loaded	0.40	0.42	0.08 to 0.72
AB loaded	0.23	0.48	–1.36 to 0.59
ER+AB loaded	0.42	0.56	–0.01 to 0.85
DF loaded	0.28	0.35	–0.05 to 0.61
ATiFL sectioned (n=4)			
N	0.00	0.18	–0.29 to 0.29
N loaded	0.05	0.62	–0.05 to 0.15
ER	–0.03	0.16	–0.28 to 0.23
ER loaded	0.09	0.27	–0.34 to 0.52
AB loaded	–0.14	0.17	–0.41 to 0.14
ER+AB loaded	–0.05	0.15	–0.29 to 0.18
DF loaded	0.11	0.18	–0.18 to 0.40
AD sectioned (n=3)			
N	0.05	0.18	–0.40 to 0.49
N loaded	0.52	0.23	–0.04 to 1.09
ER	0.27	0.40	–0.73 to 1.26
ER loaded	0.65	0.68	–1.04 to 2.34
AB loaded	1.19	0.79	–0.78 to 3.10
ER+AB loaded	1.45	1.04	–1.13 to 4.02
DF loaded	0.66	0.41	–0.35 to 1.67
PTiFL sectioned (n=2)			
N	0.07	0.15	–1.28 to 1.42
N loaded	–0.58	0.18	–4.79 to 4.53
ER	0.02	0.15	–1.34 to 1.39
ER loaded	–0.19	0.69	–6.41 to 6.04
AB loaded	–0.17	0.34	–3.26 to 2.92
ER+AB loaded	0.05	–	–
DF loaded	–0.06	0.46	–4.19 to 4.06
ATiFL and AD sectioned (n=5)			
N	–0.04	0.18	–0.26 to 0.18
N loaded	–0.68	0.60	–0.12 to 0.76
ER	0.06	0.17	–0.16 to 0.27
ER loaded	0.58	0.57	–0.18 to 1.29
AB loaded	0.87	0.97	–0.34 to 2.07
ER+AB loaded	0.98	1.01	–0.27 to 2.32
DF loaded	0.41	0.41	–0.09 to 0.92
ATiFL and PTiFL sectioned (n=5)			
N	–0.03	0.13	–0.18 to 0.13
N loaded	–0.16	0.73	–0.37 to 1.02
ER	0.09	0.23	–0.19 to 0.38
ER loaded	0.33	0.16	0.13 to 0.53
AB loaded	0.43	0.54	–0.62 to 0.71
ER+AB loaded	0.21	0.43	–0.48 to 0.90
DF loaded	0.00	0.14	–0.18 to 0.18
ATiFL, AD and PTiFL sectioned (n=10)			
N	0.01	0.20	–0.13 to 0.16
N loaded	–0.43	0.64	0.01 to 0.63
ER	0.01	0.19	–0.12 to 0.15
ER loaded	0.37	0.36	0.11 to 0.62
AB loaded	0.50	0.90	–0.14 to 1.14
ER+AB loaded	0.75	0.97	0.00 to 1.49
DF loaded	0.20	0.32	–0.30 to 0.43

See Table 1 for abbreviations.

Table 4. Translation Z:

Posterior–anterior displacement of the fibula relative to the tibia after transection of the tibiofibular and deltoid ligaments in different positions and loading conditions (mean and SD; relative to the intact neutral unloaded situation). Negative value = posterior displacement

	Translation Z		
	Mean	SD	95% CII
Intact (n=10)			
N	–	–	–
N loaded	0.13	0.89	–0.56 to 0.81
ER	–0.92	1.01	–1.64 to –0.20
ER loaded	–0.92	1.01	–1.69 to 0.15
AB loaded	0.58	0.64	0.09 to 1.07
ER+AB loaded	–0.74	0.98	–1.51 to 0.02
DF loaded	–0.62	0.54	–1.12 to –0.11
ATiFL sectioned (n=4)			
N	–0.31	0.57	–1.21 to 0.59
N loaded	0.02	0.24	–0.36 to 0.40
ER	–0.91	0.39	–1.53 to –0.29
ER loaded	–1.36	1.07	–3.07 to 0.35
AB loaded	0.37	0.34	–1.18 to 0.91
ER+AB loaded	–0.67	0.50	–1.47 to 0.13
DF loaded	–0.33	0.53	–1.17 to 0.52
AD sectioned (n=3)			
N	–0.27	0.99	–2.73 to 2.20
N loaded	–0.57	0.63	–2.53 to 3.45
ER	–1.72	1.32	–5.01 to 1.57
ER loaded	–0.85	1.17	–3.74 to 2.05
AB loaded	1.14	0.30	0.41 to 1.88
ER+AB loaded	0.01	0.99	–2.46 to 2.47
DF loaded	–0.38	0.75	–2.24 to 1.48
PTiFL sectioned (n=2)			
N	–0.42	0.56	–5.42 to 4.59
N loaded	–0.10	0.82	–7.52 to 7.31
ER	0.26	1.04	–9.05 to 9.57
ER loaded	0.14	1.91	–17.0 to 17.3
AB loaded	0.42	1.59	–13.9 to 14.7
ER+AB loaded	–0.23	–	– –
DF loaded	–0.53	0.90	–8.64 to 7.58
ATiFL and AD sectioned (n=5)			
N	–0.93	0.96	–2.12 to 0.26
N loaded	0.62	0.83	–0.41 to 1.65
ER	–1.88	1.22	–3.40 to –0.37
ER loaded	–1.55	1.23	–3.08 to –0.02
AB loaded	–0.35	1.43	–2.13 to 1.43
ER+AB loaded	–1.22	1.54	–3.14 to 0.69
DF loaded	–0.35	0.62	–1.12 to 0.41
ATiFL and PTiFL sectioned (n=5)			
N	0.10	0.68	–0.74 to 0.94
N loaded	–0.19	0.69	–1.28 to 0.90
ER	–0.43	1.62	–2.44 to 1.58
ER loaded	–0.72	2.18	–3.42 to 1.99
AB loaded	0.59	0.69	–0.80 to 0.92
ER+AB loaded	–1.23	0.85	–2.59 to 0.13
DF loaded	–0.50	0.99	–1.73 to 0.73
ATiFL, AD and PTiFL sectioned (n=10)			
N	–0.12	1.12	–0.92 to 0.68
N loaded	0.23	0.78	–0.33 to 0.79
ER	–0.88	1.63	–2.05 to 0.29
ER loaded	–1.03	1.73	–2.27 to 0.21
AB loaded	0.38	0.82	–0.20 to 0.97
ER+AB loaded	–0.85	1.06	–1.66 to –0.03
DF loaded	–0.43	1.12	–1.22 to 0.37

See Table 1 for abbreviations.

Table 5. Rotation X:

Rotation of the fibula about the x–axis relative to the tibia after transection of the tibiofibular and deltoid ligaments in different positions and loading conditions (mean and SD; relative to the intact neutral unloaded situation). Negative value = dorsiflexion

	Rotation X		
	Mean	SD	95% CII
Intact (n=10)			
N	–	–	–
N loaded	0.48	0.35	–0.22 to 0.32
ER	0.35	0.47	0.01 to 0.69
ER loaded	0.36	0.40	0.05 to 0.66
AB loaded	–0.33	0.33	–0.59 to –0.08
ER+AB loaded	0.03	0.30	–0.20 to 0.26
DF loaded	0.06	0.29	–0.21 to 0.32
ATiFL sectioned (n=4)			
N	0.35	0.39	–0.28 to 0.97
N loaded	0.52	0.23	–0.32 to 0.42
ER	0.73	0.34	0.18 to 1.27
ER loaded	0.92	0.66	–0.14 to 1.97
AB loaded	–0.20	0.34	–0.74 to 0.36
ER+AB loaded	0.21	0.55	–0.66 to 1.09
DF loaded	0.29	0.12	0.10 to 0.49
AD sectioned (n=3)			
N	0.08	0.19	–0.40 to 0.55
N loaded	0.01	0.31	–0.75 to 0.77
ER	0.61	0.41	–0.42 to 1.64
ER loaded	0.33	0.52	–0.97 to 1.63
AB loaded	–0.49	0.33	–1.32 to 0.34
ER+AB loaded	–0.12	0.13	–0.45 to 0.21
DF loaded	–0.59	0.14	–0.40 to 0.28
PTiFL sectioned (n=2)			
N	0.04	0.13	–1.14 to 1.21
N loaded	0.03	0.07	–0.58 to 0.63
ER	–0.17	0.46	–4.28 to 3.94
ER loaded	–0.18	0.48	–4.49 to 4.12
AB loaded	–0.53	0.60	–5.46 to 5.35
ER+AB loaded	–0.10	–	—
DF loaded	–0.03	0.01	–0.11 to 0.05
ATiFL and AD sectioned (n=5)			
N	0.49	0.24	0.19 to 0.79
N loaded	0.05	0.27	–0.29 to 0.38
ER	0.89	0.53	0.23 to 1.54
ER loaded	0.72	0.50	0.10 to 1.33
AB loaded	–0.6	0.45	–0.63 to 0.50
ER+AB loaded	0.27	0.72	–0.63 to 1.17
DF loaded	0.28	0.16	0.07 to 0.48
ATiFL and PTiFL sectioned (n=5)			
N	0.27	0.69	–0.59 to 1.14
N loaded	–0.14	0.05	–0.22 to –0.53
ER	0.16	1.00	–1.08 to 1.40
ER loaded	0.33	1.38	–1.39 to 2.04
AB loaded	–0.28	0.32	–0.68 to 0.12
ER+AB loaded	0.08	0.88	–1.32 to 1.47
DF loaded	0.09	0.67	–0.74 to 0.92
ATiFL, AD and PTiFL sectioned (n=10)			
N	0.31	0.33	0.07 to 0.54
N loaded	–0.08	0.04	–0.39 to 0.24
ER	–0.88	1.63	–0.79 to 1.05
ER loaded	0.58	1.13	–0.23 to 1.38
AB loaded	–0.22	0.38	–0.50 to 0.05
ER+AB loaded	0.24	0.70	–0.29 to 0.78
DF loaded	0.27	0.56	–0.13 to 0.67

See Table 1 for abbreviations.

Table 6. Rotation Y:

Rotation of the fibula about the y–axis relative to the tibia after transection of the tibiofibular and deltoid ligaments in different positions and loading conditions (mean and SD; relative to the intact neutral unloaded situation).
Negative value = external rotation

	Rotation Y		
	Mean	SD	95% CII
Intact (n=10)			
N	–	–	–
N loaded	–0.27	1.18	–1.18 to 0.64
ER	–2.50	1.38	–3.49 to –1.51
ER loaded	–2.29	1.28	–3.27 to –1.30
AB loaded	–0.26	1.69	–1.56 to 1.04
ER+AB loaded	–1.60	1.30	–2.60 to –0.60
DF loaded	0.57	3.05	–2.25 to 3.39
ATiFL sectioned (n=4)			
N	–1.54	1.46	–3.86 to 0.76
N loaded	–0.63	0.76	–1.83 to 0.58
ER	–3.66	0.76	–4.88 to –2.45
ER loaded	–3.69	1.97	–6.83 to –0.55
AB loaded	–1.10	0.67	–2.16 to –0.04
ER+AB loaded	–2.50	0.93	–3.98 to –1.03
DF loaded	–1.21	1.28	–3.25 to 0.82
AD sectioned (n=3)			
N	0.28	2.83	–6.74 to 7.30
N loaded	–0.08	2.18	–5.50 to 5.35
ER	–0.73	2.16	–6.11 to 4.64
ER loaded	–1.49	2.66	–8.09 to 5.10
AB loaded	0.89	1.34	–2.43 to 4.21
ER+AB loaded	–0.37	2.56	–6.73 to 5.99
DF loaded	–0.40	3.19	–8.33 to 7.52
PTiFL sectioned (n=2)			
N	0.11	0.26	–2.20 to 2.42
N loaded	0.64	0.34	–2.41 to 3.69
ER	–1.38	1.82	–17.7 to 15.0
ER loaded	–1.40	1.52	–15.1 to 12.3
AB loaded	0.12	1.54	–13.7 to 14.0
ER+AB loaded	0.11	–	–
DF loaded	0.38	0.64	–5.40 to 6.16
ATiFL and AD sectioned (n=5)			
N	–1.72	2.14 –	4.37 to 0.94
N loaded	–0.61	2.14	–3.27 to 2.05
ER	–3.00	2.35	–5.93 to –0.08
ER loaded	–2.77	2.81	–6.26 to 0.73
AB loaded	–1.60	3.15	–5.52 to 2.31
ER+AB loaded	–2.50	3.14	–6.41 to 1.40
DF loaded	–0.41	1.97	–2.86 to 2.04
ATiFL and PTiFL sectioned (n=5)			
N	–0.20	0.73	–1.10 to 0.70
N loaded	0.15	0.74	–1.03 to 1.32
ER	–3.67	2.37	–6.61 to –0.74
ER loaded	–4.44	3.97	–9.38 to 0.49
AB loaded	–0.15	1.66	–2.21 to 1.92
ER+AB loaded	–2.25	1.80	–5.11 to 0.61
DF loaded	–1.43	1.54	–3.35 to 0.49
ATiFL, AD and PTiFL sectioned (n=10)			
N	–1.65	1.88	–3.00 to –0.30
N loaded	–1.03	2.07	–2.51 to 0.45
ER	–3.03	2.30	–4.67 to –1.40
ER loaded	–4.05	3.71	–6.71 to –1.39
AB loaded	–0.69	2.00	–2.12 to 0.74
ER+AB loaded	–2.60	2.22	–4.31 to –0.90
DF loaded	–1.70	2.10	–3.20 to –0.20

See Table 1 for abbreviations.

Table 7. Rotation Z:

Rotation of the fibula about the z–axis to the tibia after transection of the tibiofibular and deltoid ligaments in different positions and loading conditions (mean and SD; relative to the intact neutral unloaded situation).
Negative value = abduction

	Rotation Z		
	Mean	SD	95% CII
Intact (n=10)			
N	–	–	–
N loaded	–0.11	0.36	–0.38 to 0.17
ER	0.50	0.26	0.32 to 0.69
ER loaded	0.20	0.35	–0.07 to 0.47
AB loaded	0.25	0.24	–0.16 to 0.21
ER+AB loaded	0.07	0.21	–0.09 to 0.24
DF loaded	–0.30	0.56	–0.81 to 0.21
ATiFL sectioned (n=4)			
N	–0.02	0.17	–0.29 to 0.26
N loaded	–0.24	0.28	–0.69 to 0.22
ER	0.34	0.44	–0.36 to 1.05
ER loaded	0.11	0.47	–0.65 to 0.86
AB loaded	0.11	0.40	–0.52 to 0.73
ER+AB loaded	0.08	0.30	–0.40 to 0.55
DF loaded	–0.12	0.49	–0.90 to 0.65
AD sectioned (n=3)			
N	0.08	0.20	–0.42 to 0.59
N loaded	–0.38	0.50	–1.63 to 0.87
ER	0.02	0.69	–1.68 to 1.74
ER loaded	0.00	0.25	–0.62 to 0.62
AB loaded	–0.27	0.71	–0.45 to –0.09
ER+AB loaded	–0.38	0.12	–0.67 to –0.08
DF loaded	–0.46	0.62	–1.20 to 1.09
PTiFL sectioned (n=2)			
N	–0.12	0.18	–1.77 to 1.54
N loaded	–0.19	0.12	–1.26 to 0.89
ER	0.28	0.42	–3.51 to 4.06
ER loaded	0.25	0.36	–3.02 to 3.52
AB loaded	–0.10	0.20	–1.93 to 1.74
ER+AB loaded	–0.29	–	–
DF loaded	–0.19	0.38	–3.62 to 3.24
ATiFL and AD sectioned (n=5)			
N	–0.00	0.20	–0.26 to 0.25
N loaded	–0.44	0.47	–1.03 to 0.14
ER	0.42	0.22	0.15 to 0.70
ER loaded	–0.28	0.44	–0.83 to 0.27
AB loaded	–0.25	0.28	–0.60 to 0.10
ER+AB loaded	–0.20	0.17	–0.41 to 0.02
DF loaded	–0.52	0.54	–1.19 to 0.15
ATiFL and PTiFL sectioned (n=5)			
N	–0.09	0.28	–0.44 to 0.25
N loaded	–0.42	0.33	–0.94 to 0.11
ER	0.41	0.16	0.22 to 0.61
ER loaded	0.32	0.30	–0.05 to 0.69
AB loaded	–0.26	0.43	–0.80 to 0.28
ER+AB loaded	0.01	0.35	–0.55 to 0.56
DF loaded	0.00	0.25	–0.31 to 0.32
ATiFL, AD and PTiFL sectioned (n=10)			
N	–0.06	0.21	–0.22 to 0.09
N loaded	–0.38	0.28	–0.58 to –0.18
ER	0.25	0.25	0.07 to 0.43
ER loaded	0.09	0.46	–0.24 to 0.42
AB loaded	–0.31	0.22	–0.47 to –0.15
ER+AB loaded	–0.14	0.28	–0.35 to 0.07
DF loaded	–0.26	0.39	–0.54 to 0.02

See Table 1 for abbreviations.

or sectioning condition. Most positions and conditions resulted in external rotation. The most consistent exception was P, which resulted in internal rotation unless ER or ER–L was applied. N–L resulted in adduction, ER and most of ER–L in abduction, and the other positions and conditions gave diverse results. Mean rotations about the z–axis did not exceed 0.54°.

Positions

Neutral and loaded neutral. All conditions of N, except P, resulted in a posterior translation that largely disappeared when loaded. A resulted in 1.5° external rotation. This slightly increased with A+D and A+D+P, and decreased in N–L. N–L gave a lateral translation that was largest after A+D. Under some conditions, N–L resulted in a caudal displacement.

Loaded dorsiflexion. Of all positions, DF–L caused the largest increase in tibiofibular width under any condition, as well as a tendency of cranial and posterior translation in most conditions. Rotations showed a large variety of results.

Loaded abduction. AB–L resulted in an increase in tibiofibular width under any condition. With the exception of A+D, posterior translation was seen under all conditions also. Rotations about the x–axis were mainly negative, but the other rotations showed wide variability.

Loaded external rotation–abduction. Conditions during ER+AB–L showed a tendency to lateral (except A+P) and posterior (except D) translation, as well as a relatively large external rotation (except P). Adduction resulted from conditions that included P.

External rotation and loaded external rotation. ER and some conditions of ER–L resulted in a medial translation of the fibula. All conditions except PS resulted in posterior translation and external rotation.

Discussion

By using a standard scheme, we inserted the markers in a similar pattern in all legs. Without this help, it would have been difficult to obtain an appropriate marker distribution in the fibula. Because of its small diameter, the markers cannot always be distributed far enough from the fibular central axis in this bone. The translations we have shown are translations of the geometric center of the markers.

Because we had similar patterns of markers, the effect of marker scatter on the value of the translations cannot have been large. The main influence of the scatter on the translation results was caused by other factors, such as differences in leg geometry.

For all parameters tested, there was generally a very large dispersion around the median value, indicating a low reproducibility between the cadavers or specimens. Thus, we have only highlighted the results that were consistent, which means that a certain transection condition or position always resulted in the same kind of displacement. It is of interest that in the neutral situation, displacements were found after sectioning the ligaments. This is probably because the connection between tibia and fibula at the level of the distal tibiofibular syndesmosis in the horizontal plane may be considered to be a ring (anterior tibiofibular ligament, fibula, posterior tibiofibular ligament, tibia, anterior tibiofibular ligament). In every ring there is a certain rest tension. When the ring is disrupted at one level, for example at the anterior tibiofibular ligament, the rest tension cannot be maintained and there will be a relaxation in the other structures involved, in this case the posterior tibiofibular ligament. Thus transection of one ligament will result in a displacement. Depending on the position of the leg, this may be influenced further by other forces such as gravity and the testing procedure.

We found the largest and most consistent fibular displacements at the distal syndesmosis during ER of the ankle–foot complex. This is in accordance with the general clinical knowledge that ER is the most important of the mechanisms known to injure the syndesmosis, reflected by the numerous reports that have used external rotation in the assessment of syndesmotic injuries (Lauge–Hansen 1950, Kelikian and Kelikian 1985, Boytim et al. 1991, Xenos et al. 1995, Hahn and Colton 2000, Beumer et al. 2003).

In this study, ER resulted in a rotation of the fibula that ranged between 1.2° of internal rotation and 7.7° of external rotation under all sectioning conditions. This correlates well with the 1.5–8° “negative lateral tibial rotation at the syndesmosis” (external rotation of the fibula) that Close (1956) described by measuring the angle between Steinmann pins placed in the tibia and fibula. In the intact situation, he found between 1.5° and 2.5° of external rotation in 3 specimens. After sectioning of the ATiFL, rotation increased to 2.5–4.5°, which further increased to 4–6.5° after IL had been sectioned, with a maximum of 8° of external rotation after ATiFL, IL and PTiFL had been sectioned.

These values are similar to the values we found after unloaded ER, where IL was left intact. This may suggest that additional IL sectioning might not increase external rotation of the fibula. ER resulted in a reduction in tibiofibular width. This explains why anterior syndesmotic instability cannot be seen on anterior–posterior ankle radiographs. Unloaded ER of the intact ankle resulted in posterior translation ranging from –1.1–2.6 mm, which decreased to –1.5–1.7 mm with 750 N axial load applied. This is an accurate measurement of the posterior translation of the fibula that was found and reported without giving numeric values by Xenos et al. (1995) and Close (1956), after application of an external rotation force to the talus. It is also a quantification of displacements occurring during the “external rotation stress test” that may be performed after osteosynthesis of malleolar fractures (Hahn and Colton 2000). A previous study, however, showed that this posterior translation cannot be recognized on lateral ankle radiographs due to external rotation of fibula and tibia during the external rotation stress examination (Beumer et al. 2003). Finally, it seems evident that this posterior translation during ER of the ankle provides an additional stress to the ATiFL that is already tensioned due to external rotation of the fibula. This could explain why ATiFL injuries are more common than PTiFL injuries, and how ATiFL injuries can occur without other ankle injuries.

Clinical relevance

Guidelines for the treatment of acute ligamentous syndesmotic injuries may be formulated based on the current literature and extrapolations from this study. These guidelines can only be used when no other injuries around the ankle are present.

Fibular displacements after sectioning of the ATiFL

Mechanical instability of the syndesmosis was found after isolated sectioning of the ATiFL, by applying ER or ER–L. This is in accordance with the “open book” type of injury that has been described by Kelikian and Kelikian (1985).

Displacements in N and N–L did not exceed the intact situation. This implies that the ATiFL may heal within acceptable limits if the ankle is kept in the neutral position. This can probably be achieved by a snugly fitted below–knee plaster. Although no reports can be found on this particular topic, by analogy with tibial shaft fractures, we assume that this plaster will prevent external rotation of the ankle (Zagorski et al. 1993).

