Chronic Lateral Instability of the Foot

a clinical-experimental and radiological study

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Chronic lateral instability of the foot

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aan Ester, Jan en Pia

dank aan mijn ouders

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Introduction, review of the literature and aim of the present study

Chapter 1

Introduction

Injury to the ligaments on the lateral side of the ankle and foot, caused by a sudden excessive inversion and/or torsion of the foot in relation to the leg, is probably the most common everyday injury of the locomotory system. Most of these injuries are sustained during sport, but with increasing age activities of daily life become a more dominant cause. It is estimated that one inversion injury of the ankle per 10.000 persons per day occurs. Despite adequate treatment, it is estimated that approximately 40% of the patients suffer from residual symptoms after sustaining this injury. These symptoms include recurrent sprains, 'giving way' sensations, pain, swelling and stiffness. The severity of these complaints is related to the level of demands regarding physical activities, but the great majority of the patients who note these complaints is not incapacitated by them. Presumably only a small percentage of patients with chronic lateral instability consults a general practitioner or a consultant. Based on the above mentioned percentages it can be deducted that chronic lateral instability of the foot is a very common problem.

Multiple factors, such as dysfunction of the ligaments, proprioceptive deficit and decrease of central motor control are involved in this clinical syndrome. A review of the literature concerning these factors is presented in this chapter. Although assumptions are made in literature regarding the role of the peroneal muscles, the influence of foot geometry and the role of subtalar instability, little or no studies have been reported that actually quantify these factors or present a standardized method to examine these factors. There are no reports regarding the influence of foot positioning or of passive stability of the foot on chronic lateral instability. In this thesis, a series of clinical- experimental and radiographic studies concerning the above mentioned issues are described. In chapter 2 the role of the peroneal longus muscle and tibialis anterior muscle in the stance phase of walking is examined. Differences in muscle activity found between patients with chronic lateral instability and controls are described. Chapter 3 describes a study in which the passive stability of the foot was investigated. It was examined whether the feet of patients with chronic lateral instability were less stable than the feet of a control group. After examining the influence of the static factor foot build in chapter 4, a study regarding the dynamic factor foot position is presented in chapter 5. In chapter 6 a standardized radiographic stress examination is described to establish a possible subtalar component in patients with chronic lateral instability. The latter study provided more questions than answers and further research, presented in chapter 7, was performed using CT-imaging of stressed joints, in order to find a more objective method to evaluate subtalar tilt. In the last chapter the results of these studies are summarized and discussed.

Review of the literature

Acute lateral ligament injuries

Epidemiology

Injury to the lateral ankle ligaments is a common, everyday injury. Both athletics and activities of daily life cause ankle ligament sprain (Garrick and Requa, 1973). Most ankle sprains occur in the 15 to 35 year old age group (Boruta et al., 1990). The incidence is highest for young males. After the age of 40, the incidence becomes higher for women than for men. Most sprains are sustained during sport, but with increasing age other activities become dominant (Hølmer et al., 1994). It has been estimated that there is one inversion injury of the ankle per 10.000 persons per day (Brooks et al., 1981; McCullouch et al., 1985; Ruth, 1961). One third of West Point cadets were found to have sustained ankle sprains within a 4 year time period (Jackson et al., 1974). Ankle sprains account for 25% to 50% of injuries in sports such as soccer, basketball, volleyball and other sports that include running and jumping activities (Mack, 1982). In the Netherlands it is estimated that more than 500.000 persons consult their general practitioner or attend a hospital with ankle injuries every year and that the social costs of these injuries amount to about 1.300 million guilders every year (Zeegers, 1995). In 50% of cases the injury was the result of a sporting accident.

Brief functional-anatomical description of the lateral ankle ligaments and the damage caused by an inversion injury

