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Chronic instability of the anterior syndesmosis of the ankle

Biomechanical, kinematical, radiological and clinical aspects

Annachiena Beumer

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

Thesis

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CHRONIC INSTABILITY OF THE ANTERIOR SYNDESMOSIS OF THE ANKLE

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CHRONISCHE INSTABILITEIT VAN DE ANTERIEURE SYNDESMOSE VAN DE ENKEL

Biomechanische, kinematische, radiologische en klinische aspecten

Thesis

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born in Schiedam



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List of Papers

This thesis is based on the following papers:

1. A biomechanical evaluation of the tibiofibular and tibiotalar ligaments of the ankle.
A. Beumer, W. L. W. van Hemert, B. A. Swierstra, L. E. Jasper, and S. M. Belkoff.
Foot Ankle Int 2003; 24 (5): 426-9.
2. The influence of ankle positioning on the radiography of the distal tibial tubercles.
A. Beumer and B. A. Swierstra.
Surg Radiol Anat 2003; 25(5-6): 446-50.
3. Radiographic measurement of the distal tibiofibular syndesmosis has limited use.
A. Beumer, W. L. W. van Hemert, R. Niesing, C. A. C. Entius, A. Z. Ginai, P. G. H. Mulder, and B. A. Swierstra.
Clin Orthop and Rel Res 2004; 423 (6): 227-234.
4. Effects of ligament sectioning on the kinematics of the distal tibiofibular syndesmosis. A radiostereometric study of 10 cadaveric specimens focused on presumed trauma mechanisms and possibilities of treatment.
A. Beumer, E. R. Valstar, E. H. Garling, R. Niesing, J. Ranstam, A. Z. Ginai, and B. A. Swierstra.
Acta Orthop 2006; 77 (3): 531-540
5. External rotation stress imaging in syndesmotric injuries of the ankle. Lateral radiography and radiostereometry compared in a cadaveric model.
A. Beumer, E. R. Valstar, E. H. Garling, W. J. van Leeuwen, W. Sikma, R. Niesing, J. Rans-tam, and B.A. Swierstra.
Acta Orthop Scand 2003; 74 (2): 201-5.
6. Kinematics of the distal tibiofibular syndes-mosis: radiostereometry in 11 normal ankles.
A. Beumer, E. R. Valstar, E. H. Garling, R. Niesing, J. Ranstam, R. Löfvenberg, and B.A. Swierstra.
Acta Orthop Scand 2003; 74 (3): 337-43.
7. A biomechanical evaluation of the clinical stress tests for syndesmotric ankle instability.
A. Beumer, W. L. W. van Hemert, B. A. Swierstra, L. E. Jasper, and S. M. Belkoff.
Foot Ankle Int 2003; 24 (4): 358-63.
8. Clinical diagnosis of syndesmotric ankle insta-bility. Evaluation of stress tests behind the cur-tains.
A. Beumer, B. A. Swierstra, and P. G. H. Mulder.
Acta Orthop Scand 2002; 73 (6): 667-9.
9. Late reconstruction of the anterior distal tibio-fibular syndesmosis.
A. Beumer, R. P. Heijboer, W. P. J. Fontijne, and B. A Swierstra.
Acta Orthop Scand 2000; 71 (5): 519-21.
10. Screw fixation of the syndesmosis. A cadaver model comparing stainless steel and titanium screws and 3 and 4 cortical fixation.
A. Beumer, M. M. Campo, R. Niesing, J. Day, G. J. Kleinrensink, and B. A. Swierstra.
Injury 2005; 36 (1): 60-4.
11. Kinematics before and after reconstruction of the anterior syndesmosis of the ankle. A pro-spective radiostereometric and clinical study in 5 patients.
A. Beumer, E. R. Valstar, E. H. Garling, R. Niesing, M. P. Heijboer, J. Ranstam, and B. A. Swierstra.
Acta Orthop 2005; 76 (5): 713-20.

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.

Abbreviations

AD anterior part of deltoid ligament
ATiFL anterior inferior tibiofibular ligament
IL interosseous ligament
IM interosseous membrane
PTiFL posterior inferior tibiofibular ligament

RSA radiostereometry
TL transverse ligament
TFCS tibiofibular clear space
TFO tibiofibular overlap

Introduction and background

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 widening 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.

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-ever-



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

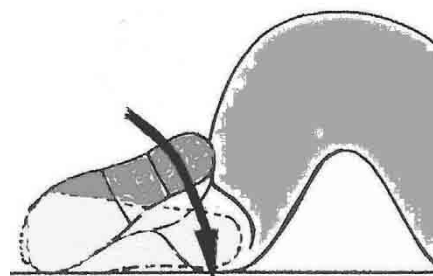


Figure 2. Syndesmotic injuries due to external rotation of ankle and foot can be the result from a direct impact put on the posterolateral aspect of the leg of a fallen rodeo bull rider or football player who is 'sitting' on the knees (Slawski and West 1997, Boytim et al. 1991).

sion 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).



Figure 3. Anterior tibiofibular diastasis.



Figure 4. Complete tibiofibular diastasis.