The amount of external rotation of the fibula after isolated sectioning of the ATiFL varied between specimens, indicating that this may vary between patients as well. In the case of suspected acute ATiFL injury, we recommend MR imaging—preferably with an additional oblique axial plane (Takoa et al. 2003, Beumer et al. 2005a) to assess the status of the ligament, and application of a plaster when a complete rupture is found. When MR imaging has excluded injuries to other structures, such as the interosseous ligament and membrane, the patient may bear weight because displacements in the neutral loaded position did not increase much after loading. If treatment is based on the clinical picture without MR imaging having been performed in the first week after the injury, the patient should be advised not to bear weight.

Fibular displacements after sectioning of AD

This sectioning condition was included in our study to assess whether isolated rupture of the deltoid ligament (such as in the stage–1 pronation–external rotation injury described by Lauge–Hansen (1950) would result in syndesmotic instability. Increased tibiofibular width and increased vertical fibular translation of the fibula were seen in most positions. However, this never exceeded displacements found in the intact situation. Thus, a functional treatment of isolated ruptures of AD seems justified.

Fibular displacements after sectioning of the ATiFL and AD

As with A or D, displacements in the neutral situation did not exceed values found in the intact situation. When compared to the condition when only the ATiFL was sectioned, displacements after A+D showed an increase in tibiofibular width during loading in nearly all positions (the largest being 2.32 mm). After A+D, the largest displacements in the neutral position did not exceed the values found when the ankle was put in DF, ER, AB and ER+AB in the intact situation. This indicates that the ATiFL and AD may heal within physiological limits after A+D, if the ankle is kept in the neutral position. We recommend that patients with these injuries be treated in the same way as those with isolated ATiFL injuries.

Fibular displacement after isolated sectioning of the PTiFL

Although we have never encountered isolated injuries of the PTiFL, we chose to include this sectioning condition for reasons of completeness.

Since posterior ankle arthroscopy and shaving procedures in the area of the TL and PTiFL become more frequent, iatrogenic isolated PTiFL injuries may be the result. A wide variety of displacements was seen after P. The most interesting and largest displacements found were 1.6 mm anterior translation and 2.7° of external rotation of the fibula during some of the trauma mechanisms. As these displacements did not exceed those in the neutral situation, a functional treatment of isolated ruptures of the PTiFL may be justified.

Fibular displacements after sectioning of ATiFL–PTiFL or ATiFL–AD–PTiFL

Very little displacement was seen after A+P and A+D+P in the neutral (unloaded or loaded) situation with regard to tibiofibular width. This may be related to the fact that the interosseous membrane and ligament were not transected. The integrity of IL probably has no influence on fibular external rotation. Indeed, a large increase in external rotation of the fibula was found after ER of the ankle–foot complex in both the unloaded and loaded situation.

Those displacements were greater than during ER in the intact situation; thus, it is clear that patients with such injuries cannot be treated functionally. In the clinical situation, combined injury of ATiFL–PTiFL or ATiFL–AD–PTiFL will be accompanied by IL injury (Lauge–Hansen 1950, Mullins and Sallis 1958, Kelikian and Kelikian 1985) and result in such diastasis and instability that surgical treatment such as placement of a syndesmotic screw (instead of plaster immobilization) is warranted. We have recently shown that with 750 N axial load on a lower leg, a syndesmotic screw to stabilize extensive syndesmotic injury will result in syndesmotic widening beyond its normal range (Beumer et al. 2005b). Based on the current literature and extrapolations from the present study, we recommend that patients with combined injury of ATiFL–PTiFL or ATiFL–AD–PTiFL should be treated with a syndesmotic screw and that they should not bear weight.

Contributions of authors

AB and BAS designed and performed the study, interpreted the results, and wrote the manuscript. ERV and EHG analyzed and interpreted the RSA examinations. RN designed and constructed the testing apparatus. AZG facilitated the radiological laboratory work. JR performed the overall statistical analysis.

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Chapter 7

External rotation stress imaging in syndesmotic injuries of the ankle

Comparison of lateral radiography and radiostereometry in a cadaveric model

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***Abstract* We compared the value of 7.5 Nm external rotation stress in diagnosing tibiofibular syndesmotic injuries of the ankle on lateral radiographs with radiostereometric analysis (RSA) in 10 cadaveric legs.**

After sectioning 2 ligaments, RSA showed an increase in posterior translation and external rotation of the fibula.

This increase in posterior translation was smaller than the posterior displacement of the fibula on the lateral radiograph, and RSA showed mainly an increase in external rotation of the fibula that can not be measured on conventional radiographs. We conclude that instability of the syndesmosis in cadaveric ankles can be detected with 7.5 Nm external rotation stress RSA, but that external rotation stress lateral radiography is unreliable.

If the tibiofibular syndesmosis is completely ruptured after injury of the ankle, diastasis can be seen on anterior-posterior (AP) or mortise (M) radiographs of the ankle. More subtle changes in syndesmotic width, however, are often missed.

Many parameters, measured on AP and M views of the ankle, have been described, and are commonly used for making decisions about treatment. However, a recent study has shown that these are unreliable (unpublished data). In a cadaveric study with an external rotation stress of 5.0 Nm applied to the ankle, Xenos et al. (1995) showed that transection of the anterior tibiofibular ligament, the anterior part of the deltoid ligament and the interosseous ligament resulted in only slight widening of the tibiofibular joint, as measured on the M view. Nevertheless they found a positive correlation between diastasis measured directly at the anterior syndesmosis, and posterior displacement of the fibula, as measured on a lateral (LAT) ankle radiograph. Since the displacement of the fibula during external rotation stress is probably a combination of posterior translation and rotation, the radiographic projection of the fibula on the LAT radiograph changes, and reduces the accuracy of the measurements. This might even be worse if the leg rotates due to the external rotation stress applied.

We compared the value of external rotation stress imaging on LAT radiographs with external rotation stress radiostereometric analysis (RSA) for syndesmotic injuries of the ankle in a cadaveric model.

Material and methods

10 fresh-frozen cadaveric lower extremities (mean age 88 (81–102) years) were sectioned through the knee. Macroscopic and radiographic examinations showed that all specimens had intact collateral and syndesmotic ligaments of the ankle with no evidence of preceding trauma, disease or osteoarthrosis.

Figure 1. Testing device: the tibia is secured, the foot is attached to a plate, allowing full range of motion, 7.5 Nm external rotation stress is being applied.

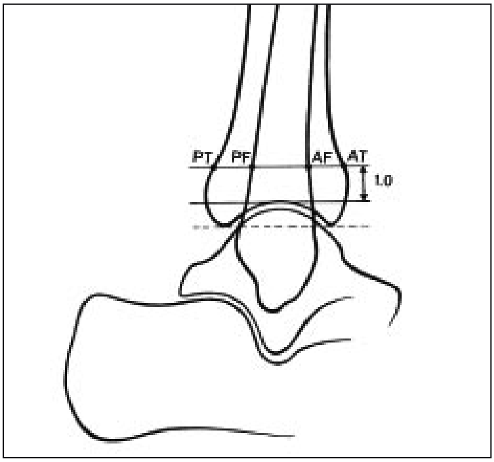

Figure 2. Measurement points on LAT radiograph:
AT = anterior tibial cortex
AF = anterior fi bular cortex
PF = posterior fi bular cortex
PT = posterior tibial cortex

All soft tissues from the knee to the tarsometatarsal joints, apart from the interosseous membrane and ligaments and capsules of the ankle, were removed. 5 Tantalum markers (0.8 mm) were placed in each distal tibia, fibula and talus. The specimens were placed on a testing device that secured the tibia, while the foot was attached to a plate, permitting full motion of the ankle (Figure 1). The ankle was placed with the intermalleolar line parallel to the floor, and the foot in a neutral, plantigrade position. This was considered the zero starting position.

External rotation stress on the ankle was applied using a Telos device (Austin and Associates, Fallston, MD) with a force of 150 N on the fi rst metatarsal bone, 5 cm distal to the center of rotation of the ankle (Lundberg et al. 1989). This resulted in a moment of 7.5 Nm (Figure 1). Two pairs of RSA radiographs were made, using a uniplanar calibration cage (Tilly Medical, Lund, Sweden): 1 pair in the zero starting position of the foot and ankle, and 1 pair with the external rotation stress applied.

After the RSA radiographs were taken, a LAT radiograph was taken while the ankle was kept in exactly the same position. RSA and LAT ankle radiographs were done in the following 4 conditions: 1) intact situation, 2) anterior tibiofibular ligament (ATiFL) or posterior tibiofibular ligament (PTiFL) or anterior part of deltoid ligament (ADL) sectioned, 3) ATiFL and ADL or PTiFL sectioned, 4) ATiFL and PTiFL and ADL sectioned. The order of transection was determined, using a modifi ed Latin-square distribution, in such a manner that the order of subsequent series of transections was a permutation of the previous series (e.g., abc, bca, cab, etc.)

All RSA radiographs were processed and analyzed at Leiden University Medical Center using RSA-CMS software (Medis, Leiden, The Netherlands). The error of calculation with this software is about 0.11 mm and 0.24° (Vrooman et al. 1998). The motion of the fibula relative to the tibia was expressed as 3 translation parameters and 3 rotation parameters of the fibula relative to the tibia. Positive directions for translations along the coordinate axes were lateral-medial, caudal-cranial, and posterior-anterior. Positive directions for rotations about the coordinate axes were plantar flexion, internal rotation, and adduction.

On the LAT radiograph, the distance between the anterior tibial and anterior fibular cortex (ATAF) and the distance between the posterior tibial and posterior fibular cortex (PTPF) were measured. All measurements were made on a line 1 cm above and parallel to the tibiotalar joint sur-

Displacement of the fibula relative to the tibia after sequential sectioning of the syndesmotic and deltoid ligaments, during 7.5 Nm external rotation stress. Figures are mean and range

Sectioned ligaments[c]	LAT[a] Posterior Translation (mm)		RSA[b] Translations (mm)			Rotations (°)		
	Anterior	Posterior	L-M	Ca-Cr	P-A	P	Int	Add
Intact								
mean	5.4	4.5	0.71	0.33	-1.59	0.74	-3.58	1.20
range	3.0–10.7	0.8–7.0	0.22–1.41	-0.43–0.79	-3.35–0.85	-1.98–2.65	-7.38– -1.02	0.21–2.07
ATiFL								
mean	7.1	5.4	0.82	0.14	-2.14	1.60	-6.19	1.34
range	4.0–10.5	3.0–7.2	0.58–1.19	0.09–0.22	-3.14– -1.41	1.07–2.05	-8.18–-2.69	0.55–1.81
AD								
mean	4.3	4.0	0.98	0.57	-2.60	1.28	-2.83	1.44
range	4.0–5.0	3.3–5.0	0.85–1.09	0.48–0.73	-3.34– -1.50	0.59–2.42	-5.67–1.20	0.78–2.11
PTiFL								
mean	5.7	4.6	0.74	0.44	-1.78	1.06	-4.84	1.97
range	2.0–9.0	0.0–7.0 0.	66–0.81	0.32–0.56	-1.79– -1.77	1.01–1.11	-6.83– -2.85	1.92–2.03
ATiFL+AD								
mean	6.9	5.2	0.52	0.33	-2.30	1.72 -	5.79	1.59
range	4.5–11.5	2.7–7.5	-0.06–0.95	0.14–0.58	-3.02– -1.56	0.74–2.91	-10.4–0.18	0.82–2.51
ATiFL + PTiFL								
mean	5.4	4.6	0.96	0.05	-2.43	1.47	-7.02	1.33
range	3.7–8.0	1.0–7.0	-0.01–1.41	-0.17–0.32	-3.71– -0.92	0.79–2.36	-12.2– -2.85	1.15–1.55
ATiFL + AD + PTiFL								
mean	5.6	4.7	1.01	0.14	-1.86	1.00	-6.36	1.66
range	2.8–11.0	0.7–7.7	0.10–2.15 -	0.08–0.36	-6.15–3.45	-4.01–3.76	-15.3– -1.19	0.45–2.40

a Posterior translations of the fibula were measured to the anterior and posterior tibial cortex

b Translations and rotations with radiostereometric analysis were considered positive in the following directions: lateral-medial (L-M), caudal-cranial (Ca-Cr), posterior-anterior (P-A), plantar flexion (P), internal rotation (Int), adduction (Add)

c Sectioned ligaments: anterior tibiofibular (ATiFL), posterior tibiofibular (PTiFL), anterior deltoid (AD)

face (Figure 2). The measurements were recorded twice to the nearest 0.5 mm by 3 independent observers using a ruler. As the differences in the recordings among the different observers never exceeded 1.0 mm, the mean of all 6 measurements was calculated.

For statistical analysis, Wilcoxon's matched pairs signed rank test and Pearson's correlation test were used with the significance level set at $p < 0.05$.

Results

Intact ligaments

After application of 7.5 Nm external rotation stress in the intact situation, the mean posterior translation of the fibula on the LAT radiograph was 5.4 mm relative to the anterior tibial cortex, and 4.8 mm to the posterior cortex. With RSA, we found a mean medial and posterior displacement of 0.7 mm, and a mean external rotation of 3.6° of the fibula (Table).

Sequentially sectioned ligaments

With RSA, an increase in posterior translation was found after transection of both ATiFL and PTiFL ($p= 0.04$) (Table). Furthermore, a nonsignifi cant increase in external rotation was detected after transection of ATiFL ($p = 0.07$) and an increase in external rotation after transection of all ligaments ($p = 0.03$), and an increase in rotation around the sagittal axis after both ATiFL and AD ($p= 0.04$) or all ligaments ($p = 0.01$) had been sectioned.

Comparison of LAT radiographs with RSA

Correlations were found between posterior translation of the fibula on the LAT radiograph when measured in relation to the posterior tibial cortex, and lateral translation of the fibula with RSA in the intact situation (r = 0.677, p = 0.05), and after transection of ATiFL (r = 0.957, p = 0.04). Posterior displacement of the fibula on the LAT radiograph was not correlated with posterior translation assessed with RSA.

Discussion

The translations of the fibula found with RSA after 2 or more ligaments were sectioned, were too small to be detected by radiography. The same is true of the rotations of the fibula. The increased translations and external rotation of the fibula did not become statistically significant after transection of ATiFL alone, which was probably due to the small number of observations, but also to rotation of the fibula after transection of ATiFL alone. This in itself, without stress applied, is enough to increase external rotation of the fibula (unpublished data).

The question arises whether an isolated rupture of ATiFL exists at all, since in our experience MRI in patients with syndesmotic instability nearly always show a thickened and amorphous deltoid ligament reflecting a previous injury. This finding should be investigated further.

Larger displacements of the fibula could have been found if a greater external rotation moment had been applied. We used a pressure load of 150 N for the stress investigations in this study. This is a purely empirical value that is internationally accepted (Scheuba, Guidebook Telos). We tested this force on ourselves, and found that a further increase in pressure was intolerable, while it did not increase the external rotation created in the ankle, as measured with a goniometer. Since our intention was to validate this stress examination for eventual use in clinical practice, we felt that an increase in the external rotation moment was not an alternative.

In agreement with our findings, Xenos et al. (1995) found that anatomic diastasis after sectioning of the ligaments of the syndesmosis correlated with posterior translation of the fibula on the LAT radiograph when a 5 Nm external rotation stress was used. The posterior displacements we measured on the LAT radiograph were 2–3 times greater than those found with RSA, and similar to those found by Xenos et al. (1995), despite the fact that they used a smaller moment. This is probably due to rotation, a view which is confi rmed by the RSA fi ndings and the fact that the displacements relative to the anterior and posterior sides were unequal.

In the fibula, it was difficult to obtain an appropriate marker distribution because the markers could not be distributed far enough from the fibular central axis because of the small diameter of the fibula. However, we have tried to insert the markers in a similar pattern in all legs. The translations we show are translations of the geometric center of the markers. Because we had similar patterns of markers, the effect of marker scatter on the value of the translations can not have been large. The main influence on the scatter of the translation results was caused by other factors, such as differences in leg geometry.

In this study, fresh-frozen material was used. Freezing has little, if any, effect on the mechanical properties of ligaments (Woo et al. 1986). This is reflected by the fact that the displacements found in this study did not exceed the external rotation and posterior displacement of the fibula reported in healthy volunteers (Beumer 2003).

In conclusion, 7.5 Nm external rotation stress RSA can be used to detect some forms of (combined) syndesmotic instability, at least in this cadaveric model. As the posterior displacement of the fibula with RSA did not correlate with the posterior displacement measured on the LAT radiograph, it is unfortunately not possible to distinguish between healthy and injured ankles using conventional radiography.

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Chapter 8

Kinematics of the distal tibiofibular syndesmosis

Radiostereometry in 11 normal ankles

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Abstract **In 11 healthy volunteers, the normal kinematics of the tibiofibular syndesmosis of the ankle during weight bearing and external rotation stress were compared to a nonweight-bearing neutral position by radiostereometry. We found very small rotations and displacements in this "normal" group, which indicated that the fibula is closely attached to the tibia, thereby preventing larger movements at the level of the ankle. We found no common kinematic pattern during weight bearing in the neutral position.Application of a 7.5 Nm external rotation moment on the foot caused external rotation of the fibula between 2 and 5 degrees, medial translation between 0 and 2.5 mm and posterior displacement between 1.0 and 3.1 mm. These data can be used as normal reference values for studies of patients with suspected syndesmotic injuries.**

Good results have been described after reconstruction of the anterior part of the distal tibiofibular syndesmosis for chronic instability (Beumer et al. 2000). Clinically, this condition is difficult to recognize because of its subtle and poorly defined symptoms, such as pain, recurrent swelling and the sensation of giving way. In clinical practice, the ankle can not be positioned in a reproducible way to measure radiologically subtle changes in syndesmotic width (McDade 1975, own unpublished data).

In a laboratory setting, lateral ankle radio-graphy during external rotation stress has been shown to have a positive correlation with directly measured widening at the anterior syndesmosis and posterior translation of the fibula (Xenos et al. 1995). In a recent study this posterior translation of the fibula was confirmed with radio-stereometry (RSA), but did not correlate with the posterior displacement as determined by conventional radiography, probably due to rotation (Beumer et al. 2003a). RSA of the ankle mathematically aligns the tibia between successive radiographs, which means that RSA is less sensitive to positioning errors. Because of this intrinsic accuracy, RSA has been used to study tibiofibular kinematics in loaded and unloaded situations (Kärrholm et al. 1985, Ahl et al. 1987, Svensson et al. 1988, Löfvenberg et al. 1990). The effect of loading with body weight versus not loading on the movement of the fibula relative to the tibia, however, has never been studied, nor has the value of external rotation stress and loaded external rotation stress been assessed accurately.

In this study we describe and quantify normal kinematics of the tibiofibular syndesmosis in healthy volunteers during weight bearing and external rotation stress by RSA, in order to relate these to a neutral nonweight-bearing situation for future comparison with patient data.

Figure 1. Pedestal for simultaneous perpendicular RSA exposures in standing position

Figure 2. External rotation stress apparatus

Patients and methods

Of 21 patients operated on for unilateral chronic lateral ankle instability between 1985 and 1992 at the University Hospital of Umeå, 11 participated with their "normal" asymptomatic ankle in the present study. The mean age of the 11 volunteers (4 women) was 50 (35–69) years. They all had tantalum markers implanted in the tibia, fibula and talus of both ankles, and 6 of them also in the calcaneus (Löfvenberg et al. 1990). At the time of the present study, 10 of the original 21 patients could not be studied: 2 were pregnant, 5 lived too far away and 3 were not included for other reasons. The remaining 11 volunteered to take part in this study and to have their contralateral, asymptomatic ankle examined. The Medical Ethics Committee of Umeå University Hospital granted permission for the study, and all volunteers gave written informed consent. The medical history was taken, and 2 investigators (AB and BAS) did physical examinations of the ankles, which included 4 syndesmotic stress tests: squeeze (Hopkinson et al. 1990), external rotation (Boytim et al. 1991), Cotton (1910), fibula translation (Ogilvie-Harris and Reed 1994), and the anterior drawer test (Cedell 1975). The squeeze and external rotation tests were considered positive if pain was felt during the test. The fibula translation test was considered positive if pain was elicited with or without increased mobility, as compared to the contralateral ankle, the Cotton and anterior drawer test if increased displacement was found during the test (Beumer et al. 2002, 2003b). Body weight, body length, foot length and signs of hypermobility (Beighton et al. 1973) were also recorded.

We performed the RSA examinations in a standing position, using the uniplanar and biplanar technique (RSA Biomedical Innovation, Umeå, Sweden). In the standing position, 3 RSA examinations were done while the volunteers were placed on a pedestal that permitted simultaneous perpendicular exposures (Figure 1). First, with the ankle unloaded while slightly lifting the leg, which was still in contact with the floor ('neutral nonweight bearing'), then, with full body weight on the examined ankle that was kept in the neutral position ('neutral weight bearing'), and finally, with full body weight and maximal internal rotation of the leg, thereby creating an actively loaded external rotation exposure ('external rotation weight bearing'). With the volunteer in the supine position, the ankle was placed in a custom-made testing ap-

Table 1. Data of 11 volunteers with normal ankles

Case	1	2	3	4	5	6	7	8	9	10	11
Age (years)	59	39	54	59	52	35	45	69	47	37	49
Sex	F	F	M	M	M	M	M	M	F	F	M
Weight (kg)	85	62	73	90	91	79	95	93	70	92	84
Length (cm)	165	168	171	183	181	181	190	177	158	170	173
Foot length (cm)	25	25	25.5	28.5	27.5	27	28.5	28	24	25.5	26
Side	L	R	L	R	R	L	R	R	L	L	R
ROM	10/30	15/40	20/50	15/40	10/40	15/35	20/40	15/40	20/45	15/50	20/45
Anterior drawer test	–	–	–	–	–	–	+	–	+	–	+
Squeeze test	–	–	–	–	–	–	–	–	–	–	–
Fibula translation test	–	–	–	–	–	–	–	–	–	–	–
External rotation test	–	–	–	–	–	–	–	–	–	–	–
Cotton test	–	–	–	–	–	–	–	–	–	–	–
Hypermobility	–	–	–	–	–	–	+	–	–	–	–

ROM range of motion (dorsiflexion/plantar flexion)

paratus, in which external rotation stress could be applied with a common Telos device (Austin and Associates, Fallston, MD, USA), using Beumer et al.'s method (2003a). The ankle was exposed first in the neutral position ('neutral'), according to the zero starting position for the foot (American Association of Orthopaedic Surgeons 1965) and then with external rotation stress applied 5 cm distal to the center of rotation of the ankle (Lundberg et al. 1989), on the first metatarsal bone, with a force of 150 N resulting in a moment of 7.5 Nm ('external rotation moment', Figure 2). All radiographs were processed and analyzed at Leiden University Medical Center, using RSA-CMS software (Medis, Leiden, The Netherlands). The error of calculation with this software has been assessed as about 0.11 mm and 0.24 degrees (Vrooman et al. 1998).