Classically, the lateral ligament complex of the ankle is described as consisting of the anterior talofibular ligament (ATFL), the calcaneofibular ligament (CFL), and the posterior talofibular ligament (PTFL). The ATFL is a thickening in the anterolateral joint capsule. Its attachment is the anterior aspect of the lateral malleolus, close to the apex, and it proceeds forward and medially to gain insertion on the lateral aspect of the talar neck. The fibers run almost horizontally when the foot is in a neutral standing position. The ATFL primarily limits internal rotation of the talus (Rasmussen, 1985). Together with forces transmitted to the talus through the contact surfaces of the bones, this ligament plays a crucial role in bringing the talus into an external rotation, which results into inversion of the foot by the tarsal mechanism as described by Huson (1961 and 1991). So, the function of this ligament is to tune the coupling of longitudinal rotation from the leg to the talus and vice versa by the talocrural joint. This ligament is not built to stabilize the foot or to carry the bodyweight and cannot resist high forces without active protection of the muscles. The function of the lateral ankle ligament complex is different from that of the medial ligament complex. The ligaments on the medioplantar side of the foot form a magnificent strong and thick structure and are built to stabilize the foot passively and to resist high forces as during sporting activities (Bøjsen-Møller, 1989). The direction of the ATFL fibers varies according to the degree of dorsal or plantar flexion in the talocrural joint (de Vogel, 1970; Rasmussen, 1985). The ATFL becomes taut and parallel to the tibia when the foot is plantarflexed. With further forced plantar flexion and/or inversion of the foot this ligament tears. This finding is probably the reason why so many authors stress the plantar flexion component in describing the traumamechanism. Broström (1965), however, recorded that rupture of the lateral ankle ligaments is generally caused by internal rotation and/or adduction of the weight-bearing foot and it seems logical that rotation is generally the more important component in the traumamechanism. The ATFL is the most commonly injured lateral ligament (Broström, 1964, 1965 and 1966b). Severing of the ATFL with its adjacent capsular structures results, depending on the position of the talocrural joint, in increased anterior talar translation and increased inversion/adduction of the talus within the talocrural mortise (this is usually called talar tilt, TT). More importantly, the mechanism of talocrural transmission may be damaged (Prins, 1978) resulting in an increase of tibiotalar delay particularly in feet belonging to subjects with rather lax talocrural ligaments (Fiévez and Spoor, 1987). In clinical studies this feature is described as anterolateral rotatory instability and in this regard the ATFL must be considered the 'key ligament'.

The CFL is an extra-articular structure. It extends from the tip of the lateral malleolus to the lateral surface of the calcaneus and is intimately associated with the posteromedial part of the peroneal tendon sheath. This ligament has an oblique orientation ranging from almost vertically downwards to almost horizontally backwards (Ruth, 1961) and is relaxed when the foot is in neutral position. The CFL, being a bi-articular structure, thus permits subtalar motion. The fibers are tensed when the foot is dorsiflexed and also during inversion of the foot, during which they take in a more vertical orientation perpendicular to the joint (de Vogel, 1970). The CFL inhibits first and foremost inversion (Rasmussen, 1985). It is rarely injured alone, but is associated with ATFL tears in more severe injuries (Prins, 1978). Damage results in further increase of inversion/adduction by 11° - 12°, independent of the position of the ankle (Rasmussen, 1985). Broström (1966b) observed that combined rupture of the talofibular and calcaneofibular ligaments occurred in less than 30% of his patients and that the calcaneofibular ligament was never ruptured alone. Rasmussen (1985) stated, that isolated cutting of the CFL did not influence inversion stability of the talocrural joint, however, Kjaersgaard-Andersen et al. (1987a) found an increased adduction in the talocalcaneal joint to a maximum of 5°, constituting two thirds of total increment in adduction of the hindfoot joint complex. They also found small, but relatively substantial, increments in external and internal rotation in the talocalcaneal joint and thus concluded that this ligament is an important structure in stabilizing the movements of the hindfoot (Kjaersgaard-Andersen et al., 1987b).

The PTFL is the strongest ligament of the lateral ligament complex. It originates in the fossa of the lateral malleolus and spreads in the shape of a fan, its anterior short fibers inserting laterally on the posterior edge of the talus and its posterior long fibers medially on the lateral tubercle of the posterior process of the talus (de Vogel, 1970; Prins, 1978). This ligament has no independent stabilizing function. The PTFL primarily inhibits external rotation and to some degree dorsiflexion (Rasmussen, 1985). The PTFL is rarely injured, except in severe ankle lesions.