Figure 5. Intercalary diastasis.

Classification

According to Kelikian and Kelikian (1985) there are 3 types of syndesmotomies without ankle fractures. The most common, and the most difficult to recognize, is the anterior syndesmotomy 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 syndesmotomy 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 syndesmotomies. 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 syndesmotomies 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, White-side et al. 1978).

Summarizing recurrent 'high' swelling, stiffness, feelings of instability or the sensation of giving way and pain over the syndesmosis during dorsiflexion are commonly 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 recovery 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 radiological 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, Pneumatics 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 per-

formed 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 'filling' 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 scintigraphy.

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 concur-

rent 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 inhomogenities 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-weighted 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 (Bartoňček 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-weighted 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 syndesmotomic 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 syndesmotomic 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 syndesmotomic injuries when graded lateral stress radiography was compared with MRI (1.5 Tesla, wrap-around surface coil, T1- and T2-weighted sequences) in acute ankle injuries.

In a bit confusing publication MRI of the bony syndesmotomic 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-weighted 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, Trattinig 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 syndesmotomic ligaments in their full length in order to be able to assess their integrity the syndesmotomic 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 syndesmotomic 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 syndesmotomic injuries.

Arthroscopy and assessment of the syndesmosis during operative treatment

Several authors have mentioned arthroscopy as a useful technique to diagnose syndesmotomic injuries (Takao et al. 2003, Ogilvie-Harris et al. 1994). According to Ogilvie-Harris arthroscopy in chronic syndesmotomic 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 arthroscopic 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 treat-

ing 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).

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 weeks; 23 mm), 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).

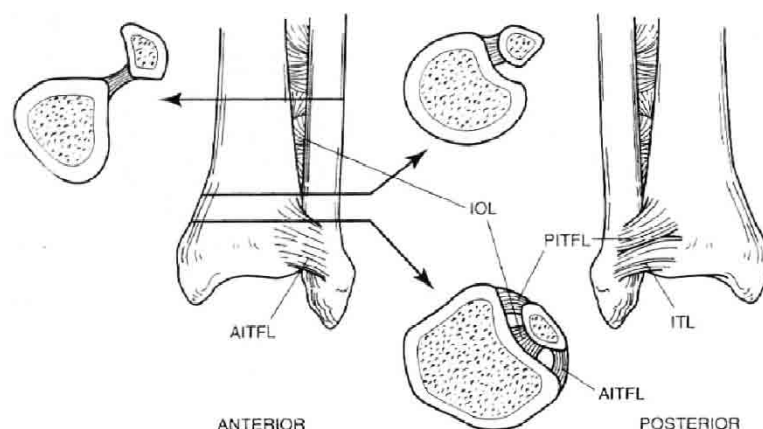


Figure 6. Schematic drawing of distal tibiofibular syndesmosis with ATiFL, IL, PTiFL and TL.

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 6) 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 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 6) 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 7), 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).

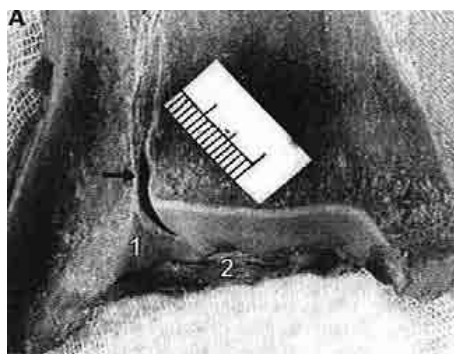


Figure 7. Coronal section through distal tibiofibular syndesmosis. Anteriorly the inferior level of the IL is bordered by fatty tissue which is lined with a synovial plica from the talocrural joint space. The medial aspect of the plica is not attached to the tibia, allowing an interosseous diverticulum from the ankle joint between the plica laterally and the tibia medially. Posteriorly the TL is visible. (Bartoníček J. Anatomy of the tibiofibular syndesmosis and its clinical relevance. *Surg Radiol Anat* 2003; 25: 379-86).



Figure 8. 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.

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 8).

The afferent (sensory) innervation (proprioception) 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 pos-

terior 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 calcaneo-tibial 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).

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 (Studies 1, 4, 6, 11).
2. To display if chronic instability of the anterior distal tibiofibular syndesmosis exists and can be objectivated (Studies 4, 5, 7, 11).
3. To assess the optimal way to diagnose syndesmotic injuries with physical examination as well as with additional investigations (Studies 2, 3, 5, 8).
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 (Studies 9, 11).

5. To optimize the postoperative treatment after reconstruction of the syndesmosis (Study 10).
6. To formulate treatment guidelines for chronic (and acute) anterior instability of the distal tibiofibular syndesmosis (General discussion, clinical relevance and treatment options for physicians treating syndesmoticinjuries).

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.

Methods and findings

Study 1. A Biomechanical evaluation of the tibiofibular and tibiotalar ligaments of the ankle

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.

Study 2. The influence of ankle positioning on the radiography of the distal tibial tubercles

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.