The motion of the fibula relative to the tibia was expressed as 3 translation and 3 rotation parameters of the fibula in relation to the tibia. Positive directions for translations along the coordinate axes were medial (transverse x-axis), cranial (longitudinal y-axis), and anterior (sagittal z-axis). Positive directions for rotations around the coordinate axes were plantar flexion (transverse x-axis), internal rotation (longitudinal y-axis), and adduction (sagittal z-axis).

RSA results are reliable only when the markers are well spread. The condition number provides an indication of the marker distribution (Söderkvist and Wedin 1993). In the evaluation of hip prostheses, the aim is to spread the markers so that the condition number will be lower than 80–90 (Börlin et al. 2002). If the condition number exceeds 120–150, the evaluation is considered unreliable. To obtain reliable results, we used the same limits for the condition number.

No double exposures to determine reproducibility were made. Since patients participated in this study with the normal ankle, and in a simultaneous study with both ankles, we felt that this would give too much radiation exposure.

Statistics

Patient characteristics and RSA measurements were analyzed, using Pearson's product momentum correlation coefficient. Hierarchical cluster analysis, based on between-group linkage of variables and their squared Euclidean distances, was performed to identify relatively homogeneous groups of variables using an algorithm that starts with each variable in a separate cluster and combines clusters until only one is left. All tests were two-sided and p-values below 0.05 were considered statistically significant.

Results

None of the syndesmotic stress tests was positive, nor did any volunteer complain of syndesmotic tenderness or irritation. In 3 volunteers, movement of the fibula during the fibula translation test was felt more than average. Since there was no pain or difference between the left and right ankles, this was considered to be normal. In 3 others, the anterior drawer test in the unoperated ankle was positive (Table 1). Only 2 tali were excluded from analysis because of too high condition numbers—i.e., 148 and 246. The condition numbers for all other bony structures lay well within limits, so reliable translations and rotations could be calculated (Table 2).

Table 2. The condition numbers for the tibia, fibula, talus and calcaneus

	Mean	Range
Tibia	36	7–52
Fibula	70	47–102
Talus	54	31–103
Calcaneus	65	38–99

Neutral weight bearing

We detected no recognizable patterns of fibular movement in relation to the tibia during neutral weight bearing, as compared to neutral nonweight bearing (Table 3). We found a correlation between the presence of hypermobility and posterior ($r = 0.73$, $p = 0.01$) as well as medial translation of the fibula ($r = 0.78$, $p = 0.005$) and external rotation of the talus ($r = 0.92$, $p = < 0.001$) during weight bearing. A positive anterior drawer test was shown to correlate with posterior displacement of the fibula ($r = 0.62$, $p = 0.04$).All volunteers, except 1, loaded their ankle with the talus in internal rotation. There was a negative correlation ($r = -0.934$, $p = < 0.001$) between this internal rotation of the talus (max. 1.2 degree) and medial displacement of the fibula (max. 0.4 mm). None of the other clinical parameters, or foot positions recorded, affected the tibiofibular distance. During neutral weight bearing, the rotation of the talus around the x-axis ranged from 11 degrees of plantar flexion to 1 degree of dorsiflexion. We found no correlation between this rotation of the talus and any of the fibular displacements during this test.

External rotation weight bearing

We observed no common patterns of fibular movement in relation to the tibia during external rotation weight bearing, when compared to neutral nonweight bearing (Table 3). Fibular external rotation showed a negative correlation with age ($r = -0.67$, $p = 0.05$).

7.5 Nm external rotation moment

The external rotation moment around the longitudinal axis resulted, on average, in 3.9 degrees of external rotation of the fibula in relation to the tibia, as compared to neutral (Table 3). During this test, we found an average 1.5 mm medial, 1.9 mm posterior and 0.2 mm cranial translation of the fibula. The external rotation and posterior translation of the fibula showed no correlation with any of the parameters studied. The external rotation of the talus during this procedure ranged from 11 to 19 degrees. In the 6 volunteers with markers in the calcaneus, we observed between 11 and 22 degrees of external rotation of the calcaneus (Table 4). We found no significant correlations between these rotations and fibular rotation.

Discussion

Kinematics of the distal tibiofibular syndesmosis have been assessed with RSA in patients and healthy volunteers in loaded and unloaded situations. In both groups, lateral translation of the fibula was found during movement from plantar to dorsal flexion, with the larger displacement

Table 3. Fibular displacements relative to the tibia (mean and range)

Translations (in mm)	Medial	Cranial	Anterior
N-WB	–0.02 (–0.41–0.44)	0.00 (–0.37–0.30)	–0.10 (–0.96–0.28)
EX-WB	0.11 (–0.19–0.63)	–0.12 (–0.59–0.23)	–0.46 (–1.98–0.56)
EX-M	1.48 (–0.06–2.52)	0.22 (–0.14–0.56)	–1.87(–3.08– -0.95)
Rotations (in degrees)	**Plantar flexion**	**Internal rotation**	**Adduction**
N-WB 0.00	(-0.92–0.80)	0.03 (–1.28–1.18)	0.01 (–0.68–0.66)
EX-WB 0.12	(–0.94–1.47)	–0.02 (–1.38–1.02)	–0.27 (–0.97–0.41)
EX-M 0.06	(–0.49–0.76)	–3.85 (–5.33– -1.89)	1.20 (0.21–2.10)

N-WB neutral weight bearing versus neutral nonweight bearing (standing), EX-WB external rotation during weight bearing versus neutral nonweight bearing (standing), EX-M 7.5 Nm external rotation moment versus neutral (supine)

Table 4. Talar and calcaneal displacements relative to the tibia during external rotation moment of 7.5 Nm, as compared to neutral (supine) (mean and range)

Translations (in mm)	Medial	Cranial	Anterior
Talus	–3.01(–7.48– -0.59)	–0.04 (–1.68–3.48)	1.85 (–0.97–4.78)
Calcaneus	2.80 (–6.37–9.18)	–1.64 (–9.04–4.66)	1.91 (–6.16–9.81)
Rotations (in degrees)	**Plantar flexion**	**Internal rotation**	**Adduction**
Talus	–0.83 (–14.18–9.89)	–15.80(–18.51– -11.53)	–2.76 (–10.07–4.75)
Calcaneus	–4.37(–13.02–10.88)	–17.60(–22.20– -10.56)	–5.31 (–12.89–0.85)

between plantar flexion and the neutral position (0.7–1.0 mm; Kärrholm et al. 1985, Ahl et al. 1987, Svensson et al.1988, Löfvenberg et al. 1990) and less between neutral and dorsal flexion (0.3 mm; Ahl et al. 1987, Svensson et al. 1988), which resulted in an average lateral translation of 1.0–1.1 mm during the movement from plantar flexion to dorsiflexion. An anterior translation of the fibula of 0.2 mm was found during movement from neutral to plantar flexion, and a posterior translation of 0.6–1.3 mm during the movement from neutral in dorsiflexion, which resulted in an average anterior-posterior translation of 0.9–1.0 mm during the movement from plantar flexion to dorsiflexion (Ahl et al. 1987, Svensson et al. 1988). Vertical displacements and rotations of the fibula were small and inconsistent in these studies (Kärrholm et al. 1985, Ahl et al. 1987, Svensson et al. 1988). Both in the above-mentioned studies and in our study, fibular displacements were small, which indicates that there is little motion in the tibiofibular joint.

The correlations found during neutral weight bearing between the presence of hypermobility or a positive anterior drawer sign and posterior displacement or external rotation of the talus suggest that clinical syndesmotic stress tests, such as the fibula translation test (Ogilvie-Harris and Reed 1994) or the external rotation stress test (Boytim et al. 1991), may show increased displacement in patients with these afflictions too, even if no syndesmotic injury is present.

Our weight-bearing data were fairly scattered. This is probably due to individual differences and to the fact that volunteers were asked to load and unload the leg in a dynamic fashion. Weight bearing in the neutral position resulted in an ankle position between 11 degrees of plantar flexion and 1 degree of dorsiflexion, when expressed as talar rotation around the x-axis. We found no correlations between these talar positions and fibular displacements so one can assume that these ankle positions were not the reason for the various fibular displacements found during neutral weight bearing, although this might be expected, based on the above-mentioned RSA studies. As none of the parameters that we recorded, except hypermobility, affected the tibiofibular distance, one must assume that interindividual variability in terms of anatomy and muscle tension, is the probable cause of the wide range of values found during neutral weight bearing.

The external rotation weight bearing procedure proved insufficient to show recognizable patterns of displacement for the same reasons. Fibular external rotation during this test was found to correlate with younger volunteer age. This contrasts with our findings after application of the external rotation moment, where no correlation was found between fibular rotation and age, or any other parameter. However, it is not surprising since the patients were asked to balance on one leg in a position about 1 meter above ground level.

The 7.5 Nm external rotation moment, applied with our custom-made stress device, provided a very recognizable 2–5 degrees of external rotation of the fibula in all volunteers. It seems possible that larger displacements of the fibula could have been found if a larger moment had been applied. The stress used in the examinations was 150 N, a purely empirical value that is internationally accepted (Telos, Stress device user's manual).

The external rotation of the fibula, due to the external rotation moment applied, showed no significant correlation with talar or calcaneal external rotation, which suggests that in a clinical setting with an intact syndesmosis, forced external rotation of the ankle has no correlation with fibular rotation. Although we can not exclude that external rotation of the fibula correlates with external rotation of the talus in an injured syndesmosis, these findings show that an increase in external rotation of the ankle should not be used to detect an injured syndesmosis by an increase in fibular rotation. During the external rotation stress test, we found, on average, 1.5 (0–2.5) mm of medial translation of the fibula. This did not accord with our previous expectations that the fibula would translate laterally during external rotation, and this is probably due to the constraints of the fibula, such as the bony anatomy, the syndesmosis and the lateral collateral ligament complex.

As with widening of the mortise during dorsiflexion, one might assume that the difference between the anterior and posterior width of the talus causes this medial translation of the fibula. This could be true if the talus were to translate so much anteriorly that the smaller posterior width of the talus would be at the level of the lateral malleolus and give the fibula space to translate medially. Our data show, however, that the talus translates, on average, only 1.9 mm anteriorly, and as much as 3 mm laterally during external rotation stress. This does not give the fibula enough space to translate medially.

Another explanation might be the inversion that the external rotation of the ankle-foot complex creates (Table 4). Inversion in the subtalar joint is based on the angled hinge principle, which forces the calcaneus medially and in adduction. The intact calcaneofibular ligament then pulls the fibula medially.

The medial translation of the fibula with respect to the tibia seems to be a sound reason why external rotation stress radiography in the intact situation shows no increase in syndesmotic widening on conventional radiography (Xenos et al.1995). Therefore, future clinical studies assessing chronic syndesmotic injuries should include RSA stress radiography (Beumer et al. 2003a).

In conclusion, we found no normal pattern of tibiofibular kinematics during weight bearing, but noted that only very small displacements occur in the normal tibiofibular joint. Application of a 7.5 Nm external rotation moment on the foot resulted in external rotation of the fibula between 2 and 5 degrees, medial translation between 0 and 2.5 mm and posterior displacement between 1.0 and 3.1 mm. These data can be used to study patients with suspected syndesmotic injuries in future.

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Chapter 9

A biomechanical evaluation of clinical stress tests for syndesmotic ankle instability

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Abstract

Displacement transducers were placed across the anterior and posterior tibiofibular ligaments of 17 fresh cadaver (78.4 ± 6.7 years old at death) lower extremities.

Displacements induced by various clinical tests (squeeze, fibula translation, Cotton, external rotation, and anterior drawer) were measured with the ankle ligaments intact and after sequential sectioning of the anterior tibiofibular ligament, anterior deltoid ligament, and posterior tibiofibular ligament.

None of the syndesmotic stress tests could distinguish which ligaments were sectioned. Furthermore, the small displacements measured during the stress tests (with the exception of the external rotation test) suggest it is unlikely that the displacement induced in injured syndesmoses can be clinically differentiated from normal syndesmoses. Therefore, pain, rather than increased displacement, should be considered the outcome measure of these tests.

Keywords

Stress Tests; Syndesmosis; Ankle; Ligaments; Injury; Biomechanical Evaluation.

Introduction

Syndesmotic sprains generally comprise only one to 11% of all ankle sprains,[5] but in populations actively involved in sporting activities, the incidence may be as high as 40%.[4,9,10] The incidence in the general population may also be higher than what has been reported because syndesmotic sprains may be underdiagnosed.[9] Compared to patients with lateral collateral injuries, patients with syndesmotic injuries tend to have more postoperative complaints (such as a longer period of recovery),[4,10] discomfort due to impingement of scar tissue, [15] and chronic instability.[14] If complete disruption of the syndesmosis is not recognized, deformity of the ankle joint may develop.[3]

The distal tibiofibular syndesmosis consists of the anterior syndesmosis (the anterior tibiofibular ligament, ATFL) and the posterior syndesmosis (the posterior tibiofibular, PTFL) and transverse ligament. The tibia and fibula are also connected by the membrana interossei, which thickens distally to form the interosseous ligament. Clinically the integrity of the syndesmosis is usually tested by means of four stress tests:

1. Cotton test,[8]
2. external-rotation test,[4]
3. squeeze test,[10] and
4. fibula-translation test.[15]

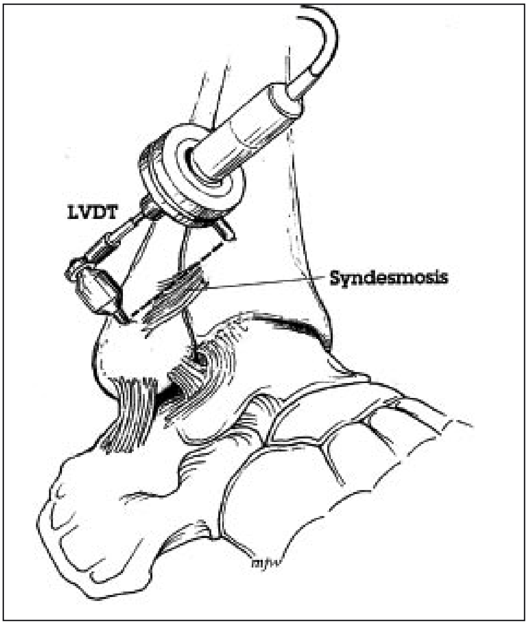

Fig. 1: Schematic of stress test set-up. The distal femur was mounted in a fixture with the lower leg in 90° of flexion. Displacement transducers were mounted over the anterior and posterior syndesmoses to measure motion induced by the various stress tests.

When lateral collateral ankle instability is present, the anterior drawer test is considered useful in ruling out lateral collateral ligament injury.[5] These tests are used to induce displacement and/or elicit pain as an aid to diagnosis, yet only the squeeze test[17] has been studied biomechanically. Our underlying assumption was that simulated injury (ligament sectioning) allows for increased displacement of the syndesmosis and that the test which creates the greatest measurable displacementwould be expected to be the most sensitive to diagnosing injury.

The goal of the current study was to measure the displacements induced by various stress tests at the anterior and posterior syndesmoses before and after ankle ligament sectioning in cadaver specimens.

Materials and methods

Seventeen fresh-frozen cadaver lower extremities were sectioned approximately 20 cm proximal to the knee. The mean age at time of death was 78.4±6.7 years; 11 from men; six from women. Macroscopic examination and conventional anteroposterior and lateral radiographs revealed no major ankle pathology, such as old fractures, osteoarthritis, or arthrodesis.

The proximal 5 cm of the femoral stump was denuded of all soft tissues and clamped in a vise. A Kirschner wire was placed transversely through the femur to prevent axial slippage from the clamp. All soft tissues about the ankle, except the interosseous membrane, ligaments and capsules of ankle and syndesmoses, were excised from a level 5 cm proximal to the ankle to the level of the tarsometatarsal joint. The femur was secured horizontally with the knee in approximately 90° of flexion. This position allowed full range of motion of the fibula, tibia, ankle, and foot and allowed the lower leg to be examined in a clinically relevant manner.

Pilot holes were drilled at the insertion sites and coincident with the longitudinal axes of the two ligaments of interest; namely the ATFL and PTFL (Fig. 1). In preliminary studies, we have found that the linear variable displacement transducers (LVDTs) (Sensotec, Columbus, OH, USA) placed over the deltoid ligament were exceptionally sensitive to foot position, so we abandoned measuring displacements at that location. Care was taken not to damage the ligaments. A threaded rod was pressed into each hole, and the LVDTs were attached to the rod ends with spherical bearings. The LVDTs had stroke lengths of 7.6 mm and were accurate to 0.02 mm. Calibration of the LVDTs was checked before each test. Displacement was considered positive when the distance between the rod ends increased and negative when it decreased.

The current study was performed in two parts. In part I, ligament displacement was measured in each of the 17 specimens as a function of ligament sectioning and clinicalstress test. The five stress tests evaluated were the:

1. squeeze test;
2. fibular translation test;
3. Cotton test;
4. external rotation test; and
5. anterior drawer test.

The squeeze test was performed by manually squeezing the fibula toward the tibia at the midpoint of the calf. This test is considered positive when resulting proximal compression produces distal pain in the area of the syndesmosis. 10 The fibular translation test was performed by manually translating the fibula anteriorly and posteriorly relative to the tibia and was originally considered positive when anteroposterior translation of the fibula created pain at the level of the syndesmosis.15 In clinical practice, however, an increased anteroposterior displacement compared with the contralateral ankle is also often considered a positive test result. The Cotton test was performed by stabilizing the distal tibia and applying lateral force to the foot. Lateral translation of the foot is indicative of syndesmotic instability.2,13 The external rotation test was performed by applying an external rotation stress to the foot and ankle while the knee was held in 90° of flexion and the ankle was held in the neutral position. The anterior drawer test was conducted by translating the calcaneus and talus anteriorly relative to the tibia.

For each stress test, ligament displacement measurements were made for each of the four conditions of sequential sectioning: 0, control (i.e., all ligaments intact);

1. either the ATFL or the anterior deltoid ligament (ADL) (i.e., one ligament sectioned), alternatingly designated;
2. the remaining ADL or ATFL (i.e., two ligaments sectioned); and
3. the PTFL (i.e., all three ligaments sectioned).

Five clinical tests were each performed three times by one observer so that the order of subsequent series of clinical tests was a permutation (via a modified Latinsquare) of the previous series. The effect of condition (0, 1, 2, 3) on ligament displacement measurements was analyzed separately with a one-way repeated measures analysis of variance (ANOVA) for each clinical test.

Differences between ligament conditions were checked for significance using Tukey's test. Unless otherwise specified, significance was set at $p<0.05$.

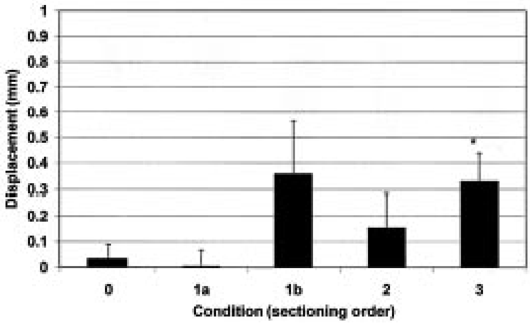

Fig. 2: External rotation test. Anterior displacements (black bars) and posterior displacements (white bars) were measured with ligaments intact (Condition 0) and after sequential sectioning. An asterisk indicates a significant change in displacement relative to Condition 0. Condition 1a is with the anterior deltoid sectioned; Condition 1b is with the anterior tibiofibular ligament sectioned. Condition 2 is both ATFL and ADL sectioned. Condition 3 is with all ligaments sections (ATFL, PTFL, ADL).

In Part II of the study, we investigated interobserver variability by randomly selecting seven of the specimens in Part I and repeating each test three times by each of three observers (a medical student, an orthopaedic registrar, and an orthopaedic surgeon). We checked for an effect of condition and observer on displacement measurements, using a twoway repeated measures ANOVA for each of the five clinical tests. Factors were observer and condition. Post-hoc comparisons were checked for significance ($p<0.05$) with Tukey's test.

Results

Part I

Squeeze Test. The squeeze test revealed a significant increase in displacement at the anterior syndesmosis only after all ligaments were sectioned (Table 1). There was no significant effect on displacement at the posterior syndesmosis as a result of sectioning the various ligaments (Table 2). The squeeze test produced an increased anterior diastasis and a decreased posterior width.

Table 1: Displacements Measured (mm) at the Anterior Syndesmosis

Test	Displacement at the following Conditions (mm±SEM)				
	0	1a	1b	2	3
Squeeze	0.03±0.06	0.00±0.06	0.36±0.20	0.15±0.13	0.33±0.12
Fibular translation	0.28±0.03	0.24±0.07	0.59±0.16	0.42±0.05	0.66±0.10
Cotton	0.23±0.05	0.30±0.06	0.37±0.05	0.40±0.09	0.56±0.08
External rotation	0.83±0.10	1.08±0.23	1.77±0.31	01.85±0.21	2.13±0.23
Anterior drawer	0.50±0.08	0.50±0.13	0.91±0.19	0.73±0.13	0.80±0.14

Table 2: Displacements Measured at the Posterior Syndesmosis.

Test	Displacement at the following Conditions (mm±SEM)				
	0	1a	1b	2	3
Squeeze	-0.15±0.06	-0.14±0.10	-0.26±0.18	-0.33±0.10	-0.39±0.12
Fibular translation	0.20±0.04	0.27±0.07	0.28±0.08	0.29±0.04	0.52±0.07
Cotton	0.17±0.04	0.18±0.04	0.25±0.09	0.23±0.04	0.30±0.04
External rotation	-0.61±0.16	-1.16±0.25	-1.14±0.27	-1.57±0.18	-1.54±0.35
Anterior drawer	0.21±0.04	0.14±0.03	0.25±0.06	0.26±0.06	0.28±0.10

Fibular Translation Test. There was no significant increase in anterior or posterior displacements after the initial sectioning of the ADL or ATFL, nor was there a significant change when both the ADL and ATFL were sectioned. However, when compared with Condition 0 (intact), there was a significant difference in displacement at both the anterior and posterior syndesmosis after Condition 3 (all ligaments sectioned). There was also a significant difference in displacement between Conditions 2 and 3.

Cotton Test. There was a significant increase in anterior diastasis after Condition 3 relative to Condition 0. However, the Cotton test did not result in any significant increase in displacement at the posterior syndesmosis, regardless of condition.

External Rotation. At the anterior syndesmosis site (Fig. 2), displacement increased significantly relative to the Condition 0 only when the ATFL alone, but not the ADL alone, was sectioned. Displacement increased significantly when both the ATFL and ADL were sectioned (Condition 2), regardless of order. Displacement after Condition 2 was significantly higher than that after Condition 0. Similarly, displacement after Condition 3 (all ligaments sectioned) was significantly greater than in Condition 0.

At the posterior syndesmosis, only displacement after Conditions 2 and 3 were significantly different than that for Condition 0.