Diagnosis and treatment

The diagnosis and treatment of acute tears of the lateral ankle ligaments has received a vast amount of attention in literature. In the Netherlands it has been the subject of numerous theses (van der Ent, 1984; van Moppes, and van den Hoogenband, 1982; Prins, 1978; Bleichrodt, 1987; van Dijk, 1994; Zeegers, 1995). In clinical practice, sprains of the ankle have been classified as grade I (mild), II (moderate), or III (severe). Almost all authors agree that patients who have a grade I or grade II injury recover quickly with a conservative treatment program, usually called functional treatment, and that the prognosis is almost without exception excellent or good. The treatment of acute complete (grade III) tears, however, has generated much controversy in the medical literature. Although the long-term prognosis is excellent or good in most patients, regardless of the treatment, some studies cited one reservation: the young, active athlete for whom primary operative repair should be considered (Broström, 1966a; Grønmark et al., 1980; Korkala et al., 1987). In the Netherlands, Prins (1978) and van der Ent (1984) recommended operative repair as the basic method of treatment and until recently 4000 acute ankle ligament ruptures per year were still treated operatively (van Linge, 1988b). After a critical review of twelve prospective randomized studies that had been carried out for the purpose of identification of the proper treatment of complete tears Kannus and Renström (1991) concluded that functional treatment is clearly the treatment of choice. Functional treatment with a bandage is the standard treatment propagated by the Dutch Society of General Practitioners (Nederlands Huisartsen Genootschap, 1989). Consequently, specific radiological examinations such as arthrography or stress radiography are not indicated. Also, the indication for routine radiography can be established on grounds of careful physical examination and the number of X-ray examinations can be drastically reduced without harm to the patient, and with appreciable reductions in workload, radiation levels and costs (Zeegers, 1995; van Linge, 1988b).

Functional treatment includes ICE treatment (Ice, Compression and Elevation), only a short period of protection by tape, bandage, or a brace, and allows early weight bearing. Range of motion exercises, as well as motor control training of the ankle and foot should begin early. This program clearly provides the quickest recovery to a full range of motion, return to work and physical activity. It does not compromise the late mechanical stability more or produce more late symptoms than the other treatments. In addition, functional treatment seems to be virtually free from complications, while after other methods, especially operation, serious complications sometimes occur.

There are other reasons to consider functional treatment as the treatment of choice. First, for patients who do need secondary operative reconstruction or delayed repair of the lateral ankle ligaments, the results of surgical treatment compare favourably with those of primary acute repair, also when performed years after the injury (Trevino et al., 1994; Kannus and Renström, 1991). Furthermore, in the cost-benefit analysis of functional versus operative treatment, functional treatment achieves excellent results for the majority of patients without the expense of hospitalization, surgery, and treatment of surgical complications. Functional treatment means enormous economic savings compared to an operation, especially when one also considers that the great majority of ankle injuries can be treated by the general practitioner and do not need to be seen in emergency rooms.

In some situations, however, operation should be considered. Such situations include the presence of lesions such as displaced osteochondral fracture or large avulsions of bone. An elective operative procedure may also be appropriate when the injury is severe and combined with a long history of chronic instability and multiple severe sprains despite adequate previous conservative treatment. Obtaining a complete medical history is important to discover patients at risk for complications, also with functional treatment. One of these risk factors is the presence of neuropathy. Severe deformation as a result of neuropathic disintegration of the foot and ankle can occur after a simple sprain of the ankle.

Residual complaints after acute lateral ligament injury

Despite adequate treatment, 10% to 40% of patients suffer from residual symptoms after sustaining an acute lateral ligament injury (Bonnin, 1944; Bosien et al., 1955; Broström, 1966a; Freeman, 1965b; Hansen et al., 1979; Linde et al., 1986; van

Moppes and van den Hoogenband, 1982; Prins, 1978; Zwipp et al., 1991). These symptoms include recurrent sprains, pain, swelling, stiffness and 'giving way' sensations. In a prospective study, comparing four conservative methods of treatment of acute lateral ligament injuries, Zeegers (1995) found that 30% of the patients complained of pain and 44% suffered some degree of instability, 5 years after their injury. The incidence of these chronic complaints might be thought to be surprisingly high, however, the great majority of the patients who note these complaints are not incapacitated by them. Linde et al. (1986) performed a prospective study following 150 patients after functional treatment of a lateral ligament injury. After 1 month 90% was free from pain and 97% had resumed work. Sport was resumed by 70% of athletes after 1 month and 90% after 3 months. At 1 year follow-up (n = 137), 18% had not fully recovered and experienced pain (14%) or instability (7%) or had not resumed sport at their normal level (7%). Only 8% found the condition inconvenient. Increased risk of residual symptoms was clearly related to athletic activities and symptoms occurred in 32% of top athletes after 1 year. These findings are comparable with those of other studies. Hansen et al. (1979) found that out of 144 patients 20.8% had residual symptoms after a mean follow-up of 4.2 years. Only four patients had major complaints. The symptoms influenced work or sport if these activities severely strained the foot. Freeman (1965b) recorded an incidence of 39%. Almost all his patients were fit young soldiers with high demands regarding sport and probably their complaints would have passed unnoticed in a sedentary life. As explained by van Dijk (1994) the variation in the percentage of residual symptoms can also be caused by other factors such as the duration of follow-up and the interpretation of the concept 'residual symptoms'.