Study 3. Radiographic measurement of the distal tibiofibular syndesmosis has limited use

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 distance between the floor of the tibial incisure and the medial side of the fibula exceeded 5 mm on standard AP ankle radiography

(film focus distance = 1.05 m). 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 syndesmotomic integrity. Tibiofibular overlap and medial and superior clear space are the most useful, because one-sided traumatic absence of tibiofibular overlap, as well as a distance between the floor of the tibial incisure and the medial side of the fibula that exceeds 5 mm, may be an indication of syndesmotomic injury, and a medial clear space larger than a superior clear space is indicative of deltoid injury. Additional quantitative measurement of all syndesmotomic parameters with repeated radiographs of the ankle cannot be done reliably and therefore are of little value.

Study 4. 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

Syndesmotomic 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 syndesmotomic injuries. 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 tibio-fibular 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.

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. 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 treated 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 syndesmotomic screw.

Study 5. External rotation stress imaging in syndesmotomic injuries of the ankle—comparison of lateral radiography and radiostereometry in a cadaveric model

We compared the value of 7.5 Nm external rotation stress in diagnosing tibiofibular syndesmotomic 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.

Study 6. Kinematics of the distal tibiofibular syndesmosis—radiostereometry in 11 normal ankles

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 syndesmotom injuries.

Study 7. A biomechanical evaluation of clinical stress tests for syndesmotom ankle instability

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 syndesmotom 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.

Study 8. Clinical diagnosis of syndesmotom ankle instability—evaluation of stress tests behind the curtains

We studied the feasibility of clinical tests in the diagnosis of syndesmotom injury of the ankle. 9 investigators examined 12 persons twice, including 2 patients with an arthroscopically-confirmed syndesmotom 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 syndesmotom tests was uniformly positive in chronic syndesmotom 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 syndesmotom instability. The final diagnosis of such instability, however, should be made by additional diagnostic imaging and/or arthroscopy.

Study 9. Late reconstruction of the anterior distal tibiofibular syndesmosis—good outcome in 9 patients

We present a new, anatomic reconstruction of the anterior tibiofibular syndesmosis of the ankle for chronic instability. An oblique anterolateral inci-

sion 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 0.7×0.7 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 syndesmotomic 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.

The mean follow-up was 45 (38–62) months. After reconstruction, all considered the ankle to be improved, none complained of instability. Transient sympathetic reflex dystrophy was seen in 2 patients and entrapment of the intermediate dorsal cutaneous nerve in scar tissue in 1 patient.

Study 10. Screw fixation of the syndesmosis: a cadaver model comparing stainless steel and titanium screws and three and four cortical fixation

We assessed syndesmotomic set screw strength and fixation capacity during cyclical testing in a cadaver model simulating protected weight bearing. Sixteen fresh frozen legs with artificial syndesmotomic injuries and a syndesmotomic 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. Syndesmotomic fixation failure was defined as: bone fracture, screw fatigue failure, screw pull-out, and/or excessive syndesmotomic 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. ± 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 syndesmotomic set screw cannot prevent excessive syndesmotomic widening when loaded with a load comparable with body weight. Therefore, we advise that patients with a syndesmotomic set screw in situ should not bear weight.

Study 11. Kinematics before and after reconstruction of the anterior syndesmosis of the ankle—a prospective radiostereometric and clinical study in 5 patients

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.

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

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.

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

General discussion, 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 non-operatively 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 (Fritchey 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, Pneumaticsos 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-weighted 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 (Shakhpur and Grainger 2001, Tratnig 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 move-

ment (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 syndesmotomic 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 syndesmotomic 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 ana-

tomical 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 syndesmotomic 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 syndesmotomic 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).

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.

Introduction and background 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.

Development and anatomy of the ankle and the distal tibiofibular syndesmosis 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.

Study 1 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, whereas 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.

Study 2 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.

Study 3 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.

Study 4 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 study 4 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

Study 5 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 study 5 been described in the literature. To obtain such data, these examinations were assessed in asymptomatic volunteers with RSA.

Study 6 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.

Study 7 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 fibula 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.

Study 8 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.

Study 9 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 syndesmotomic setscrew. Postoperative treatment consisted of six weeks of non weight bearing in a below-knee plaster, after which the syndesmotomic 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 syndesmotomic screw fixation capacity for stainless steel and titanium screws through 3 or 4 cortices was tested.

Study 10 presents a cadaveric study in which sixteen fresh frozen legs with artificial syndesmotomic 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 syndesmotomic 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 syndesmotomic 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 syndesmotomic set screw cannot prevent excessive syndesmotomic 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 syndesmotomic set screw should be advised not to weight-bear to ascertain healing of the syndesmotomic 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 syndesmotomic 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 syndesmotomic instability.

Study 11 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 syndesmotomic 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 syndesmotomic 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.

General discussion, clinical relevance and treatment options for physicians treating syndesmotomic injuries describes the clinical relevance, as well as recommendations for recognition, examination and treatment of syndesmotomic 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 9 and the prospective study 11 clearly show that patients with chronic anterior syndesmotic instability benefit from anatomical surgical reconstruction of the anterior syndesmosis.

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