Anterior Drawer Test. The anterior drawer test produced no significant changes in anterior or posterior displacement, regardless of condition.

Part II

At the anterior syndesmosis, the effect of observer on displacement measurements was significant only for the fibular translation and anterior drawer tests. For both tests, the differences were between the displacements induced by each investigator and were not a function of ligament sectioning.

At the posterior syndesmosis, there was no significant effect of observer for any of the stress tests.

Discussion

In the current study, we measured displacements produced at the anterior and posterior syndesmosis sites during four syndesmotic tests and the anterior drawer test after sequential sectioning of the anterior tibiofibular ligament (ATFL), anterior deltoid ligament (ADL), and posterior tibiofibular ligament (PTFL).

Squeeze Test

Displacement during the squeeze test has been assessed with a differential variable reluctance transducer inserted in the origin and insertion of the ATFL.[17] Those investigators found that transection of this ligament produced a significant displacement of nearly 0.4 mm, similar to the 0.36-mm displacement found in the current study. Teitz and Harrington[17] found that transection of ATFL, PTFL, interosseous membrane, and the deltoid ligament resulted in displacement of nearly 0.3 mm, a value similar to the 0.33-mm displacement we measured after transection of the ATFL, PTFL, and ADL. It should be noted that, in the current study, we sectioned only the anterior portion of the deltoid ligament, whereas Teitz and Harrington[17] sectioned the entire deltoid. The fact that both studies measured similar displacements during the squeeze test suggests that transection of the posterior part of the deltoid likely has no effect on anterior displacement during the squeeze test. In both studies, squeeze test results showed that the largest displacement occurred anteriorly after transection of the ATFL.

In the current study, displacement after transection of the ADL was comparable to the intact condition, suggesting that it is unlikely that pain would be elicited if only the ADL were ruptured and the anterior syndesmosis remained intact. Our finding that the squeeze test elicited anterior syndesmotic displacement but no significant posterior syndesmotic displacement supports clinical observations that patients nearly always complain of pain at the anterior syndesmosis during the squeeze test. The small negative displacements at the level of the posterior syndesmosis could occur because the fibula moves in a posterior direction. We have often noticed this movement while performing the squeeze test during arthroscopy. Another explanation may be that the fibula is externally rotating axially, which could foreshorten the apparent length of the ligament (or the span between the attachment sites).

Fibular Translation Test

In our study, the significant posterior translations produced by the fibular translation test after Condition 3 were smaller than known physiologic movements occurring in plantar-dorsiflexion.1 It is unlikely that physicians can distinguish patients with a syndesmotic injury from normal individuals by means of increased fibular displacement. Therefore, pain, not increased displacement, should be considered a positive test. This distinction is additionally validated by our interobserver results, which show that determination of the amount of displacement during the fibular translation test is observer dependent, even though the final test results were similar. This conclusion is substantiated by clinical practice, where different observers can interpret the fibular translation test as positive based on a variety of indications such as pain, increased displacement, or painful increased displacement.

Cotton Test

In the literature, we found no quantitative data for fibular displacement induced by the Cotton test. Clinical experience has shown that the ankle should be in a neutral position during this test because one may obtain false positive results if the ankle is plantarflexed during the test. In the current study, significant displacement after Condition 3 occurred only at the anterior syndesmosis. Because the talus is broader anteriorly, it may displace the fibula laterally during the Cotton test, causing the increased displacement measured at the anterior syndesmosis but not at the posterior syndesmosis.

External Rotation Test

A positive test produces pain over the anterior or posterior syndesmosis or over the interosseous membrane.[4] With the use of roentgen stereophotogrammetry, the external rotation of the fibula as a result of weight-bearing in 20° of external rotation of the talus/foot in normal volunteers was reported to be 0.6°, with an average of 0.7 mm of combined translation.12 This value is similar to 0.8-mm displacement we found anteriorly when the external rotation test was performed in Condition 0 (intact). The negative displacements we found posteriorly during this test are in accordance with the report of Close,[6] who found that diastasis in the tibiofibular joint during external rotation was greater anteriorly than posteriorly. In contrast to our expectations, we measured no significant increase in displacement after the ADL was sectioned. Increased external rotation of the talus, as reported after transection of the ADL,[16] likely does not result in increased external rotation of the fibula. This information suggests that a clinical observation of increased external rotation of the talus and/or foot is not indicative of syndesmotic injury.

Several explanations could be made for the fact that, in our study, the external rotation test produced the largest displacements. For example, external rotation of the foot causes the talus to open the syndesmosis, thereby directly loading the syndesmotic ligaments (ATFL and PTFL) along their long axes. Thus, the external rotation test produces displacement directly, rather than indirectly as do the other stress tests. Foremost, however, is the fact that the external rotation test must overcome the least constraints. The squeeze test is limited by the amount of interosseous membrane that remains intact, the fibular translation test is limited by the bony anatomy (tibial tubercles and incisure) and the lateral collateral ligaments, and the Cotton and anterior drawer tests are limited by the strong remaining posterior part of the deltoid ligament and the lateral collateral ligaments. The only constraint for external rotation of the fibula is the lateral collateral ligament complex. This complex consists of the weak and untensioned anterior fibulotalar ligament, which relaxes during external rotation, [7] and the posteriorly orientated fibulocalcaneal and posterior fibulotalar ligaments. None of these ligaments is an important constraint for external rotation of the fibula.

Anterior Drawer Test

Löfvenberg et al.[11] used roentgen stereophotogrammetry to assess fibular displacement during the anterior drawer test in patients with one normal (asymptomatic) ankle and one ankle with chronic lateral instability.

Those investigators applied posterior loads of 40 and 160 N to both the normal and unstable ankles and recorded an anterior displacement of the fibula.

In contrast to that study, we did not detect significant displacement during this test. Because the anterior drawer test produced a minimal (and not significant) difference in displacement after Condition 3 (all ligaments sectioned) relative to Condition 0, we have concluded that the anterior drawer test is not valuable for assessing syndesmotic instability.

Our underlying assumption was that simulated injury (ligament sectioning) allows increased displacement of the syndesmosis and that the test that creates the greatest measurable displacement would be expected to be the most sensitive to diagnosing injury. The pain associated with performance of the various stress tests is assumed to be related to the amount of displacement a given tests elicits. Because we were unable to measure pain in a cadaver study, the validity of this underlying assumption is unknown.

A clinical study is needed to correlate the diagnoses of the various stress tests with the diagnoses indicated by imaging studies. Even if pain is related to displacement and if displacement is an indication of injury, it is unknown what magnitude of displacement constitutes injury. In the current study, the external rotation test produced the greatest measured displacement. In some cases, the displacements measured after ligament sectioning were significantly greater than those measured in the intact state, yet on average, the increase in displacement was approximately 1 mm. The clinical significance of such a small displacement is unknown.

Conclusion

All syndesmotic stress tests showed significant displacement anteriorly after Condition 3

(ATFL, PTFL, and ADL sectioning). Posterior displacement after Condition 3 was significant only for the fibular translation and external rotation tests. Because displacements measured after ankle ligament sectioning were generally within the normal physiologic range, it is unlikely that syndesmotic injury can be accurately identified by increased displacement during one of the syndesmotic tests. Furthermore, it remains unknown how increased displacement relates to pain.

For these reasons we believe the positive identification of ligament injury should be based on the presence of elicited pain during these tests.

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Chapter 10

Clinical diagnosis of syndesmotic ankle instability

Evaluation of stress tests behind the curtains

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Abstract

We studied the feasibility of clinical tests in the diagnosis of syndesmotic injury of the ankle. 9 investigators examined 12 persons twice, including 2 patients with an arthroscopically-confirmed syndesmotic injury. They sat behind a curtain that exposed only the lower legs. We found a statistically significant relation between the final arthroscopic diagnosis and the squeeze, fibula translation, Cotton, and external rotation tests as well as for limited dorsal flexion. None of the syndesmotic tests was uniformly positive in chronic syndesmotic injury. The external rotation test had the fewest false-positive results, the fibula translation test the most. The external rotation test had the smallest inter-observer variance. The physical diagnosis was missed in one fifth of all examinations. When in accordance with medical history and physical examination, positive stress tests should raise a high index of suspicion of syndesmotic instability. The final diagnosis of such instability, however, should be made by additional diagnostic imaging and/or arthroscopy.

The integrity of the distal tibiofibular syndesmosis may be clinically tested by the following 4 stress tests. The Cotton (1910) test was originally used to diagnose an ankle fracture. It is positive when more movement is felt during translation of the talus from medial to lateral than on the other side. The external rotation test (Boytim et al. 1991), done by applying an external rotation stress to the involved foot and ankle with the knee held at 90 degrees of flexion and the ankle in the neutral position, causes pain at the anterior or posterior syndesmotic ligament or over the interosseous membrane. The squeeze test (Hopkinson et al. 1990) is done by squeezing the fibula towards the tibia halfway up the calf. When positive, this test produces pain in the area of the syndesmosis. Finally, the fibula translation test (Ogilvie-Harris and Reed 1994) was originally considered positive if anteroposterior translation of the fibula causes pain at the level of the syndesmosis. In clinical practice, however, it is often considered positive when the anteroposterior displacement of the fibula is greater than on the other side. Some authors have also used pain on palpation of the anterior tibiofibular ligament (Taylor et al.1992) and reduced passive dorsal flexion (Ward 1994) to recognize syndesmotic injuries. In lateral collateral ankle instability, an important differential diagnosis of syndesmotic instability, the anterior drawer test (Cedell 1975) is usually used. The ability of the syndesmotic tests to distinguish between healthy subjects and patients with an arthroscopically-proven syndesmotic injury has never been assessed.

We evaluated the feasibility of these ankle tests in the physical diagnosis of chronic syndesmotic injuries.

Patients and methods

12 persons, 3 patients suspected of a chronic syndesmotic rupture and 9 healthy volunteers

Study persons were placed behind a curtain that only exposed the lower legs.

with asymptomatic ankles, were placed in a sitting position behind a curtain that exposed only the lower legs (Figure). The suspected rupture in these patients was based on the medical history, physical examination, and diagnostic imaging on previous visits to the outpatient clinic. Both ankles of all persons were examined twice in a different order by 7 examiners (4 orthopedic surgeons, 3 orthopedic registrars). The examinations included the squeeze, Cotton, fibula translation, external rotation, and anterior drawer tests, and range of motion. They were told not to speak during the investigations, and to indicate pain by tapping on a wooden board followed by indicating the place where the pain was felt with one finger. A test was considered positive when more movement was felt than on the other side or local pain was involved at the syndesmosis. After assessing each ankle, the examiner had to make a "physical diagnosis" regarding the presence or absence of a syndesmotic injury. On the following day, the 3 patients underwent an arthroscopy of the ankle to determine the presence of a syndesmotic injury (Beumer et al. 2000).

Statistics

In the comparison of the various diagnostic tests concerning the statistical evaluation of variations in outcome due to inter- and intra-observer components, both ankles of 1 person were regarded as giving separate independent contributions to those components, so that n = 24 ankles (12 persons × 2 ankles) were used in a variance component analysis to estimate the inter- and intra-observer variance. The other statistical tests were done in 12 persons, after averaging the measurements per person. Correlations between tests were analyzed using the Spearman rank correlation coefficient. Differences in test outcomes between a positive (n = 2 patients, 1 side per patient) and a negative (n = 10 persons, 2 sides per person) arthroscopic diagnosis were analyzed using the Mann-Whitney test. Differences in scoring between two different sets of types of observers were tested using the sign test.

Results

The final arthroscopic diagnosis of a syndesmotic injury was made in 2 ankles. The third patient had generalized joint laxity and lateral collateral instability.

The total number of each test performed on these ankles was 7 investigators × 2 rounds × 2 ankles = 28. The number of positive tests in these injured ankles ranged from 13/28 (Cotton) to 21/28 (fibula translation), and the physical diagnosis of syndesmotic injury was made in 23/28.

The total number of each test done in asymptomatic ankles was 7 investigators × 2 rounds × (24–3) = 294. The number of positive tests in these asymptomatic ankles ranged from 3/294 (external rotation) to 35/294 (fibula translation), while the physical diagnosis of a presumed syndesmotic injury was made 15/294.

We found a relationship between the final arthroscopic diagnosis and the squeeze ($p = 0.02$), fibula translation ($p = 0.03$), external rotation ($p = 0.03$), and Cotton tests ($p = 0.04$), reduced dorsal flexion ($p = 0.01$), and physical diagnosis ($p = 0.03$), but none of the tests was uniformly positive in the presence of a syndesmotic rupture. The anterior drawer test showed no correlation to the final diagnosis. Small differences in the evaluation of the tests between the first and the second investigations showed no particular pattern. The findings with the external rotation test were the most consistent in (12 persons × 2 ankles) = 24 ankles in both rounds; the small variations in the same ankle were mainly due to intra-observer variability.

Discussion

In this study, the investigators were biased since they were focused on the recognition of a chronic syndesmotic injury, which differs from that in clinical practice. However, this was corrected to a certain extent by the few syndesmotic injuries in relation to asymptomatic ankles—i.e., comparable to the reported incidence of syndesmotic injuries of 1–11% of all ankle injuries (Cedell 1975, Hopkinson et al. 1990)—and by changing the order of the persons examined during 2 rounds. The final physical diagnosis of syndesmotic instability was missed in one fifth of all examinations. This could be partly due to the fact that the investigators were not informed about the medical history. In clinical practice, medical history and physical examination interact to lead to the clinical diagnosis. Chronic syndesmotic injury should be suspected in cases of long-standing complaints of pain in the region of the syndesmosis, sensation of instability and recurrent swelling (Hopkinson et al. 1990, Ogilvie- Harris and Reed 1994, Beumer et al. 2000). None of the syndesmotic stress tests per se proved to have a satisfactory predictive value. Despite its significant relationship with the final arthroscopic diagnosis of a syndesmotic injury, the fibula translation test showed the highest number of false positive results in asymptomatic ankles, which was probably due to the subjective evaluation by the investigators of increased movement as a test parameter. Pain instead of increased movement should therefore be used as an outcome measure for this test. Alonso et al. (1998) found that the external rotation test had the best inter-observer agreement of 4 tests. This accords with our smallest inter-observer variance for this test. The similar test results during the first and second rounds indicate that these tests were not affected by repeated examinations. In conclusion, the combination of a medical history of a high ankle sprain with an unusually long period of recovery, sensation of instability, positive external rotation, fibula translation, Cotton and squeeze tests, as well as reduced dorsal flexion should arouse a strong suspicion of chronic syndesmotic instability. Ideally, in future, the final diagnosis will be made by further diagnostic imaging, such as specific MRI investigations, focused on the recognition of chronic syndesmotic ruptures. As such investigations are not yet available, arthroscopy is still the mainstay in the diagnosis of chronic syndesmotic instability.

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Chapter 11

Technical note. Late reconstruction of the anterior distal tibiofibular syndesmosis

Good outcome in 9 patients

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We present a new, anatomic reconstruction of the anterior tibiofibular syndesmosis of the ankle for chronic instability.

Technique (Figure)

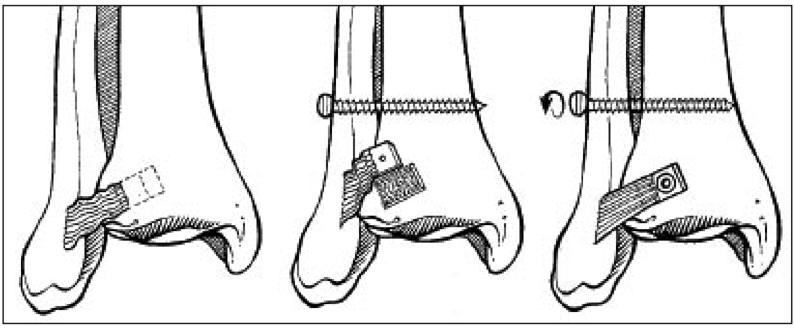
An oblique anterolateral incision is made 4 cm above the joint space starting over the fibula directed towards the distal tibia. Attention must be paid to the intermediate dorsal cutaneous nerve, which crosses superficially on the anteromedial side of the wound.

The slack anterior tibiofibular ligament is identified and is carefully dissected free. Its insertion in the tibia is lined out by cautery, and thereafter osteotomized and mobilized with a bone block of 0.7 x 0.7 cm. A gutter is made in the tibia, directed medially and slightly proximally. A screw is placed above the syndesmosis in the fibula and tibia, through 4 cortices, with the foot in maximal plantar flexion and compression of the mortise.

After medialization, the bone block is secured with a small screw. The syndesmotic screw is then turned loose 2 twists, while the foot is forced in dorsalflexion, which increases the tension of the ligament and allows the ankle joint to obtain its neutral position.

After 6 weeks of no weight bearing in a belowknee plaster, the syndesmotic screw is removed and full weight bearing is allowed.

Figure. The new, anatomic reconstruction of the anterior tibiofibular syndesmosis of the ankle for chronic instability. The tibial insertion of the slack anterior tibiofibular ligament is lined out by cautery, osteotomized and mobilized with a bone block. A gutter is made in the tibia, directed medially and slightly proximally. A screw is placed above the syndesmosis for compression of the mortise. After medialization, the bone block is secured with a small screw. The syndesmotic screw is then turned loose 2 twists, while the foot is forced in dorsal flexion, which allows the ankle joint to obtain its neutral position.



Pre- and postoperative ankle scores according to Karlsson (1991), Tegner and Lysholm (1985) and Sefton et al. (1979)

Case	Sex, age (yrs)	Follow-up (months)	Pre/postop Karlsson score	Pre/postop Tegner score	Postop Sefton score	Degenerative changes[a]	Complication
1	M 23	43	42 / 100	3 / 7	1	1 / 0	–
2	F 42	38	17 / 47	0 / 2	3	2 / 1	SRD [b]
3	F 17	43	72 / 87	6 / 7	2	0 / 0	–
4	F 25	48	77 / 87	1 / 6	1	0 / 0	Entrapment [c]
5	F 28	46	22 / 87	0 / 4	2	0 / 0	SRD
6	M 17	56	40 / 60	2 / 3	3	1 / 0	–
7	M 39	62	52 / 100	2 / 7	1	0 / 1	–
8	M 45	41	65 / 87	5 / 5	2	0 / 0	–
9	F 17	44	32 / 59	5 / 5	3	0 / 0	–

[a] *Radiographic degenerative changes showing scores on the affected side/ unaffected side at follow-up*
Grade 0: normal joint or subchondral sclerosis, Grade 1: osteophytes, without joint space narrowing,
Grade 2: joint space narrowing with or without osteophytes

[b] *SRD: sympathic reflex dystrophy*

[c] *Entrapment: of intermediate dorsal cutaneous nerve*

Patients (Table)

9 patients with arthroscopically-confirmed instability of the syndesmosis (i.e., wide, hypermobile on testing and easily accessible for the test probe) were operated on with this technique. All complained of pain, 7 of feelings of giving way and of swelling. The mean duration of symptoms was 27 (4–102) months. Other diagnoses, like lateral instability or chondral damage of the talus, were excluded.

The mean follow-up was 45 (38–62) months.

After reconstruction, all considered the ankle to be improved, none complained of instability.

Transient sympathic reflex dystrophy was seen in 2 patients and entrapment of the intermediate dorsal cutaneous nerve in scar tissue in 1 patient.

Discussion

Syndesmotic injuries are usually seen in combination with ankle fractures, but can occur isolated as well. They are estimated to occur in 1–11 % of ankle sprains (Cedell 1975, Hopkinson et al. 1990) and result mainly from external rotation, and/or dorsiflexion injury (Rasmussen et al. 1982). Patients tend to have more complaints than in ordinary lateral collateral ligament injury, a longer period of recovery (Hopkinson et al. 1990) and more residual complaints, due to impingement of scar tissue (Ogilvie-Harris and Reed 1994) or chronic instability (Close 1956).

Good results with impingement have been reported after shaving scar tissue in the syndesmosis (Ogilvie-Harris and Reed 1994). Kelikian and Kelikian (1985) described a method for reconstruction of the anterior syndesmosis by tenodesis with the extensor tendon of the fifth or fourth toe, or with the plantaris tendon, fascia or dura mater. Beals and Manoli (1998) presented a case of late syndesmotic reconstruction after ankle fracture involving removal of scar tissue medial and lateral in the talocrural joint, and reconstruction of the anterior syndesmosis with use of a cuff of firm fibrous tissue and placement of a syndesmotic screw. We found, even in late cases, that the distal tibiofibular ligament, though slack, is always present. By analogy with the reconstruction of the talofibular ligament, one may assume that an anatomic repair using the original tibiofibular ligament should be better (Bahr et al. 1997). Our technique for an anatomic repair of the anterior tibiofibular syndesmosis of the ankle has not, to the best of our knowledge, been described before, and the results given here are encouraging.

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Chapter 12

Screw fixation of the syndesmosis: a cadaver model comparing stainless steel and titanium screws and three and four cortical fixation

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Keywords
Syndesmotic set screw; Three-cortical; Four-cortical; Stainless steel; Titanium; Ankle; Cadaver model; Syndesmotic injury; Weight bearing

Summary
We assessed syndesmotic set screw strength and fixation capacity during cyclical testing in a cadaver model simulating protected weight bearing. Sixteen fresh frozen legs with artificial syndesmotic injuries and a syndesmotic set screw made of stainless steel or titanium, inserted through three or four cortices, were axially loaded with 800 N for 225,000 cycles in a materials testing machine. The 225,000 cycles equals the number of paces taken by a person walking in a below knee plaster during 9 weeks.

Syndesmotic fixation failure was defined as: bone fracture, screw fatigue failure, screw pull-out, and/or excessive syndesmotic widening.

None of the 14 out of 16 successfully tested legs or screws failed. No difference was found in fixation of the syndesmosis when stainless steel screws were compared to titanium screws through three or four cortices. Mean lateral displacement found after testing was 1.05 mm (S.D. 1/4 0.42). This increase in tibiofibular width exceeds values described in literature for the intact syndesmosis loaded with body weight. Based on this laboratory study it is concluded that the syndesmotic set screw cannot prevent excessive syndesmotic widening when loaded with a load comparable with body weight. Therefore, we advise that patients with a syndesmotic set screwin situ should not bear weight.

Introduction
Without adequate treatment, injuries of the syndesmosis of the ankle whether isolated or in combination with a fracture can result in syndesmotic instability. This may be caused by external rotation of the talus when only the anterior syndesmosis is injured, or lateral talar shift when the deltoid ligament is also damaged.[5,7] Lateral shift and external rotation of the talus larger than 2 mm, respectively, 5° reduce the mean joint contact area and increase the contact pressures in the ankle.[6,15] This may be as much as 42% decrease in ankle contact area in the initial 1 mm lateral talar shift.[14] Lateral displacement of the distal fibula fragment of more than 2 mm generally led to a poor result after ankle fractures. In the long term this can cause degenerative changes.[10] To prevent these sequelae, adequate

reduction and stabilization of the syndesmosis is required.