Chronic lateral instability

The diagnosis of chronic lateral instability relies primarily on the history. In the majority of cases the history includes an injury of the lateral ligaments, but not all patients remember a primary injury. Patients complain of 'giving way' sensations or the feeling of instability, pain, swelling and actual reinjuries. These may occur during sports, walking on uneven ground, or activities of daily life.

Clinically, it seems practical to differentiate between patients who predominantly complain of pain, swelling and/or stiffness and patients with mainly instability complaints. When patients mainly complain of pain this can be attributed to several intra-articular lesions, such as chondral lesions, osteochondral lesions, intra-articular adhesions and pinching of (peri-)synovial tissue (Hutton, 1985; Biedert, 1991; Borelli, 1989; Stone, 1991). Pain is typically related to activity when walking or running or to a particular sport. Pain located on the medial side of the ankle joint can be caused by injury of the cartilage with or without loose body formation as found arthroscopically by van Dijk (1994) in a high percentage of patients after acute rupture of the lateral ligaments. Other diagnoses which should be looked for when rehabilitation does not progress as anticipated include a.o. fractures due to traction or compression around the 'axis' of inversion, ligamentous injury in the lines of Chopart and Lisfranc, peroneal tendon subluxation or dislocation, Achilles tendon rupture and reflex sympathetic dystrophy (DeMaio et al., 1992).

Another patient group, to which the patients examined in the present study belong, seems to be formed by those who predominantly have instability complaints. They complain of 'giving way' sensations and often of recurrent sprains. Typically, the patients say that they already give way or sprain the foot when they misstep on a small stone or walk on an uneven surface. Symptoms like pain and swelling are less prominent and are more related to actual reinjuries. Between injuries these patients generally walk without pain and without limping. Although they might present with synovitis because of recurrent sprains there are otherwise no signs of intra-articular damage.

Etiology of chronic lateral instability

Mechanical instability

In 1944 Bonnin described the 'hypermobile ankle' as a distinct entity capable of radiological proof. He found unilaterally increased inversion in 24% of all sprained ankles and bilateral hypermobility in patients with severely sprained ankles in a higher percentage (42%) than in a group of controls (13%). He concluded that hypermobility, being excessive inversion tilt either of the talocrural or of the tarsal joints, was a prime factor in the incidence of sprains and produced a feeling of instability with complaints of 'going over'. Motion beyond the physiological range of motion will further be referred to as mechanical instability.

Other authors have also reported a significant correlation between mechanical instability and chronic lateral instability complaints (Anderson and Lecocq, 1954; Karlsson, 1989; Broström, 1966a and 1966b). Karlsson (1989) performed a radiographic investigation showing that a diagnosis of mechanical instability can be reached in over 90% of the chronic instable ankles. A so-called Telos device is used to perform stress radiography in a standardized manner. Two provocation tests are performed, one in the sagittal plane and one in the frontal plane. Thus, the amount of anterior talar translation (ATT) and the amount of inversion tilt of the talus (TT) within the ankle mortise are determined. Karlsson (1989) defined the ATT as the shortest distance in millimeters between the posterior border of the joint surface of the distal tibia and the talus, as proposed by Landeros et al.(1968). The TT is measured as the angle made by the superior articular trochlear facet of the talus and the inferior tibial joint surface. He concluded that mechanical instability can be defined as an ATT of 10 mm or more and a TT of 9° or more, or a difference in ATT and TT between stable and unstable ankle joints of more than 3 mm and 3° respectively.

The majority of the available literature on chronic lateral instability consists of reports on operative treatment. More than 50 procedures or modifications have been described (Karlsson, 1989). Both non-anatomical and anatomical repairs are used to reconstruct the function of the injured ligaments. Although, most commonly, also other indications than the presence of mechanical instability (based on radiographic criteria) are used to proceed to surgery. The fact that the outcome of these procedures is good and excellent in about 90% of the patients (Peters et al., 1991) seems to indicate that mechanical stability plays an important role.

Subtalar mechanical instability

Mechanical instability is most often located at the talocrural level. Since Rubin and Witten (1962) for the first time suggested the clinical significance of subtalar instability, this topic has received increasing attention (Laurin et al., 1968; Brantigan et al., 1977; Zollinger et al., 1983; Zwipp and Tscherne, 1982; Vidal et al., 1974; Zell et al., 1986; Clanton, 1989). Subtalar instability must be considered as a cause of symptoms after an inversion injury, particularly if other causes of instability have been excluded. Mechanical instability of the subtalar joint must also be considered when patients continue to complain of instability after reconstructive procedures not taking into account reconstruction of a ruptured calcaneofibular ligament (Brantigan et al., 1977; Clanton, 1989).