A syndesmotic set screw is indicated in all injuries with an unstable syndesmosis as shown by: a complete traumatic radiographic tibiofibular diastasis, as demonstrated by unilateral absence of tibiofibular overlap or a medial clear space that exceeds 2 mm or exceeds the superior clear space or,[3,9,13] a fibular fracture more than 5 cm above the tibiotalar joint, or a torn syndesmosis at inspection. Furthermore, an injury of the syndesmosis should be considered when posterior translation of the fibula[2,20] during external rotation stress imaging is found. The amount of posterior translation of the fibula can only be quantified reliably by radiostereometry which is not suitable for daily practice.[2]

No consensus exists on the syndesmotic set screw engaging three or four cortices, or the use of one or two screws, but two screws are advocated in cases with multiple fibular fractures.[9] There is said to be no biomechanical advantage in the use of a single 4.5 mm screw over a single 3.5 mm screw.[17] It is common to remove the screws before weight bearing, [11,12] because the screw prevents normal tibio-fibular movement and because of complications that might result from screw breakage.

Recently, titanium screws have been marketed and superseded stainless steel screws. As yet no studies have reported on the difference in failure strength between stainless steel and titanium screws, or between three or four cortical purchase in syndesmotic fixation. The aim of this study was to assess the difference between three or four cortical syndesmotic fixation in a cadaver model simulating 9 weeks of protected weight bearing. A second aim was to compare stainless steel with titanium screws for fixation of the syndesmosis in the same model.

Materials and methods

The authors used 16 fresh—frozen human cadaver lower legs with a mean age at death of 85 (78—102) years. The legs were examined visually and radiographically to rule out major ankle pathology. All tissues of the leg and ankle, with exception of capsules and ligaments were removed. The syndesmotic ligaments and anterior part of the deltoid ligament were sectioned, together with the distal 10 cm of the interosseous membrane in order to simulate a syndesmotic rupture without associated fracture. The legs were mounted on a materials testing machine (Lloyd Instruments Limited, Fareham, Hampshire, UK) and secured at the tibial plateaux and the feet. The tibial plateaux were fixed in a negative print of the plateau in a Petri dish filled with Bosworth Fastray® cement (Bosworth, Skokie, IL, USA) which allowed equal force transfer through the entire plateau (Fig. 1). The feet were fixed at the calcaneus with two screws from the sides, and at the forefoot with a transverse clamp over the metatarsophalangeal joints.

A custom made device with strain transducers to measure syndesmotic widening was placed with a flat surface area of 25 mmover the malleoli (Fig. 2). Malleolar displacement was recorded using a strip chart.

The specimens were kept constantly moist using saline soaked towels and foil wraps around the legs. To monitor tibial displacement due to bone failure the load at, and displacements of the tibial plateaux were recorded every 25th cycle. In all ankles, a 3.5 mmfully threaded cortical screw was inserted in a 308 anteromedial direction, parallel to and 2 cm above the talocrural joint according to the following scheme: Group I stainless steel—three cortices, Group II stainless steel—four cortices, Group III titanium—three cortices, Group IV titanium—four cortices (the titanium screws were made of Ti6A17Nb 1/4 TAN).

All legs were subjected to the same axial loading, which was a fatigue load of 800 N (average body weight) for 225,000 cycles. The number of cycles applied had been calculated by multiplying the daily values retrieved from step counting studies over 63 days.[8,16,19] It is an estimation of the amount of steps taken by a not very active person, and thus comparable to walking in a below knee plaster during 9 weeks. Nine weeks was chosen to simulate a period with ample time for ligament healing, and is longer than patients

Figure 1 Cadaveric leg in testing machine, with protective plastic covering.

with a syndesmotic injury are usually kept in a plaster cast. Failure was defined as bone fracture, screw loosening, screw fatigue failure, screw pull-out, or larger than physiological syndesmotic widening.

Differences in increased syndesmotic width between the four groups were analysed using a randomeffectsmodel assuming compound symmetry for the covariance matrix of the repeated measures, using data from all cycles and accounting for two different sources of variation, both between and within subjects, with significance set at $P < 0.05$.

Results

Fourteen out of 16 legs were tested for the total amount of 225,000 cycles. The fixation of the foot to the test rig failed in four legs. Two feet could be repositioned and testing of the legs completed. The two other legs could not be tested to the full amount of cycles due to complete fracture of the calcaneus. One of these legs (Group III) was tested to 60,000 cycles, approximately 14 days of walking), the other (Group IV) to 67,000 cycles (approximately 16 days).

The average vertical translation of the malleoli during the testing did not exceed 10 mm, which is well within the 25 mm range of the transducer surface. During loading the mean partially reversible incremental lateral movement of the fibula for the entire group was 0.14 mm(S.D.: 0.06) per cycle. The final total increase in tibiofibular width after testing was 1.05 mm(S.D.: 0.42). None of the 14 successfully tested legs showed macroscopic evidence of tibial or fibular fracture, screw loosening, screw fatigue failure or pull out during or after the testing.

There was no statistically significant difference in syndesmotic widening between the four groups (steel versus titanium P 1/4 0.754, three versus four cortices P 1/4 0.943).

Discussion

There is still debate as to whether one should engage three or four cortices with a syndesmotic set screw, or if a better fixation is achieved by using titanium or stainless steel screws. Neither is it known if patients should be allowed to bear weight with a syndesmotic screw in situ. The aim of this study was to address these questions in a cadaver model for protected weight bearing. Our model can be considered as a worst case scenario. Lower limbs of elderly people were used, most probably with some degree of osteoporosis. It may be assumed that the conditions in clinical practice with younger patients may result in better fixation than found in the cadaver specimens of this model. Furthermore, an injury model for a ruptured anterior and posterior syndesmosis with associated anterior deltoid ligament and interosseous membrane injury was used. This is a more severe ligamentous injury than in the average patient. Most patients with surgically treated ankle fractures will have more intrinsic stability than this model. During weight bearing, one sixth of the force is transferred to the fibula from

Figure 2 Malleolar clamp with strain transducers.

the talus.[18] For this force transfer, a stable syndesmosis is required. Fixation of the syndesmosis with a screw resists normal tibio-fibular motion and vertical loading of a leg subjects the screw to mechanical stresses that theoretically could cause screw failure. In the present study, this load transfer is confirmed by the cyclic increase in tibiofibular width during loading, and the increasing width during the test.

In the 14 successfully tested legs no screw loosening, screw breakage, screw pull-out, or fracture occurred. The mean final increase in tibiofibular width after testing was 1.05 mm (S.D.: 0.42).

Previous radiostereometric studies showed a mean physiological syndesmotic widening of 0.24 (range: 0.38—1.13) mm in intact cadaveric ankles after applying 750 N axial load,4 and of 0.02 (0.44 0.41) mm in healthy volunteers actively loading their ankles.[1] The displacements found in the present study largely exceed the physiological mobility. Therefore, one must assume that weight bearing with a syndesmotic screw in situ impairs normal healing of the syndesmotic structures, and it should be advocated that patients do not bear weight in the period necessary for ligaments to heal. No statistically significant difference was found between the three- or four-cortical fixation, or between fixation with titanium or stainless steel screws. Regarding fixation the methods are equal, and thus the surgeon may choose whichever is convenient. The advantage of four-cortical fixation is that screw removal after screw breakage is a much easier via a small window in the medial tibial cortex.

Conclusion

This study shows that, in a cadaver model simulating protected weight bearing after screw placement for syndesmotic instability, physiological axial loading of the lower leg will not result in screw loosening, breakage, pullout or bone failure, but in excessive syndesmotic widening. Therefore, it is advised that, even in below knee cast, patients should not bear weight.

No difference in fixation during the test period was found between three or four cortical fixation or between stainless steel or titanium screws.

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Chapter 13

Kinematics before and after reconstruction of the anterior syndesmosis of the ankle

A prospective radiostereometric and clinical study in 5 patients

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Background **We have previously shown that patients with instability of the anterior syndesmosis benefit from an anatomical reconstruction. It is not known whether this is because of restored kinematics.**

Methods **In a prospective study of 5 patients, we assessed clinical findings and tibiofibular kinematics, evaluated by radiostereometry, before and after reconstruction of a chronic syndesmotic injury.**

Results **We found no statistically significant differences in tibiofibular kinematics before and after reconstruction. The kinematics of the fibula relative to the tibia during external rotation stress differed from that known in asymptomatic volunteers, but the differences were not typical enough to differentiate between patients and healthy subjects. Clinical examination and ankle scores, however, showed that all patients benefited from reconstruction of the anterior syndesmosis.**

Interpretation **Radiostereometry is not an adequate technique to diagnose chronic syndesmotic instability or to demonstrate restoration of the kinematics of the ankle as a cause of the beneficial effect of anatomical reconstruction of the syndesmosis.**

Several studies have shown that a rupture of the anterior tibiofibular and/or deltoid ligament results in instability (Close 1956, Mullins and Sallis 1958, Rasmussen et al. 1982, Xenos et al. 1995, Beumer et al. 2003a).

Patients with instability of the anterior syndesmosis of the ankle benefit from an anatomical reconstruction of the anterior tibiofibular syndesmosis by a surgical technique which showed promising results in a retrospective study (Beumer et al. 2000). In this study, we prospectively assessed the clinical result of reconstructive surgery of the anterior syndesmosis. A second aim was to determine whether abnormal tibiofibular motion could be demonstrated with radiostereometry (RSA) in patients with syndesmotic instability.

Patients and methods

We studied 5 patients (2 women) with unilateral chronic syndesmotic instability. Their mean age was 32 (22–36) years (Table 1).

The suspicion of chronic instability of the anterior syndesmosis of the ankle was based on medical history, physical examination, radiographs (plain and stress, anteroposterior and lateral) and MRI.

The patients underwent arthroscopy of the ankle and if syndesmotic instability was found, they participated in the study. The study was approved by the medical ethics committee of the Erasmus Medical Centre, Rotterdam, the Netherlands. All patients gave written informed consent. The patients had 1.5 (1–3) years of complaints of the ankle after they had sustained a sprain. All had a

Table 1. Patient data

Patient	1	2	3	4	5
Sex	F	M	M	M	F
Age (years)	36	31	35	39	22
Site	L	R	L	L	L
Work	Nurse	Sport instructor	Account manager	Adviser	Cashier
Trauma	Work	Sport	Sport	Sport	Daily living
Months of complaints	18	12	12	10	33
Pain [a]	Syn	Syn, M, L	Syn	Syn, M, L	Syn, M, L
(Pseudo) locking	–	–	+	–	–
Radiograph [b]	Normal	Avulsion M	Avulsion M	Normal	Normal
Tegner [c]	4 (3)	5 (0)	5 (2)	4 (2)	4 (2)
Karlsson [c]	87 (20)	95 (40)	80 (47)	77 (55)	95 (29)
Sefton [c]	1 (4)	1 (3)	2 (3)	3 (2)	1 (4)
Ankle-Hindfoot scale [c]	90 (42)	100 (68)	83 (74)	83 (69)	100 (64)

[a] *Syn: syndesmosis, M: medial, L: lateral.*

[b] *Anteroposterior and lateral ankle radiograph. Avulsion M: medial malleolus avulsion.*

[c] *Scores of the Tegner, Karlsson, Sefton and Ankle-Hindfoot scale after (before) reconstructive surgery.*

sensation of giving way and problems with walking on uneven ground, without frank giving way. In addition, stiffness, limited dorsiflexion, and a recurrent swelling at the level of the syndesmosis were present. All patients indicated pain at the anterior syndesmosis and 3 out of 5 had tenderness around the medial and lateral malleolus also. The squeeze (Hopkinson et al. 1990), external rotation (Boytim et al. 1991), and fibula translation test (Ogilvie- Harris et al. 1994) were positive (i.e. painful) in all patients, while no patient had a positive (i.e. unilaterally increased mobile) anterior drawer test. No patient showed signs of hypermobility according to Beighton et al. (1983). The complaints had not disappeared with nonoperative treatment which consisted of anti-inflammatory medication and plaster immobilization, followed by exercises to improve proprioception and strength.

In 2 patients, plain ankle radiography showed a periosteal reaction at the medial malleolus above the insertion of the deltoid ligament, that might have resulted from a tear of the periosteum together with the attachment of the deltoid liga-

Figure 1. Avulsion of the periosteum above the insertion of the deltoid ligament.

Figure 2. The RSA external rotation stress examination.

ment (Figure 1). No patient showed increased talar tilt or anterior translation on stress radiographs. MRI findings were not conclusive with regard to syndesmotic injury, as the anterior tibiofibular ligament cannot be visualized along its entire length in the orthogonal planes of conventional MRI—and no reports had been presented at that time on the MRI findings of chronic syndesmotic injuries. The periosteum at the medial malleolus and the deltoid ligament of the 2 patients with calcification at the medial malleolus showed thickening and loss of fascicular detail with MR imaging, indicating old injury.

After arthroscopic confirmation of the diagnosis of syndesmotic instability by demonstrating increased movement of the fibula, easy access of the test probe into the syndesmosis, and increased tibiofibular width by easy turning of the transverse end of the test probe (Ogilvie-Harris et al. 1994, Beumer et al. 2000), 5 tantalum markers (0.8 mm) were placed in the involved distal tibia and fibula each, controlled by fluoroscopy during arthroscopy to provide optimal marker distribution.

Before arthroscopy, and 6 months after reconstruction, we assessed the function of the ankle with the squeeze test, the external rotation test, and the fibula translation test, as well as the Tegner-activity level score (Tegner and Lysholm 1985), the Karlsson (1991) score, the Sefton et al. (1979) score, and the Ankle-Hindfoot scale (Kitaoka et al. 1994). About 6 weeks after the arthroscopy, reconstruction of the anterior syndesmosis was performed by medialization and cranialization of the tibial insertion of the slack anterior tibiofibular ligament, after a syndesmotic set screw was placed during compression of the mortise (Beumer et al. 2000). Postoperative treatment consisted of 6 weeks of non-weight bearing in a below-knee plaster, followed by removal of the screw under local anesthesia. Thereafter, weight bearing and unlimited exercise were allowed.

RSA examinations were performed in one or more of the following ways: A. Standing non-weight bearing, B. Standing weight bearing, C. Supine neutral, D. Supine with the application of a 7.5-Nm external rotation stress at the base of the first metatarsal (Figure 2; Beumer et al. 2003a). These examinations were performed on the day before reconstruction (A, B, C, D), the day after reconstruction (C), 6 weeks after reconstruction (just after the syndesmotic setscrew had been removed; C), and 3 months after reconstruction (A, B, C, D).

Weight-bearing examinations were performed while the patients stood on a pedestal. External rotation stress and also the “standard neutral” examinations were done in the supine position. Displacements of the fibula relative to the tibia during neutral weight bearing versus neutral non-weight bearing (“neutral weight bearing”), during external rotation stress versus neutral supine (“7.5-Nm external rotation stress”), and also in the standard neutral position after reconstruction versus before reconstruction (“standard neutral post-reconstruction”) were assessed, and expressed as 3 translation parameters and 3 rotation parameters of the fibula relative to the tibia. Positive directions for translations along the coordinate axes were lateromedial (transverse axis), caudocranial (longitudinal axis), and posterioranterior (sagittal axis). Positive directions for rotations about the coordinate axes were plantar flexion (transverse axis), internal rotation (longitudinal axis), and adduction (sagittal axis).

We scanned the radiographs with a Vidar VXR-12 scanner (Vidar, Lund, Sweden), at 150 dots per inch resolution and 8-bit gray scale resolution. The measurement of marker coordinates in

Table 2. Reproducibility of the examination assessed by double exposures of 2 patients

	Translations (in mm)			Rotations (in degrees)		
Exposure[a]	L-M	Ca-Cr	P-A	P	Int	Add
Neutral (supine) 1	–0.14	0.08	–0.41	–0.12	0.52	–0.28
Neutral (supine) 2	0.18	0.45	0.11	–0.09	–0.78	0.16
Neutral non-weight bearing 1	0.18	0.02	–0.43	–0.84	–0.41	0.03
Neutral non-weight bearing 2	–0.09	–0.11	–0.03	–0.26	–1.29	–0.05
Neutral weight bearing 1	–0.16	0.16	0.20	0.35	0.30	–0.08
Neutral weight bearing 2	0.22	–0.12	–0.09	–0.16	–0.24	0.28
External rotation b 1	–0.31	0.03	0.27	–0.12	0.75	–0.23
External rotation b 2	–0.18	–0.27	0.53	0.36	0.01	–0.55
Mean	–0.04	0.03	0.02	–0.11	–0.14	–0.09
SD	0.20	0.22	0.33	0.38	0.68	0.26

[a] 1: patient 1, and 2: patient 2

[b] 7.5-Nm external rotation examination (supine)

Table 3. Neutral weight bearing compared to neutral non-weight bearing. Fibular displacements relative to the tibia for 5 patients

Translations (in mm)	L-M	Ca-Cr	P-A
Preoperative, mean (range)	-0.06 (-0.34–0.24)	0.18 (-0.25–0.61)	0.07 (-0.16–0.51)
3-months postoperative, mean (range)	0.48 (0.28–0.67)	-0.27 (-0.76– -0.04)	-0.16 (-0.65–0.39)
95% confidence interval	-0.51–0.08	-1.09–1.50	-0.80–0.30
Rotations (in degrees)	**P**	**Int**	**Add**
Preoperative, mean (range)	-0.19 (-1.06–0.11)	0.30 (-0.17–1.53)	0.09 (-0.11–0.33)
3-months postoperative, mean (range)	-0.33 (-0.90–0.05)	-1.51 (-2.98–0.01)	0.20 (-0.44–0.12)
95% confidence interval	-1.63–1.07	-1.75–2.23	-0.60–0.15

Translations were considered positive in the following directions: lateromedial (L-M), caudocranial (Ca-Cr), posterioranterior (P-A), plantar flexion (P), internal rotation (Int), adduction (Add). 95% confidence interval refers to pre-/post- comparisons between preoperative status and postoperative status (at 3 months) as an estimation of the operation effects with 95% confidence intervals.

the digitized radiographs, the three-dimensional reconstruction of the marker positions, and the micromotion analysis were done with RSA-CMS (MEDIS, Leiden, the Netherlands), a software package that performs the RSA procedure automatically in digitized or digital radiographs (Valstar et al. 2000).

Reliability of RSA depends on nonlinear marker distribution. The condition number provides a geometrical interpretation of the distribution of the markers in 3-D space (Söderkvist and Wedin 1993). We used the same upper limits for the condition number as described in the literature, i.e. a condition number lower than 80–90 representing a reliable distribution (Börlin et al. 2002). Double exposures of all 4 examinations were made in 2

Table 4. Standard neutral post-reconstruction (supine postoperative versus to preoperative). Fibular displacements relative to the tibia for 5 patients

Translations (in mm)	L-M	Ca-Cr	P-A
Directly post-reconstruction, mean (range)	1.10 (0.21–2.34)	0.52 (0.15–0.83)	1.03 (0.07–1.83)
6 weeks after screw removal, mean (range)	0.43 (-0.16–1.20)	0.23 (-0.41–0.84)	0.60 (-0.04–1.31)
3-months postoperative, mean (range)	-0.21 (-0.86–0.10)	-0.16 (-0.79–0.30)	0.03 (-0.36–0.69)
Rotations (in degrees)	**P**	**Int**	**Add**
Directly post-reconstruction, mean (range)	0.08 (-0.24–0.40)	-0.66 (5.06– -4.08)	-0.82 (0.23– -2.49)
6 weeks after screw removal, mean (range)	0.20 (-0.90–1.20)	-0.93 (-2.75–0.16)	-0.41 (-0.98–0.32)
3-months postoperative, mean (range)	0.23 (-0.52–0.98)	-0.84 (-2.28–0.24) -	0.08 (-0.56–0.65)

Translations and rotations were considered positive in the following directions: lateromedial (L-M), caudocranial (Ca-Cr), posterior-anterior (P-A), plantar flexion (P), internal rotation (Int), adduction (Add).

Table 5. External rotation stress (7.5 Nm) compared to neutral (supine).

Translations (in mm)	L-M	Ca-Cr	P-A
Preoperative, mean (range)	0.35 (-0.55–1.19)	0.32 (0.00–0.73)	-0.97 (-2.45– -0.08)
3-months postoperative, mean (range)	0.35 (-0.40–0.97)	0.58 (0.13–1.01)	-0.78 (-1.32–0.02)
95% confidence interval	-0.77–0.76	-0.28–0.79	-0.53–0.91
Rotations (in degrees)	**P**	**Int**	**Add**
Preoperative, mean (range)	0.47 (-0.02–0.86)	-2.32 (-3.49– -0.91)	1.19 (0.96–1.50)
3 months postoperative, mean (range)	0.52 (-0.27–1.09)	-1.74 (-3.94– -0.06)	1.12 (0.74–1.44)
95% confidence interval	-0.66–0.76	-0.36–1.53	-0.24–0.10

Translations were considered positive in the following directions: lateromedial (L-M), caudocranial (Ca-Cr), posterioranterior (P-A), plantar flexion (P), internal rotation (Int), adduction (Add). 95% confidence interval relates to pre-/post- comparisons between preoperative status and postoperative status (at 3 months) as an estimation of the operation effects with 95% confidence intervals.

patients in order to assess the reproducibility of the measurements.

Statistics

We assessed normality of the data with the Shapiro-Francia W' test. Differences between pre- and postoperative values were performed using paired t-tests. 95% confidence intervals for differences in pre- and postoperative values were calculated using the t-distribution. All tests were two-sided and had 5% significance level.

The pre- and postoperative displacements of the fibula relative to the tibia during neutral weight bearing and external rotation stress were compared with data assessed from asymptomatic volunteers (Beumer et al. 2003b) (see appendix). Differences between the patients in this study and those asymptomatic volunteers were analyzed with Wilcoxon Sum Rank Test (Mann-Whitney U-test), with the significance level set at $p < 0.05$.

Results

6 months after reconstruction, the ankles of all 5 patients had improved, as shown by the various ankle scores (Table 1). No patient complained of instability or pain anymore. After the operation, all the syndesmotic tests had turned from positive to negative.

The condition number for the tibia was 23 (14–32), and that for the fibula was 17 (12–24). No segment was excluded from analysis. These condition numbers lay well below the limits we set, so that reliable translations and rotations could be calculated. We assessed the reproducibility of the different examinations by repeating 8 of them. The standard deviations for the rotations about the transverse, longitudinal and sagittal axes were 0.4, 0.7, and 0.3 degrees, and the standard deviations for the translations were 0.2, 0.2, and 0.3 mm (Table 2).

Neutral weight bearing

Pre- and postoperative displacement of the fibula showed a large interindividual variation (Table 3).

There were no statistically significant differences between the weight-bearing kinematics of the preoperative and postoperative examinations, nor between the kinematics of the patients in this study and the healthy volunteers during weight bearing.

Standard neutral post-reconstruction

Directly after reconstruction, the fibula had translated ($p = 0.04$) in a medial direction by on average 1.1 (0.21–2.34) mm, thus decreasing tibiofibular width (Table 4). After 6 weeks (removal of the syndesmotic setscrew) and 3 months, it was seen that tibiofibular width gradually returned to its approximate preoperative value. When the direct postoperative data were compared to the preoperative situation, reduced translations of the fibula in a cranial ($p = 0.04$) and posterior ($p = 0.04$) direction were found during the neutral supine investigations.

We found no statistically significant differences during the neutral supine investigations between the preoperative findings and those recorded 6 weeks and 3 months after reconstruction.

7.5-Nm external rotation stress

Preoperative displacement of the fibula relative to the tibia showed a mean posterior translation of 0.97 (0.08–2.45) mm and 2.32 (0.91–3.49) degrees external rotation when compared to the neutral situation. Postoperative (3 months) versus preoperative displacement of the fibula relative to the tibia showed smaller posterior translations (mean 0.78 mm, range -0.02–1.32; $p = 0.35$) and external rotation (mean 1.74o, range 0.06–3.94; $p = 0.14$) (Table 5).

In comparison with the asymptomatic volunteers, the patients displayed smaller displacements during the external rotation stress investigation before reconstruction, for medial ($p = 0.01$) and posterior ($p = 0.04$) translation, as well as for external rotation ($p = 0.04$). In comparison with the control ankles, smaller displacements were found 3 months after reconstruction for medial ($p = 0.005$) and posterior ($p = 0.003$) translation, and external rotation ($p = 0.04$), as well as larger cranial displacements ($p = 0.05$).

Discussion

We used RSA to assess displacements at the tibiofibular syndesmosis before and after reconstruction of the anterior syndesmosis, as conventional radiography is unreliable and not sensitive when repeated radiographs are necessary (McDade 1975, Beumer et al. 2004). The data acquired were compared with the kinematics of healthy volunteers who took part in an RSA study that was performed to obtain “normal” values (Beumer et al. 2003b).

Post-reconstruction differences in tibiofibular kinematics relative to preoperative findings were not statistically significant. In contrast to a previous cadaveric study (Beumer et al. 2003a), we were unable to demonstrate syndesmotic instability as a statistically significant increased posterior translation of the fibula during the external rotation stress examination in these patients. This is probably because we did not have an individual "intact" situation.

Furthermore, the result of the above examination in cadavers may be different from the chronic situation in patients because of healing of the ligament in the chronic situation. In all the syndesmotic reconstructions we performed, a continuous but slack anterior tibiofibular ligament was found. The cadaveric study, however, is best compared with an acute ligament rupture. For ethical reasons, we chose not to perform the RSA external rotation stress examination in the contralateral ankle.

Preoperative external rotation stress examinations resulted in an external rotation of the fibula of between 0.91 and 3.49 degrees. 2 patients exhibited radiological features that might indicate old deltoid injury. One of these patients showed external rotation smaller than average; the other had the largest external rotation found preoperatively. It has been described that deltoid ligament rupture results in increased talar external rotation which increases further after additional sectioning of the syndesmosis (Rasmussen 1985).

In view of the functional instability (Freeman 1965), an unexpected observation was that our patients showed smaller displacements of the fibula relative to the tibia during the external rotation stress investigation (for medial and posterior translation, as well as external rotation) than the asymptomatic volunteers. Apart from the wide range of values found in healthy volunteers, and combined with the small number of patients in our study, several reasons might be given for this finding. Firstly, with respect to positioning of the ankle, plantarflexion and dorsiflexion are known to change the tibiofibular relationship. The ankles of the patients and the healthy volunteers were placed in the testing device by 2 investigators (AB, BAS) according to the zero starting position for the foot (American Academy of Orthopedic Surgeons 1965). It is therefore unlikely that a positioning error would be the reason for this observation. Secondly, one might speculate that the fibulas of the volunteers could show increased displacement if they suffered from generalized joint laxity, since they underwent reconstruction of the lateral collateral ligaments of the contralateral ankle in the past. This, however, was not the case—as none showed signs of hypermobility and none had complaints of instability, or a positive anterior drawer or syndesmotic stress test (Beumer et al. 2003b).

Also, it was shown previously with RSA that the volunteers had tibiofibular kinematics that were different to those of patients with bilateral chronic lateral instability of the ankle (Löfvenberg et al. 1990).

Another reason for the smaller displacements of the fibula in these patients compared to the volunteers could be the effect of posttraumatic changes around the syndesmosis, as have been described by Ogilvie-Harris et al. (1994). During arthroscopy, however, the triad described by these authors (disruption of the interosseous and posterior inferior tibiofibular ligament and chondral fracture of the posterolateral portion of the tibial plafond) was not found. Differences in pain sensation between the patients and the volunteers during the stress examination and reactive (in)voluntary muscle tensioning can be the reason for smaller displacements during the stress examination.

The most likely reason for the small displacements (especially external rotation) of the fibula in these patients during the stress examination is an altered position of the fibula due to rupture of the anterior tibiofibular ligament. A cadaveric study showed that the fibula rotates on average 1.5 (0.1–3.4) degrees externally after transection of the anterior tibiofibular ligament (Beumer et al. in press). This is in accordance with findings from studies not using RSA (Close 1956, Rasmussen et al. 1982, Xenos et al. 1995). One might assume that the fibula remains in this position when no reduction is performed and secured in the acute situation.

The combination of the fibula being in this externally rotated position and changes in viscoelastic behavior of the ligament due to injury (Frank and Shrive 1994) could account for the smaller displacements of the fibula found during the external rotation stress examination in these patients, when compared to the healthy volunteers.

Directly after reconstruction of the syndesmosis, a decrease in tibiofibular width of 1 mm was found due to application of the syndesmotic setscrew.

This had returned to the preoperative situation 3 months after reconstruction, indicating that the screw had temporarily fixated the syndesmosis. Furthermore, this finding suggests that overtightening of the syndesmosis will not easily be achieved in the ligamentous repair we perform.

We could not reveal the syndesmotic instability by the RSA external rotation stress examination. As the displacements measured may be largely influenced by voluntary muscle tensioning and movement, and since RSA is an invasive procedure— not suitable for diagnostic imaging in dailypractice—we conclude that the RSA external rotation stress examination is not the proper tool to assess chronic syndesmotic instability in a patient who has not been anesthetized.

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Appendix. Fibular displacements relative to the tibia for 11 normal ankles. Values are mean (range). From Beumer et al. 2003b

Translations (in mm)	Medial	Cranial	Anterior
N-WB	-0.02 (-0.41–0.44)	0.00 (-0.37–0.30) -	0.10 (-0.96–0.28)
EX-WB	0.11 (-0.19–0.63)	-0.12 (-0.59–0.23)	-0.46 (-1.98–0.56)
EX-M	1.48 (-0.06–2.52)	0.22 (-0.14–0.56)	-1.87 (-3.08– -0.95)
Rotations (in degrees)	**Plantar flexion**	**Internal rotation**	**Adduction**
N-WB	0.00 (-0.92–0.80)	0.03 (-1.28–1.18)	0.01 (-0.68–0.66)
EX-WB	0.12 (-0.94–1.47)	-0.02 (-1.38–1.02)	-0.27 (-0.97–0.41)
EX-M	0.06 (-0.49–0.76)	-3.85 (-5.33– -1.89)	1.20 (0.21–2.10)

N-WB: neutral weight bearing versus non-weight bearing (standing)
EX-WB: external rotation during weight bearing versus non-weight bearing (standing)
EX-M: 7.5-Nm external rotation moment versus neutral (supine)
Translations and rotations were considered positive in the following directions: lateromedial (L-M), caudocranial (Ca-Cr), posterior-anterior (P-A), plantar flexion (P), internal rotation (Int), adduction (Add).

Chapter 14

Clinical relevance and treatment options for physicians treating syndesmotic injuries

In The Netherlands with a population of 16 million inhabitants ankle sprains occur in 45000 patients a year (Verhagen 2004). Between 1 and 10 % of patients with severe ankle sprains suffer from an injury of the distal tibiofibular syndesmosis (Broström 1964). This number of injuries may increase to more than 40 % in those involved in high contact or collision sporting activities (Gerber et al. 1998). Syndesmotic injuries are often mistaken for the more common lateral ankle sprains and subsequently not treated properly (Gerber et al. 1998, Boytim et al. 1991), which can result in chronic syndesmotic instability (Beumer et al. 2005c, Grass et al. 2003, Beumer et al. 2000, Bonnin 1965, Mullins and Sallis 1958). This can be avoided by proper evaluation of ankle injuries at the accident and emergency department and by instruction of general practitioners, physiotherapists, (sport) physicians and orthopaedic and trauma surgeons. Three types of syndesmotic instability may be recognized: intercalary diastasis (displaced fracture of the fibula and the distal physis of the tibia with intact syndesmotic ligaments and torn interosseous membrane), complete tibiofibular diastasis and anterior tibiofibular diastasis (Kelikian and Kelikian 1985).

Mechanical instability is defined as motion beyond the physiological range of a joint. When patients have instability complaints while an increased range of motion cannot be demonstrated, the condition is defined as functional instability (Peters et al. 1991, Freeman 1965).

The current thesis is focused on chronic mechanical instability of the anterior syndesmosis, which is the chronic type of anterior tibiofibular diastasis. This type of injury is described by Kelikian and Kelikian as an 'open book' type injury resulting from external rotation and posterior translation of the fibula (Kelikian and Kelikian 1985). In the present chapter conclusions from the studies that this thesis comprises are put into recommendations for the diagnosis and treatment of chronic anterior syndesmotic instability, with additions from the current international literature. The treatment of the other types of syndesmotic instability are mentioned briefly.

Medical history and physical examination

Syndesmotic injuries occur less frequently than lateral collateral ligament injuries (Broström 1964). This occurrence may be attributed to the fact that the syndesmotic ligaments are stronger than the lateral collateral ligaments (Beumer et al. 2003b, St Pierre et al. 1983, Sauer et al. 1978). Although syndesmotic injuries usually result from different trauma mechanisms (external rotation, abduction or dorsiflexion) than lateral collateral ligament injuries, inversion injuries are also mentioned (Hopkinson et al. 1990, Karl and Wrazidlo 1987).

Syndesmotic injuries are probably underdiagnosed because clinicians lack familiarity with this type of injury (Gerber et al. 1998) and because displacements at the syndesmosis are usually small (Beumer et al. 2006). Larger displacements may occur during trauma but often reduce spontaneously (Kelikian and Kelikian 1985). The possibility therefore, of a syndesmotic injury should always be considered in the (unusual) severe ankle sprain.

Typical for (isolated) syndesmotic injuries is the 'high ankle sprain', a swelling that is localized above the level of the malleoli (Teitz and Harrington 1998). It is more proximal and more anterior than the swelling seen in lateral ankle sprains (Miller et al. 1995, Boytim et al. 1991, Karl and Wrazidlo 1987, Frick 1978, Kelikian and Kelikian 1985). Patients have tenderness over the anterior syndesmosis, extending proximally over the region of the interosseous membrane (Nussbaum et al. 2001, Dittmer and Huf 1987). Tenderness and/or haematoma over the deltoid ligament may be present, as deltoid ligament injuries are seen in association with syndesmotic injuries (Lauge Hansen 1949).

Four syndesmotic stress tests may be performed. These tests are the fibula translation-, external rotation-, squeeze-, and Cotton test (Ogilvie-Harris et al. 1994, Boytim et al 1991, Hopkinson et al. 1990, Cotton 1910). If positive, these tests elicit pain during sagittal translation of the fibula, external rotation of the ankle, compression of tibia and fibula, and lateral-medial translation of the talus in the mortise respectively (Beumer et al. 2003c, Beumer et al. 2002). During the first days after the injury it is difficult to perform the syndesmotic stress tests because of the patients' discomfort.

Patients with a syndesmotic sprain usually have severe swelling and often a radiograph is made to exclude ankle fracture. If no fracture is seen one must consider to treat the severe ankle sprain as an anterior syndesmotic ligament rupture, unless proven otherwise by MRI because of the significant morbidity of chronic syndesmotic injuries.

As much as 15 - 60 % of the patients with acute syndesmotic injuries that are treated nonoperatively have a protracted period of recovery, with long term complaints such as instability, ankle pain, stiffness and persistent swelling. Also heterotopic ossifications may be found (Grass et al. 2000, Taylor et al. 1992, Frick 1978, Mullins and Sallis 1958). In contrast, most operatively treated patients were found to have complete relief of pain and instability (Fritchy 1989, Hopkinson et al. 1990, Mullins and Sallis 1958).

Patients with chronic anterior instability of the syndesmosis often have very long standing complaints after an ankle injury (Beumer et al. 2005c and 2000, Ogilvie-Harris et al.1994, Boytim et al. 1991, Hopkinson et al. 1990, Katznelson et al. 1983). The same patients have pain in the region of the syndesmosis and also frequently at the medial and/or lateral side of the ankle. Stiffness, recurrent swelling and feelings of instability without frank giving way also should raise a high index of suspicion for this kind of injury, especially in patients with a history of high contact sporting activities (Grass et al. 2000, Taylor et al. 1992, Frick 1978, Mullins and Sallis 1958).

Clinical examination should comprise the standard examination of the ankle and foot to exclude other conditions and to assess if dorsiflexion is limited (Dittmer and Huf 1987, Ward 1994). Limited dorsiflexion is a subtle finding that is often seen in chronic (anterior) syndesmotic instability (Beumer et al. 2000). It is best assessed in the squatting position with the feet flat on the floor. All syndesmotic stress tests except the fibula translation test have been used in the acute and the chronic stage (Ogilvie-Harris et al. 1997, Ogilvie-Harris et al. 1994, Boytim et al 1991. Hopkinson et al. 1990, Mullins and Sallis 1958, Cotton 1910). The external rotation test has the highest sensitivity and the fewest false positive results (Beumer et al. 2002, Grass et al. 2000, Alonso et al. 1998, Frick 1978). The fibula translation test has the most false positive and the truest positive results (Beumer et al. 2002). For chronic anterior syndesmotic instability, the best predictive value is obtained when physical examination (range of motion, stability and pain assessment) and all of the previously mentioned syndesmotic stress tests are combined into one clinical diagnosis regarding the absence or presence of this condition (Beumer et al. 2002). Additionally the anterior drawer test should be performed to assess the lateral collateral ligaments (Cedell 1975).

Additional examinations

To exclude other injuries lateral and anterior posterior (AP) or mortise (according to the examiner's preference) ankle radiographs need to be made. AP or mortise views can be used to assess the deltoid ligament integrity because the medial clear space should not exceed the superior clear space (Beumer et al. 2004) or 4 mm (Nielson et al. 2005, Brage et al. 1997) in any non-weight bearing radiograph of the ankle. In repeated ankle radiography which is often mandatory in clinical practice, quantitative assessment of the tibiofibular clear space and overlap is unreliable and thus of no use (Beumer et al. 2004). However, if tibiofibular overlap is unilaterally absent or if the distance between the floor of the tibial incisure and the medial side of the fibula exceeds 5 mm on standard radiography (film focus distance = 1.05m) a syndesmotic injury should be suspected (Beumer et al. 2004, Pneumaticos et al. 2002).

Radionuclide imaging is of no use in the assessment of syndesmotic instability or acute syndesmotic injuries, but it may show a band like activity over the interosseous ligament and membrane or a focal activity over the syndesmosis in chronic injuries (Frater et al. 2002, Ogilvie-Harris et al. 1997, Marymont et al. 1986).

In experienced hands ultrasound of the anterior tibiofibular ligament and interosseous membrane may clearly display acute ruptures by visualization of the torn ligament ends (Durkee et al. 2003, Milz et al. 1998). It has no reported use in the diagnosis of chronic injuries.

CT scanning has been used for both acute and chronic injuries. With CT increased tibiofibular width can reliably be assessed if this increase is larger than 3 mm (Ebraheim et al. 1997). It is also useful when a (gross) displacement of the fibula can be seen in the coronal or sagittal plane. Due to the 'round' shape of the fibula and the absence of bony landmarks on its surface it is not possible to determine if external rotation of the fibula is present with CT. As yet no absolute guidelines to exclude or confirm acute or chronic syndesmotic injuries have been presented in the literature.

The value of MRI in acute and chronic syndesmotic injuries has been described in several papers (Beumer et al. 2005b, Brown et al. 2004, Takao et al. 2003). In the acute stage complete ruptures of the ligaments may be seen or incomplete ruptures visualized by irregularly increased internal signal intensities in T1- and T2-weigthed sequences, as well as intermediately marked enhancement in the T1- weighted post contrast sequences. (Muhle et al. 1998, Vogl et al. 1997, Schneck et al. 1992). MRI in a 45° lateral-medial caudal-cranial oblique axial plane is useful to assess the continuity of the anterior and posterior tibiofibular ligaments because these ligaments can be visualized in their entire length in this plane (Beumer et al. 2005b, Hermans and Beumer 2002). In acute and chronic syndesmotic injuries it is important to assess the height of the tibiofibular recess because an increased height is an indication for an (old) anterior tibiofibular ligament injury (Uys and Rijke 2002). Furthermore MRI is useful to assess the presence of other injuries such as posterior lip fractures, interosseous membrane ruptures, chondral fractures and synovitis (Nielsen et al. 2004). If no synovial effusion is present (MR) arthrography may be indicated to assess intraarticular lesions (Shakhapur and Grainger 2001, Trattnig et al. 1999, Lee et al.1998).

Arthroscopy is at present the main stay to confirm the diagnosis of anterior instability of the tibiofibular syndesmosis. A typical finding during arthroscopy in the acute stage is increased movement (more than 2 mm) of the fibula with respect to the tibia (Takao et al. 2003, Ogilvie-Harris et al. 1994). In the chronic stage easy access of the test probe into the syndesmotic joint and the possibility to fully rotate the 3 mm long transverse end of the anteriorly inserted probe within the tibiofibular joint are typical findings of anterior syndesmotic instability (Beumer et al. 2005c, 2000). This increased space within the tibiofibular joint probably results from the 'open book' injury. Biomechanical studies have shown that transection of the anterior tibiofibular ligament results in posterior translation and external rotation of the fibula, with an increase in tibiofibular width if the interosseous ligament and/or deltoid ligament are transected or when external rotation stress is applied (Beumer et al 2006, Beumer et al 2003a, Xenos et al. 1995, Close 1956). Arthroscopy is also useful to demonstrate the absence of other intra-articular pathology, such as the triad of findings (torn interosseous and posterior tibiofibular ligament and avulsion fracture of the posterior tibial dome) described by Ogilvie-Harris et al. (1994, 1997). These findings, however, have not been described by other authors.

Treatment for syndesmotic instability

In the acute and subacute stage intercalary diastasis needs reduction of the syndesmosis, followed by immobilization in a below knee plaster for 4 weeks (Kelikian and Kelikian 1985). The need for osteosynthesis is dependent of the result of the reduction, because the tibial fracture is a physeal fracture. Complete tibiofibular diastasis needs reduction of the syndesmosis and placement of a syndesmotic screw. When necessary this may be accompanied by fixation of a ligamentous avulsion (Kelikian and Kelikian 1985). Patients should be advised to have a plaster and to refrain from weight bearing (Beumer et al. 2006 and 2005a).

(Sub) acute isolated anterior tibiofibular instability may be accompanied by deltoid injury (Lauge Hansen 1949). Although Kelikian and Kelikian (1985) advise a long leg cast, one may assume that these patients can be treated with a well fitting below knee cast (Beumer et al. 2006). When MRI has excluded injuries to other structures, such as the interosseous ligament and membrane, the patient may weight bear (Beumer et al. 2005a). If treatment is based on the clinical assessment only without MRI having been performed in the first week after the injury it has been suggested that the patient should not weight bear (Beumer et al. 2006, Muhle et al. 1998, Kelikian and Kelikian 1985, Vogl et al. 1997, Schneck et al. 1992).

Immobilization time for all injuries is (at least) 6 weeks after which unprotected weight bearing and removal of the syndesmotic screw may be planned (Kelikian and Kelikian 1985, Outland 1943).

No reports on treatment possibilities for chronic intercalary diastasis have been published. As a congruent ankle mortise is inherent to this type of diastasis, patients usually do not suffer from instability.

In chronic complete tibiofibular diastasis anatomical reconstruction, plication of a band of fibrous tissue, tenodeses or fibular osteotomies may be performed (Chao et al. 2004, Harper 2001, Beals and Manoli 1998).

In chronic anterior syndesmotic instability the torn anterior tibiofibular ligament of the majority of patients has turned into a slack, but continuous, band of fibrous tissue located at the original position of the ligament. In those patients anatomical surgical reconstruction of the anterior syndesmosis is possible (Beumer et al. 2000). This anatomical reconstruction which is described in this thesis comprises medialization and cranialization of a piece of bone with the tibial attachment of the anterior tibiofibular ligament after a single 3.5 mm syndesmotic set screw has been inserted through 4 cortices during compression of the mortise (Beumer et al. 2000). In the rare case that no remaining tissue of the ATiFL is found other procedures available are several types of tenodeses or ligamentoplasties with other materials such as fascia lata or dura mater (Grass et al. 2003, Mosier-LaClair et al. 2002, Harper 2001, Jäger and Wirth 1995, Podesva 1985, Kelikian and Kelikian 1985). Finally permanent stabilization with a syndesmotic screw or tibiofibular fusion can be performed as a salvage operation (Grath 1960, Mullins and Sallis 1958, Outland 1943).

Postoperative treatment for anatomical reconstruction of the anterior syndesmosis should consist of 6 weeks of non-weight bearing in a below knee plaster. Thereafter, the set screw can be removed and full function can be regained by unlimited exercise (Beumer et al. 2005c, 2000).

Results are good after anatomical reconstruction of the syndesmosis in chronic anterior instability. In general patients have no instability left and are able to resume their former activities (Beumer et al. 2005c, 2000).

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Chapter 15

Summary

The distal tibiofibular syndesmosis is a connection between tibia and fibula that consists of the anterior tibiofibular ligament, the posterior tibiofibular ligament, the transverse ligament and the interosseous ligament. Syndesmotic ligament injuries are most often seen in combination with ankle fractures, but can occur in isolation as well. The term 'isolated syndesmotic injury' is used for the syndesmotic rupture without ankle fracture, although concomitant other injuries may be present. These isolated injuries, which are often accompanied by deltoid ligament injuries, are the subject of this thesis. Presumed trauma mechanisms amongst others include: external rotation, abduction, dorsiflexion and combinations of these. According to the frequently quoted literature syndesmotic ankle sprains comprise between 1-11% of all ankle sprains. However, in people actively involved in high impact or collision sports, the incidence may be higher than 30%. Tibiofibular ligament injuries have a higher morbidity and longer recovery time than the more commonly occurring lateral collateral ligament injuries. They are clinically important because they may lead to chronic instability if they are not recognized or are insufficiently treated.

The studies described in this thesis are all focused on chronic instability of the distal tibiofibular syndesmosis as a clinical entity and comprise biomechanical, clinical, radiological and therapeutic aspects.

Chapter 1 introduces chronic instability of the distal tibiofibular syndesmosis with an overview of the literature on incidence, trauma mechanism, long term complications, medical history, physical examination, diagnostic imaging, arthroscopy and treatment.

Chapter 2 describes the embryology and anatomy of the ankle focusing on the distal tibiofibular joint. The tibiofibular joint is a syndesmosis: a fibrous joint with ample intervening fibrous connective tissue. It consists of four ligaments: the anterior inferior tibiofibular ligament, the posterior inferior tibiofibular ligament, the transverse ligament and the interosseous ligament. The latter is the most distal part of the interosseous membrane.

For normal development of the tibiofibular syndesmosis, the fibula and the subtalar joint complex, superposition of the talus over the calcaneus is essential. When this process fails congenital diastasis of the tibiofibular joint might be seen in combination with deformities such as the clubfoot or split hand-foot complex.

The lower incidence of isolated syndesmotic injuries, relative to lateral ankle sprains, may be attributed to the fact that the trauma mechanisms required to injure the syndesmosis occur less frequently than the inversion mechanism associated with lateral ankle sprains. Other reasons may be the intrinsic stability of the syndesmosis with the fibula secured in the incisura tibialis and greater strength of the tibiofibular ligaments when compared to the lateral ligaments.

Chapter 3 describes a biomechanical study, in which strength, stiffness and mode of failure of the posterior tibiotalar component of the deltoid ligament, and the anterior and posterior tibiofibular ligaments were determined. The posterior tibiofibular ligament was found to be stronger than the anterior tibiofibular and the posterior tibiotalar component of the deltoid ligament, but not significantly so. No significant difference in stiffness was seen between the three ligaments tested. The dominant mode of failure for the anterior tibiofibular ligament was ligament substance failure, primarily near its fibular insertion, where as the failure mode of the posterior tibiofibular ligament was evenly split between substance failures and fibular avulsions. The tibiotalar ligament failed most often through its substance near the talar insertion. The tibiofibular ligaments showed greater strength than the lateral collateral and deltoid ligaments, as mentioned in literature.

These findings support the hypothesis that the strength of the tibiofibular ligaments is one of the reasons for the lower incidence of isolated syndesmotic injuries relative to lateral ankle sprains.

Regardless of whether the low incidence rate of syndesmotic sprains is related to greater tibiofibular ligament strength, the trauma mechanism needed to injure the syndesmosis occurring less frequently, or other factors, it can be stated that the tibiofibular ligaments play an important role in stabilizing the ankle. It may be assumed that such ligaments probably need treatment once they are injured, and give rise to complaint if not treated properly.

Before further studies on biomechanics and clinical aspects of isolated syndesmotic injuries can be performed, it is necessary to know what an intact syndesmosis looks like. Diagnostic imaging of the syndesmosis in clinical practice often relies on a number of parameters measured on anterior-posterior and mortise radiographs of the ankle. Two parameters are most frequently used; the tibiofibular clear space (TFCS) and the tibiofibular overlap (TFO). The tibiofibular clear space is described as either the distance between the posterolateral border, the anterolateral border or the incisura fibularis of the tibia, and the medial border of the fibula. The tibiofibular overlap is defined as the horizontal distance between the medial border of the fibula and the lateral border of the anterior tibial tubercle. The tibiofibular clear space and overlap are measured on a line 1 cm proximal and parallel to the tibiotalar joint space. For both parameters discrimination between the anterior and posterior distal tibial tubercles is necessary, as these are the boundaries of the clear space and overlap. Because the existing literature is inconsistent about the appearance of the distal tibial tubercles on radiographs, a study of the projection of these tubercles was performed.

Chapter 4 describes a cadaveric study on the appearance of the distal tibial tubercles on ankle radiographs in different positions of rotation. The anterior tubercle has an angular shape with its maximum dimension at approximately 1 cm above the joint line. The posterior tubercle is a rounded structure in continuity with the posterior lip of the tibia, projecting caudally from the anterior tubercle and superimposed on the talus. In every position of rotation the distal tibial tubercles can be identified based on their distinctive features. Ankle rotation can be assessed by studying the projections of these tubercles and the talocrural joint spaces.

It was shown, that the tibiofibular clear space (TFCS) and tibiofibular overlap (TFO) differ considerably with rotation and that neither depicts a constant syndesmotic interval. To increase uniformity TFCS and TFO should, if measured, preferably be assessed on an anterior-posterior radiograph. They should be measured as the distance between the medial side of the fibula and the floor of the incisura fibularis (TFCS), and as the distance between the medial side of the fibula and the anterior tubercle (TFO).

Although radiography is frequently used to assess syndesmotic integrity and specific parameters are often used, no consensus exists as to how syndesmotic integrity should be defined. One reason for this is that reliability of syndesmotic parameters in repeated ankle radiography has not been studied. Once the appearance of the tibial tubercles had been described, the reliability of those parameters in repeated ankle radiography for syndesmotic integrity could be assessed.

Chapter 5 describes a study that used the radiographic image of plastinated human cadaveric lower legs in twelve positions of rotation to assess the effect of positioning of the ankle on specific radiologic parameters in order to find the optimal parameter for reliable assessment of syndesmotic and ankle integrity. It was found that some tibiofibular overlap was present in all radiographs in any position of rotation. Furthermore, the distance between the medial side of the fibula and the incisure of the tibia was always equal to or smaller than 5 mm. Finally, the medial clear space was smaller than or equal to the superior clear space in all radiographs. Intra-class correlation coefficients of the frequently used radiographic parameters around the fibulotalar and tibiofibular joint space were found to be too weak for reliable quantitative measurements. This resulted from the impossibility to perform reproducible ankle positioning even in optimal laboratory circumstances.

It was concluded that no optimal radiographic parameter exists to assess syndesmotic integrity. Tibiofibular overlap and medial and superior clear space are the most useful in the assessment, because one-sided traumatic absence of tibiofibular overlap may be an indication of syndesmotic injury and a medial clear space larger than a superior clear space is indicative of deltoid injury. Quantitative measurement of syndesmotic parameters, with exception of the distance between the medial side of the fibula and the incisure of the tibia, is of little value in repeated radiography because it cannot be done reliably.

As plain ankle radiography was shown to be of limited use to assess syndesmotic integrity, a more sensitive examination was tried. Radiostereometry (RSA) was used to assess the normal kinematics of the distal tibiofibular syndesmosis as well as the kinematics after sectioning of the syndesmotic ligaments.

Chapter 6 describes the kinematics of the distal tibiofibular syndesmosis assessed with radiostereometry in cadaveric specimens, before and after transection of its ligaments. To assess which of the known trauma-mechanisms would create the largest displacements at the syndesmosis, the ankle was brought in the following positions: dorsiflexion, external rotation, abduction and a combination of external rotation and abduction. Furthermore, an axial load of 750N, comparable to bodyweight, was applied.

It was found that the largest displacements of the fibula in the neutral situation consisted of external rotation and posterior translation. Loading the ankle with 750 N did not evidently increase or decrease the displacements of the fibula, but gave a larger variety in displacements.

In every position section of a ligament resulted in some fibular displacement when compared to the intact situation. Sectioning of the anterior tibiofibular ligament resulted invariably in external rotation of the fibula and also in mechanical instability of the syndesmosis. Of all trauma-mechanisms external rotation of the ankle resulted in the largest and most consistent displacements found at the syndesmosis.

With the knowledge of syndesmotic kinematics obtained, the value of a standardized external rotation stress test as a non-invasive imaging procedure to diagnose syndesmotic instability could then be studied with standard lateral ankle radiography versus RSA. External rotation stress imaging was chosen because the study in Chapter 6 had shown that the largest displacements in the syndesmosis after transection of its ligaments occurred during external rotation. This phenomenon had previously been reported, using techniques other than RSA

Chapter 7 describes the value of 7.5 Nm external rotation stress in diagnosing tibiofibular syndesmotic injuries of the ankle on lateral radiographs with radiostereometry (RSA) in 10 cadaveric legs, after sequential and alternating sectioning of the tibiofibular ligaments and the anterior part of the deltoid ligament. After sectioning the anterior tibiofibular ligament RSA showed external rotation of the fibula and after sectioning the anterior tibiofibular ligament and the posterior tibiofibular ligament an increase in posterior translation of the fibula. This increase in posterior translation was smaller than the posterior displacement of the fibula seen on the lateral radiograph. The increase in external rotation of the fibula that RSA showed could not be measured on conventional radiographs. We conclude that instability of the syndesmosis in cadaveric ankles can be detected with 7.5 Nm external rotation stress RSA. In the acute situation this examination can probably determine instability of the distal tibiofibular syndesmosis as well, when compared to the other side. However, this is an invasive procedure which is not suitable for clinical practice. Unfortunately, conventional external rotation stress lateral radiography is unreliable.

It can be assumed that the kinematics of the syndesmosis will be altered after injury of its ligaments. Normal kinematics of the distal tibiofibular syndesmosis during weight bearing compared to non-weight bearing and during the 7.5 Nm external rotation stress examination described in Chapter 7 have not been described in the literature. To obtain such data, these examinations were assessed in asymptomatic volunteers with RSA.

Chapter 8 describes a study of the tibiofibular kinematics in eleven asymptomatic volunteers using RSA. The normal values for weight bearing that were found in this study were very diverse. Only small rotations and translations were found at the syndesmosis. This expresses the close connection between fibula and tibia and reflects the intrinsically stable construction of the syndesmosis.

In the same volunteers a 7.5 Nm external rotation stress applied at the foot resulted in external rotation of the fibula between 2 and 5 degrees, medial translation between 0 and 2.5 mm and posterior displacement between 1 and 3.1 mm. These data may be used as reference data to study patients with suspected syndesmotic injuries.

To diagnose syndesmotic instability four different clinical tests have been described in the literature. One is the squeeze-test which generates pain at the syndesmosis when the fibula is squeezed towards the tibia at the midpoint of the calf. Another is the Cotton-test which assesses increased medial-lateral translation of the talus by stabilizing the distal tibia and applying a medial-lateral force to the foot. The fibula translation-test creates pain with or without increased movement during anteroposterior translation of the fibula. The final test reported is the external rotation-test, which is positive if an external rotation stress is applied to the involved foot and ankle, and produces pain over the anterior and/or posterior syndesmosis. With the exception of the squeeze test the biomechanics of these tests are unknown.

Chapter 9 describes a biomechanical evaluation of the syndesmotic stress tests in a cadaveric study. Displacement transducers were placed across the anterior and posterior tibiofibular ligaments. The displacements were induced by four clinical tests. They were measured with the ankle ligaments intact and after sequential sectioning of the anterior tibiofibular ligament, anterior deltoid ligament, and posterior tibiofibular ligament.

The external rotation test showed significant displacement at the anterior syndesmosis after the anterior tibiofibular ligament, with or without the anterior deltoid ligament had been sectioned. All syndesmotic stress tests showed significant displacement at the anterior syndesmosis, after all three ligaments had been sectioned. Displacement at the posterior syndesmosis was significant only for the fibular translation test after sectioning all ligaments and for the external rotation test after sectioning the anterior tibiofibular and anterior deltoid ligaments as well as after sectioning of all ligaments. None of the syndesmotic stress tests could distinguish which ligaments were sectioned.

With the exception of the external rotation test, the displacements measured during the stress tests were small and generally within the physiologic range. This suggests it is unlikely that the displacement induced in injured syndesmoses can be clinically differentiated from normal syndesmoses. Therefore, pain, rather than increased displacement, should be considered the outcome measure of these tests.

In view of the findings of Chapter 9 a clinical study concerning the clinical value of the syndesmotic stress tests was performed in volunteers and patients.

Chapter 10 describes the feasibility of four clinical tests in the diagnosis of syndesmotic injury of the ankle. Nine investigators examined both ankles of twelve subjects twice, while they were sitting behind a curtain which exposed only the ankles to be tested. Among the twelve volunteers were two patients with an arthroscopically confirmed unilateral chronic anterior syndesmotic injury. The investigators assessed pain and range of motion, and performed the four syndesmotic tests. Based on these findings they made a final physical diagnosis regarding the presence or absence of syndesmotic injury.

There was a significant relation between chronic anterior syndesmotic instability assessed arthroscopically and a positive squeeze-test, fibula translation-test, Cotton test and external rotation-test as well as reduced dorsiflexion. However, none of the tests was uniformly positive in the patients with a syndesmotic injury. The external rotation test had the fewest false-positive results, the fibula translation test the most. The external rotation test had the smallest inter-observer variance. The physical diagnosis was missed in one fifth of all examinations. Based on this study it was concluded that these clinical tests in combination with medical history and physical examination should raise a high index of suspicion for a syndesmotic injury. The final diagnosis of a chronic anterior syndesmotic instability should therefore be made by further diagnostics, such as radiological imaging or arthroscopy as no sufficiently reliable clinical test is currently available.

When chronic instability of the syndesmosis is present, treatment is justified depending on the patient's complaints. Several procedures to reconstruct the anterior tibiofibular ligament are described in the literature, using for example the extensor digitorum tendon, the plantaris tendon or a fascia lata strip. In analogy with reconstruction of the lateral collateral ligaments for lateral ankle instability, it may be assumed that an anatomical repair using the original tibiofibular ligament would result in more normal biomechanics than the tenodeses. Such an anatomical surgical technique has been developed at the orthopaedic department of the Erasmus University Medical Center Rotterdam and has been used since 1995.

Chapter 11 presents a description of the operative technique of the anatomical reconstruction of the anterior syndesmosis, and a retrospective study of the results. The operation involved mobilization of a piece of bone with the tibial insertion of the anterior tibiofibular ligament, which was then advanced in a medial and proximal direction and fixed with a small screw after the ankle mortise was compressed and secured with a syndesmotic setscrew. Postoperative treatment consisted of six weeks of non weight bearing in a below-knee plaster, after which the syndesmotic setscrew was removed and full weight bearing was begun. After a follow-up of a mean of 45 (38-62) months all 9 patients considered their ankle function and stability to be improved, as was reflected in various ankle scores. None of the patients had any complaints of remaining instability.

As patients after osteosynthesis of ankle fractures or ligamentous reconstruction of the syndesmosis may benefit from early mobilization and rehabilitation, the question arises if weight bearing with a syndesmosis set screw in situ could be justified. In a cadaveric study syndesmotic screw fixation capacity for stainless steel and titanium screws through 3 or 4 cortices was tested.

Chapter 12 presents a cadaveric study in which sixteen fresh frozen legs with artificial syndesmotic injuries were axially loaded during a cyclic testing procedure (800 N, 225.000 cycles). The 225.000 cycles equals the number of paces taken by a person walking in a below knee plaster during 9 weeks. The artificial syndesmotic injuries consisted of transection of the anterior and posterior tibiofibular ligaments, the interosseous ligament, the distal 10 cm of the interosseous membrane and the anterior part of the deltoid ligament. Four groups of four legs were tested. A 3.5 mm syndesmotic setscrew made of stainless steel or titanium was inserted through three or four cortices. Two specimens could not be tested for the full 225.000 cycles because of collapse of the foot skeleton during the test. None of the fourteen out of sixteen successfully tested legs or screws failed.

No statistically significant difference was found between the groups with fixation of the syndesmosis with stainless steel screws when compared to titanium screws through three or four cortices.

Mean lateral displacement found after testing was 1.05 mm (SD = 0.42). This increase in tibiofibular width exceeds values described in the literature and in chapter 6 and 8 for the intact syndesmosis loaded with body weight.

This study shows that the syndesmotic set screw cannot prevent excessive syndesmotic widening when a completely dissected syndesmosis is loaded with a load equal to body weight. The results of the study provide evidence that patients with a syndesmotic set screw should be advised not to weight-bear to ascertain healing of the syndesmotic ligaments with the proper length. As a screw through four cortices can be extracted more easily, if broken, than a screw through three cortices, and fixation is equal, the former may be preferable.

Finally the syndesmotic kinematics after anatomical surgical reconstruction of the anterior syndesmosis were assessed in a prospective clinical and RSA study regarding the diagnosis and treatment of chronic syndesmotic instability.

Chapter 13 describes clinical findings and tibiofibular kinematics evaluated by radiostereometry in a prospective study of 5 patients. Data were acquired before and after anatomical surgical reconstruction of a chronic anterior syndesmotic injury.

In patients the kinematics of the fibula relative to the tibia during external rotation stress differed from that known in the asymptomatic volunteers described in chapter 8, but the differences were not typical enough to differentiate between patients and healthy subjects. No statistically significant differences in tibiofibular kinematics before and after reconstruction were found. It is concluded that RSA is not an adequate technique to diagnose chronic anterior syndesmotic instability or to demonstrate restoration of the kinematics of the ankle as cause of the beneficial effect of anatomical reconstruction of the syndesmosis in an outpatient setting.

This study shows that anatomical reconstruction of the anterior syndesmosis restores ankles function and relieves complaints of instability.

Chapter 14 describes the clinical relevance, as well as recommendations for recognition, examination and treatment of syndesmotic injuries.

In this thesis biomechanical, clinical, radiological and therapeutic aspects of chronic instability of the anterior part of the distal tibiofibular syndesmosis, as well as a surgical procedure to treat this condition were described.

The retrospective study described in chapter 11 and the prospective study described in chapter 13 clearly show that patients with chronic anterior syndesmotic instability benefit from anatomical surgical reconstruction of the anterior syndesmosis.

Chapter 16

Samenvatting

De distale tibiofibulaire syndesmose is een verbinding tussen tibia en fibula ter hoogte van de enkel. De syndesmose bestaat uit het anterieure tibiofibulaire ligament, het posterieure tibiofibulaire ligament, het ligamentum transversum en het ligamentum interosseum. Letsels van de syndesmose komen meestal voor in combinatie met fracturen van de enkel, maar soms ook geïsoleerd. De term 'geïsoleerd syndesmose letsel' wordt gebruikt voor de letsels zonder bijkomende enkel fractuur, hoewel ander letsel aanwezig kan zijn. Deze geïsoleerde letsels, die vaak begeleid worden door een letsel van het ligamentum deltoïdeum, zijn het onderwerp van dit proefschrift.

Veronderstelde traumamechanismen zijn onder andere exorotatie, abductie, dorsiflexie en combinaties hiervan. Volgens recent gepubliceerde literatuur komen syndesmose letsels voor in 1 tot 11% van alle enkeldistorsies. Bij personen die actief betrokken zijn in high-impact sport of sport met veel fysiek contact kan het echter wel meer dan 30% van alle letsels betreffen.

Letsels van de tibiofibulaire ligamenten hebben een langere herstelperiode vergeleken met laterale enkelbandletsels. Deze syndesmoseletsels zijn klinisch van belang omdat ze chronische instabiliteit ten gevolge kunnen hebben, als ze niet herkend of onvoldoende behandeld worden.

De in dit proefschrift beschreven studies zijn gericht op chronische instabiliteit van de distale tibiofibulaire syndesmose als een klinische entiteit en zij behandelen de biomechanische, klinische, radiologische en therapeutische aspecten.

Hoofdstuk 1 geeft een inleiding over chronische instabiliteit van de distale tibiofibulaire syndesmose met een literatuuroverzicht betreffende incidentie, traumamechanisme, lange termijn problemen, anamnese, lichamelijk onderzoek, aanvullend diagnostisch onderzoek, arthroscopie en behandelingswijzen.

Hoofdstuk 2 beschrijft de ontwikkeling en anatomie van de enkel met de nadruk op het distale tibiofibulaire gewricht. Dit tibiofibulaire gewricht is een syndesmose: een fibreus gewricht met veel bindweefsel. Het omvat vier ligamenten: het anterieure inferieure tibiofibulaire ligament, het posterieure inferieure tibiofibulaire ligament, het transverse ligament en het interosseous ligament, hetgeen het meest distale deel van de membrana interossea is.

De onderste extremiteit verschijnt in de vierde week van de ontwikkeling. In de vijfde week is deze zo ver ontwikkeld dat de benen en voeten zichtbaar zijn. Voor de normale ontwikkeling van de distale tibiofibulaire syndesmose en het subtalaire gewricht is superpositie van de talus boven de calcaneus noodzakelijk. Als dit niet goed verloopt wordt soms een aangeboren wijde syndesmose gevonden, die geassocieerd is met klompvoeten en het gespleten hand-voet complex.

De lagere incidentie van geïsoleerde syndesmoseletsels vergeleken met laterale enkelbandletsels, kan wellicht toegeschreven worden aan het feit dat de veronderstelde traumamechanismen minder vaak voorkomen dan het inversiemechanisme dat behoort bij de laterale enkeldistorsie, alsmede aan het feit dat de syndesmose een intrinsieke stabiliteit kent doordat de fibula is gelegen in de incisura tibialis. Daarnaast zou het feit dat de tibiofibulaire ligamenten sterker zijn dan de laterale collaterale enkel ligamenten bij kunnen dragen aan het minder vaak voorkomen van geïsoleerde syndesmose letsels.

Hoofdstuk 3 beschrijft een biomechanische studie waarin de sterkte, stijfheid en het faalmechanisme van het posterieure tibiotalaire deel van het ligamentum deltoideum en de anterieure en posterieure tibiofibulaire ligamenten werden bepaald. Het posterieure tibiofibulaire ligament bleek sterker dan het anterieure tibiofibulaire ligament en dan het posterieure tibiotalaire deel van het ligamentum deltoïdeum. Echter, dit verschil was statistisch niet significant. In dit onderzoek werden evenmin significante verschillen in stijfheid tussen de drie geteste ligamenten gezien. De meest voorkomende plaats van falen was intraligamentair voor het voorste tibiofibulaire ligament, meestal nabij de fibulaire insertie. Bij het posterieure tibiofibulaire ligament kwamen avulsies van de fibula even vaak voor als intraligamentair falen. Het tibiotalaire deel van het ligamentum deltoideum faalde met name intraligamentair ter plaatse van de talaire insertie.

Wanneer deze gegevens vergeleken worden met de literatuur over laterale enkelligamenten blijkt dat de benodigde gemiddelde kracht voor falen van het posterieure tibiotalaire deel van het ligamentum deltoideum en de anterieure en posterieure tibiofibulaire ligamenten groter was dan de gevonden waarden voor de laterale enkelligamenten.

De bevindingen uit hoofdstuk 3 ondersteunen de hypothese dat de sterkte van de syndesmose ligamenten bijdraagt aan het minder vaak voorkomen van geïsoleerde syndesmose letsels dan laterale enkeldistorsies. Ongeacht of de lage incidentie een gevolg is van de grotere sterkte van de ligamenten, het zeldzamer traumamechanisme of van andere factoren kan gesteld worden dat de ligamenten van de syndesmose een belangrijke rol spelen in de stabiliteit van de enkel en dus naar alle waarschijnlijkheid behandeling behoeven na letsel.

Voordat verdere studies betreffende de biomechanica en kliniek van syndesmoseletsels uitgevoerd kunnen worden, is het van belang de afbeelding van de intacte syndesmose te kennen. Het radiologisch vaststellen van een syndesmoseletsel gebeurt doorgaans aan de hand van een aantal parameters welke op voorachterwaartse en vorkfoto's van de enkel gemeten worden. Twee parameters worden geregeld gebruikt. De eerste is de tibiofibulaire 'clear space' (TFCS). Deze wordt beschreven als de afstand tussen de posterolaterale tibia cortex, de anterolaterale tibia cortex of de incisura fibularis en de mediale cortex van de fibula. De tweede is de tibiofibulaire overlap (TFO). Hierbij wordt de horizontale afstand tussen de mediale fibula cortex en de laterale begrenzing van de anterieure tibia tuberkel gemeten. De tibiofibulaire 'clear space' en 'overlap' worden op een lijn 1 cm boven en parallel aan de tibiotalaire gewrichtsspleet gemeten. Voor beide parameters is het noodzakelijk dat een onderscheid gemaakt wordt tussen de voorste en achterste tuberkel van de tibia. Omdat in de literatuur een verwarrend gebrek aan consensus bestaat over de verschijningsvorm van deze tuberkels, werden deze tuberkels in een radiologische studie bestudeerd.

Hoofdstuk 4 beschrijft de verschijningsvormen van de distale tibia tuberkels op enkelfoto's in verschillende posities van rotatie. De anterieure tuberkel had een hoekige vorm met een maximale afmeting op ongeveer 1 cm boven het talocrurale gewrichtsoppervlak. De posterieure tuberkel was ronder van vorm en meer caudaal gelegen van de anterieure tuberkel. De posterieure tuberkel beeldde zich af in continuïteit met de posterieure malleolus en projecteerde zich naar caudaal over de talus. Het bleek dat de tuberkels duidelijk van elkaar onderscheiden konden worden, en dat men de rotatie van de enkel kon beoordelen aan de hand van de projectie van deze tuberkels en van verschillende aspecten van het talocrurale gewricht. Verder werd duidelijk dat TFCS en TFO veranderen met rotatie en dat geen van beide een constant interval van de syndesmose weergeeft. Voor het verkrijgen van uniformiteit verdient het aanbeveling om de tibiofibulaire clear space en overlap, indien gemeten, te bepalen op een voorachterwaartse enkelfoto als de afstand tussen de mediale fibula cortex (tibiofibulaire clear space) en de incisura fibularis of de voorste tuberkel (tibiofibulaire overlap).

Hoewel radiologie vaak gebruikt wordt om letsels van de syndesmose vast te stellen en een aantal parameters hierbij vaak gebruikt wordt, bestaat er geen *consensus hoe integriteit van de syndesmose met deze parameters vastgesteld zou moeten worden. Een oorzaak hiervan is het ontbreken van een studie naar de betrouwbaarheid van de syndesmose parameters bij herhaling van enke foto's. Nadat de projectie van de tuberkels van de tibia precies bekend was, kon vervolgens de betrouwbaarheid van deze parameters bij herhaalde enkelfoto's bepaald worden.*

Hoofdstuk 5 beschrijft een studie aangaande de radiografische projectie van geplastineerde humane kadaveronderbenen in twaalf rotatieposities. Het doel was de optimale parameter voor betrouwbare beoordeling van de integriteit van de enkel en de syndesmose te vinden, alsook om het effect van het positioneren van de enkel op deze parameter te bestuderen. Op alle foto's was de afstand tussen de mediale zijde van de fibula en het diepste punt van de incisuur kleiner dan of gelijk aan 5 mm (film focus afstand 1.05m). Tevens was op alle foto's sprake van tibiofibulaire overlap. Tenslotte werd gevonden dat de 'medial tibiotalar clear space', in elke positie van rotatie, kleiner dan of gelijk aan de 'superior tibiotalar clear space was'. De berekende intraclass correlatiecoëfficiënten voor de voorheen gebruikelijke radiologische parameters bleken te zwak voor het betrouwbaar meten van herhaalde enkelfoto's. Dit was onder andere een gevolg van de onmogelijkheid de enkels, zelfs in deze optimale laboratoriumomstandigheden, reproduceerbaar te positioneren.

Geconcludeerd kan worden dat er geen parameter bestaat om de integriteit van de syndesmose met zekerheid vast te stellen. Het bepalen van de tibiofibulaire overlap en de medial and superior tibiotalar clear space bleek het meest zinvol omdat eenzijdig post-traumatisch ontbreken van tibiofibulaire overlap een indicatie voor een syndesmoseletsel is. Een medial clear space die groter is dan de superior clear space maakt een letsel van het ligamentum deltoïdeum erg waarschijnlijk. Met uitzondering van het meten van de afstand tussen de mediale zijde van de fibula en het diepste punt van de incisuur zijn verdere quantitative metingen van alle syndesmose parameters bij herhaalde enkelfoto's niet betrouwbaar en hebben dus weinig waarde.

Nadat aangetoond werd dat gewone enkelfoto's weinig nut hebben voor het aantonen van een syndesmoseletsel werd een gevoeliger meetmethode, namelijk radiostereometrie (RSA), gebruikt om de normale kinematica van de syndesmose vast te leggen, alsmede die na een kunstmatig letsel van de syndesmose.

Hoofdstuk 6 beschrijft een kadaveronderzoek waarin de kinematica van de tibiofibulaire syndesmose voor en transectie van de ligamenten vastgelegd met radiostereometrie. Om de kinematica van de syndesmose tijdens belasten te beschrijven, werd de enkel in posities gebracht die verondersteld worden letsels van de tibiofibulaire ligamenten te bewerkstelligen. Deze posities waren dorsiflexie, exorotatie en abductie alsmede een combinatie van deze laatste twee. Tevens werd een axiale belasting van 750 N aangebracht, vergelijkbaar met lichaamsgewicht.

De grootste bewegingen van de fibula in de neutrale situatie waren exorotatie en posterieure translatie. Het aanbrengen van 750 N belasting maakte de uitslagen niet veel groter of kleiner, maar wel meer divers. In elke positie resulteerde doorsnijding van een ligament in enige verplaatsing van de fibula vergeleken met de intacte situatie. Doorsnijding van het anterieure tibiofibulaire ligament resulteerde steeds in exorotatie van de fibula alsmede in mechanische instabiliteit van de syndesmose. Van alle traumamechanismen gaf exorotatie de grootste en meest consistente verplaatsing in de syndesmose.

Met de kennis betreffende de kinematica van de syndesmose werd de waarde van een gestandaardiseerde exorotatie-stress test als niet-invasief onderzoek voor de diagnose van syndesmoseletsels getest met behulp van gewone radiografie en radiostereometrie. Voor een exorotatie onderzoek werd gekozen omdat in hoofdstuk 6 werd beschreven dat de grootste verplaatsing ter plaatse van de syndesmose het gevolg was van exorotatie, hetgeen voorheen ook door anderen met andere technieken dan radiostereometrie was vastgesteld.

Hoofdstuk 7 beschrijft de waarde van een 7.5 Nm exorotatie-stress laterale enkelfoto vergeleken met 7.5 Nm exorotatie-stress radiostereometrie na achtereenvolgend en alternerend doornemen van de anterieure en posterieure tibiofibulaire ligamenten en het voorste deel van het ligamentum deltoïdeum. Uit deze studie bleek dat de fibula na het doornemen van het anterieure tibiofibulaire ligament een toegenomen exorotatie liet zien en na doornemen de anterieure en posterieure tibiofibulaire ligamenten een toegenomen posterieure translatie die met radiostereometrie konden worden vastgelegd. De toegenomen posterieure translatie van de fibula na doornemen van bovengenoemde ligamenten was op de laterale enkelfoto niet gelijk aan de met radiostereometrie gemeten waarde. Uiteraard kon de exorotatie van de fibula niet op de laterale foto gezien worden. Hieruit blijkt dat conventionele laterale exorotatie-stress radiografie niet zinvol is voor het vastleggen van syndesmoseletsels. Instabiliteit van de distale tibiofibulaire syndesmose kan vastgelegd worden in kadaver enkels met het 7.5 Nm exorotatie-stress radiostereometrie onderzoek. In de acute situatie kan dit onderzoek waarschijnlijk instabiliteit van de voorste syndesmose aantonen wanneer vergeleken wordt met de niet aangedane zijde. RSA is echter een invasief onderzoek en derhalve niet geschikt voor de dagelijkse praktijk.

Men mag verwachten dat de kinematica tijdens belasten verandert wanneer de syndesmose beschadigd is. Echter, de normale kinematica van de distale tibiofibulaire syndesmose, tijdens belasting van de enkel en in vergelijking met de onbelaste situatie, is nooit met radiostereometrie beschreven bij gezonde vrijwilligers. Ter verkrijging van normaal waarden werd een dergelijk onderzoek verricht. Tevens werd bij deze personen de beweging in de intacte syndesmose met behulp van het in hoofdstuk 7 beschreven exorotatie-stress onderzoek vastgelegd.

Hoofdstuk 8 beschrijft de studie waarin de tibiofibulaire kinematica van de syndesmose bij elf gezonde vrijwilligers werd vastgelegd met behulp van radiostereometrie. In deze studie werden ver uiteenlopende normaalwaarden gevonden tijdens het belasten. Slechts erg kleine rotaties en translaties traden op rondom de syndesmose, hetgeen de stijfheid van de verbinding tussen fibula en tibia weerspiegelt. Bij dezelfde vrijwilligers gaf 7.5 Nm exorotatiestress een exorotatie van de fibula tussen de 2 en 5 graden en een mediale translatie van de fibula tussen de 0 en 2.5 mm, alsmede een posterieure verplaatsing van de fibula tussen de 1.0 en de 3.1 mm. Deze gegevens kunnen beschouwd worden als normaalwaarden, waarmee patiënten met mogelijke syndesmoseletsels vergeleken kunnen worden.

Om instabiliteit van de syndesmose vast te stellen zijn 4 verschillende klinische testen beschreven. De squeeze-test, waarbij halverwege het onderbeen de fibula naar de tibia geduwd wordt. Deze test geeft bij een syndesmoseletsel pijn ter plaatse van de syndesmose. De Cotton test, welke wordt uitgevoerd door de distale tibia te stabiliseren en de talus van lateraal naar mediaal in de enkelvork te transleren. De fibula translatietest, die pijn tijdens een voorachterwaartse beweging van de fibula registreert. En tenslotte de exorotatietest, die positief is wanneer exorotatie van enkel en voet pijn over de voorste en eventueel achterste syndesmose geeft. Van deze testen werd tot op heden alleen de biomechanica van de squeezetest in een kadavermodel getest, zodat verder onderzoek op dit gebied noodzakelijk was.

Hoofdstuk 9 beschrijft een biomechanische evaluatie van vier klinische syndesmose stresstesten in een kadaveronderzoek. In deze studie werden verplaatsingstransducers aangebracht over de voorste en achterste tibiofibulaire ligamenten. In de intacte situatie en na sequentieel doorsnijden van de ligamenten werden de bewegingen van de fibula ten opzichte van de tibia tijdens deze syndesmose testen gemeten.

De exorotatietest resulteerde in een significante verplaatsing ter hoogte van de voorste syndesmose wanneer het anterieure tibiofibulaire ligament met of zonder het voorste deel van het ligamentum deltoïdeum was doorsneden. Nadat deze drie de ligamenten waren doorgenomen, lieten alle syndesmose stresstesten een significante beweging ter plaatse van de voorste syndesmose zien. Verplaatsingen rondom de achterste syndesmose waren alleen significant voor de fibula translatie test nadat alle ligamenten waren doorgenomen. Verplaatsingen rondom de achterste syndesmose waren alleen significant voor de exorotatie-test na doornemen van het anterieure tibiofibulaire ligament and het anterieure deel van het ligamentum deltoideum en nadat alle ligamenten waren doorgenomen. Geen der testen kon determineren welk ligament doorsneden was. Met uitzondering van de exorotatie-test, vielen de verplaatsingen, die gemeten werden tijdens de syndesmose stresstesten na doornemen van de ligamenten, in het algemeen binnen de normale fysiologische spreiding. Er kan dus verondersteld worden dat letsels van de syndesmose niet accuraat vastgesteld kunnen worden door middel van toegenomen verplaatsing van de fibula tijdens deze testen. Identificatie van een patiënt met een chronisch syndesmoseletsel met behulp van deze testen is slechts mogelijk wanneer de patiënt pijn aangeeft.

Gezien de bevindingen van hoofdstuk 9 werd vervolgens het nut van de genoemde testen bij vrijwilligers en patiënten die vermoed werden een chronisch syndesmose letsel te hebben bestudeerd.

Hoofdstuk 10 beschrijft de studie waarin de toepasbaarheid van de klinische testen voor syndesmoseletsels werd onderzocht. Negen onderzoekers beoordeelden tweemaal beide enkels van twaalf personen. Deze personen waren gezeten achter een gordijn, waardoor alleen de enkels zichtbaar waren. Onder de twaalf vrijwilligers waren twee patiënten met een arthroscopisch bevestigd unilateraal voorste syndesmoseletsel. De onderzoekers legden de beweging van de enkel en eventuele pijn vast, daarnaast voerden ze de vier eerder beschreven syndesmose testen uit. Op grond van het geheel van bevindingen gaven ze een klinische diagnose met betrekking tot de aanwezigheid of afwezigheid van een voorste syndesmoseletsel. Er werd een significante relatie gevonden tussen de definitieve arthroscopische diagnose van voorste instabiliteit van de syndesmose en een positieve squeezetest, fibula translatie test, Cotton test en exorotatietest. Dezelfde relatie werd gevonden met beperkte dorsiflexie. Geen van de genoemde testen was uitsluitend positief in geval van een voorste syndesmoseletsel. De exorotatietest liet de kleinste inter-observer variatie zien. De exorotatietest test gaf tevens het kleinste aantal vals-positieve waarnemingen, de fibula translatie test het grootste aantal vals-positieve waarnemingen. In een vijfde van alle onderzoeken werd de diagnose chronisch voorste syndesmoseletsel gemist.

Op basis van deze studie wordt geconcludeerd dat de combinatie van anamnese en lichamelijk onderzoek met positieve syndesmosetesten een hoge verdenking op een syndesmoseletsel geeft, maar dat voor de uiteindelijke diagnose aanvullend (radiologisch) onderzoek of een arthroscopie nodig zijn, aangezien er geen volledig betrouwbare klinische test beschikbaar is.

Indien chronische instabiliteit van de voorste syndesmose waarschijnlijk is gemaakt, dan is afhankelijk van de klachten van de patiënt behandeling gerechtvaardigd. In de literatuur zijn verschillende procedures beschreven om het anterieure tibiofibulaire ligament te herstellen, onder andere tenodesen met gebruik van bijvoorbeeld de extensor digitorumpees, de plantarispees of een reep fascia lata. Naar analogie van reconstructies van het laterale bandcomplex voor enkelinstabiliteit kan men veronderstellen dat een anatomische reconstructie met gebruik van het originele tibiofibulaire ligament beter de kinematica zal normaliseren dan de hiervoor genoemde tenodesen. Een dergelijke techniek werd op de afdeling orthopaedie van het Erasmus Universiteit Medisch Centrum ontwikkeld en is in gebruik sinds 1995.

Hoofdstuk 11 beschrijft de operatie techniek van deze anatomische reconstructie en de resultaten hiervan in een retrospectief onderzoek. De operatie omvat het mobiliseren van een botblokje met de tibiale insertie van het anterieure tibiofibulaire ligament. Dit botblokje wordt in een mediale en craniale richting verplaatst en vastgezet met een schroefje, nadat de enkelvork gecomprimeerd en gefixeerd is met een syndesmose stelschroef. De postoperatieve behandeling bestaat uit zes weken onbelast mobiliseren met een onderbeensgips waarna de syndesmose stelschroef verwijderd werd en de patiënt volledig mag belasten. Na een gemiddelde follow-up van 45 (38-62) maanden, bleek bij alle patiënten de enkel te zijn verbeterd. Geen der patiënten had instabiliteitsklachten overgehouden en de verschillende enkelscores waren verbeterd.

Aangezien patiënten na operatieve behandeling van enkelfracturen of ligamentaire reconstructies mogelijk baat zouden kunnen hebben bij vroegtijdig belasten, ontstond de vraag of volledig belasten van een enkel met een syndesmose stelschroef in situ verantwoord zou zijn. In een kadaveronderzoek werd de fixatie kracht van roestvrij stalen en titanium schroeven vergeleken, als mede de fixatie door 3 of 4 cortices.

Hoofdstuk 12 laat de resultaten zien van een studie waarin de fixatie van de syndesmose van zestien vers ingevroren onderbenen met een kunstmatig aangebrachte syndesmoseletsel werd getest. Deze onderbenen werden axiaal belast gedurende een cyclische testprocedure (800 N, 225.000 cycli) als model voor 9 weken belasting in een onderbeensloopgips. Het syndesmoseletsel bestond uit het doorsnijden van de anterieure en posterieure tibiofibulaire ligamenten, het ligamentum interosseum met de 10 distale centimeters van de membrana interossea en het voorste deel van het ligamentum deltoïdeum. Vier groepen benen werden getest. Deze benen hadden een 3.5 mm syndesmose stelschroef gemaakt van roestvrijstaal of van titanium die werd ingebracht door 3 of 4 cortices.

Twee benen moesten van de studie uitgesloten worden, bij deze benen faalde de proefopstelling, omdat het voetskelet inzakte tijdens het testen. Geen van de 14 succesvol geteste benen of schroeven faalde. Er werd geen verschil gevonden tussen fixatie van de syndesmose met roestvrijstalen of met titanium schroeven, noch tussen fixatie door 3 of door 4 cortices.

De gemiddelde laterale verplaatsing van de distale fibula na testen was 1.05 mm (SD = 0.42). De maximale toename in de tibiofibulaire breedte was meer dan welke beschreven is in hoofdstuk 6 en 8 voor de intacte syndesmose tijdens een belasting vergelijkbaar met het lichaamsgewicht. Derhalve laat de huidige laboratoriumstudie zien dat, in geval van een volledige doorsnijding van de syndesmose, de syndesmose stelschroef excessieve verbreding van de enkelvork niet tegenhoudt tijdens belasten. De resultaten ondersteunen het advies dat patiënten met een dergelijk letsel en een syndesmose stelschroef hun enkel niet moeten belasten, om herstel van de ligamenten met een normale lengte te verzekeren. Aangezien een schroef door 4 cortices, in het geval van schroefbreuk, eenvoudiger te verwijderen is dan een schroef door 3 cortices, en de fixatie vergelijkbaar is, wordt geadviseerd vier cortices te gebruiken.

Tenslotte werd de kinematica van de syndesmose na anatomische reconstructie van de voorste syndesmose bestudeerd in een prospectieve klinische en radiostereometrie studie naar de diagnose en behandeling van chronische instabiliteit van de voorste syndesmose.

Hoofdstuk 13 beschrijft de klinische bevindingen en de tibiofibulaire kinematica vastgelegd met radiostereometrie in een prospectieve studie van 5 patiënten. Onderzoeken werden voor en na de eerder beschreven anatomische reconstructie van de voorste syndesmose verricht. De huidige studie laat zien dat patiënten met chronische instabiliteit van de voorste syndesmose een significant andere kinematica van de fibula tijdens exorotatiestress vertoonden dan de gezonde vrijwilligers die in hoofdstuk 8 beschreven zijn. Deze verschillen waren niet zo kenmerkend dat patiënten van vrijwilligers onderscheiden konden worden. Het exorotatie stress radiostereometrie onderzoek bleek niet geschikt om bij patiënten voor en na de reconstructie verschil in kinematica aan te kunnen tonen.

Geconcludeerd kon worden dat radiostereometrie geen geschikte techniek is om chronische instabiliteit van de voorste syndesmose of normalisatie van de tibiofibulaire kinematica na reconstructie van de syndesmose vast te stellen in deze poliklinische setting.

Deze studie bevestigt de eerder beschreven bevinding dat herstel van de voorste syndesmose bij patiënten met chronische instabiliteit de klinische verschijnselen van de instabiliteit opheft.

Hoofdstuk 14 beschrijft de klinische relevantie en geeft aanbevelingen voor het herkennen, onderzoeken en behandelen van syndesmoseletsels.

In dit proefschrift zijn biomechanische, klinische, radiologische en therapeutische aspecten van chronische instabiliteit van de voorste syndesmose beschreven, alsmede een chirurgische procedure voor een anatomisch herstel van de voorste syndesmose. De retrospectieve studie in hoofdstuk 11 en de prospectieve studie in hoofdstuk 13 laten duidelijk zien dat patiënten met een chronisch voorste syndesmoseletsel baat hebben bij deze anatomische reconstructie.

List of publications

The straight line graph in limb length inequality.
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Annechien Beumer 2007

Curriculum Vitae

Annechien Beumer was born in Schiedam, The Netherlands, on August 18, 1968.

After finishing high school education at Stedelijk Gymnasium, Schiedam, she started a one year course in Dutch Law at the Erasmus University Rotterdam (EUR), because of the numerus fixus for medical study places in The Netherlands.

Medical study was pursued at the same university, with a Master's thesis on the sensitivity of Plasmodium Falciparum to chloroquine, in Manyemen (Cameroon).

After completing medical study, in 1994, she worked as a Research Fellow at the Department of Orthopaedics of the Erasmus University Rotterdam for one year (1995), supervised by B.A. Swierstra MD, Ph.D., and as a registrar in general surgery at the Sint Clara Hospital in Rotterdam (1996 - 1997), under the supervision of T.I.Yo. M.D., Ph.D.

The basis for this current thesis was laid during her orthopaedic specialisation (1998-2002) at the University Hospital Rotterdam, supervised by Professor J.A.N. Verhaar, including six months training in the Reinier the Graaff Hospital, Delft (Head of Department: R te Slaa, M.D., Ph.D.).

During her orthopaedic training, Annechien also developed interest in hand surgery and traumatology, which resulted in a fellowship in Orthopaedic Traumatology, with an emphasis on hand surgery, at the Trauma Unit of the Royal Infirmary Edinburgh, Scotland in 2000 (Head of Department: Prof. C. Court Brown).

Shortly after her qualification as Orthopaedic Surgeon in 2002, her interest in hand surgery developed further by a research fellowship at the International Center for Orthopaedic Advancement, Department of Orthopaedic Surgery, Johns Hopkins University-Bayview Medical Center, Baltimore, MD, USA (Heads of Department: Professor S.M Belkoff and late Professor J. Wenz).

Since 2003, Annechien has worked as an orthopaedic surgeon in The Netherlands, with several shorter periods abroad, further to develop her skills in hand surgery.

In 2005, she joined the Upper Limb Unit of the Sint Maartenskliniek in Nijmegen, The Netherlands. She has been awarded the travelling fellowship of the European Society of Foot and Ankle Surgery, in 2005, and the travelling fellowship of the Federation of Societies for Surgery of the Hand, in 2006.