Not only the calcaneofibular ligament, but also ligaments located in the sinus and canalis tarsi are described to play a role in hindfoot instability. The sinus and canalis tarsi are located in the region between the neck of the talus and the anterosuperior surface of the calcaneus. The canalis tarsi, which is bordered by a sulcus in both the talus and the calcaneus, contains the interosseous talocalcaneal ligament centrally and extending medially in the canal and the three roots of the inferior extensor retinaculum laterally (Cahill, 1965; Schmidt, 1978). These roots are described as the intermediate and medial roots deriving from a layer deep to the extensor tendons and a lateral root deriving from a superficial layer. In the sinus tarsi, slightly anterior to the intermediate root a relatively thick ligament, the cervical ligament, is located, passing from the neck of the calcaneus to the neck of the talus. Significant variability is described, however, in general a lateral talocalcaneal ligament can be found crossing the posterior facet of the subtalar joint. This ligament is relatively narrow, thin, parallel with, and slightly anterior to the calcaneofibular ligament.

Isolated cutting of the calcaneofibular ligament results in increase of inversion and of rotation (Kjaersgaard-Andersen et al., 1987a and 1987b). The increments found at the talocalcaneal level are small, but because they involve a large percentage of total increment found in the tibio-talo-calcaneal joint complex, they are considered to be important. The same arguments account for the situation found after cutting of only the ligaments of the sinus and canalis tarsi, which also results in small increments of inversion and rotation (Kjaersgaard-Andersen et al., 1988). Zwipp and Tscherne (1982) found tilting of the calcaneus of more than 5° and medial shift of more than 5 mm to be indicative of subtalar instability.

Different methods have been proposed for measuring instability of the subtalar joint (Rubin and Witten, 1962; Laurin et al., 1968; Brantigan et al., 1977; Zollinger et al., 1983; Zwipp and Tscherne, 1982; Kato, 1995). It seems that in spite of continuing efforts, methods for documenting or quantifying inversion instability of the foot remain elusive (Harper, 1992).

Proprioceptive deficit

Proprioceptive sensory feedback is utilized by the central nervous system for conscious appreciation of the position and movement of the body and limbs. It is suggested that proprioceptive deficit is caused by the ligamentous and capsular trauma which damages the many articular nerve fibers terminating in mechanoreceptors in the capsule and ligaments of joints (Freeman and Wyke, 1964). Freeman and Wyke (1967) described four types of receptors in feline ankle ligaments. It is thought that Type-I receptors provide postural sense to the central nervous system, Type-II receptors convey a sense of the beginning of joint motion, Type-III receptors provide sensation at the extremes of movement and that Type-IV receptors are responsible for nociceptive sensation. Michelson and Hutchins (1995) showed the presence of Type-II and -III receptors to be abundant in human ankle ligaments. They infrequently found Type-I receptors and were unable to demonstrate the presence of Type-IV receptors. Aside from the proprioception it is suggested that the sensory output from mechanoreceptors in the ligaments assists in controlling muscle stiffness and coordination around a joint, thereby increasing stability. They are thought to have roles in kinesthesia, muscle tone and articular reflexes (Freeman et al., 1967). Thus, rupture of ligaments may lead to partial joint de-afferentation and this leads to disturbances of control of locomotion and reflex behaviour.

Freeman performed an extensive study of injuries to the lateral ligaments of the ankle, resulting in a series of papers (1964; 1965a and b; Freeman et al., 1965). He introduced the term ‘functional instability’ to designate the disability to which patients refer when they say that their foot tends to ‘give way’. He found that mechanical instability of the talus in the ankle mortise, in fact, rarely, if ever, was responsible for initiating functional instability. He concluded a) that ligamentous injuries at the foot and ankle frequently produce a proprioceptive deficit affecting the muscles of the injured leg, b) that such a deficit is responsible for the symptom of ‘giving way’ of the foot and c) that the incidence of both the proprioceptive deficit and the symptom of ‘giving way’ can substantially be reduced by treatment with coordination exercises.

The finding of a prolonged peroneus reaction time in unstable legs seems to substantiate this theory. Studies have been performed using a trapdoor to elicit and simulate ankle sprains. Karlsson (1989) used surface EMG to measure the time from tilting of the plate to the first response of the peroneus longus or brevis muscles. Comparing the symptomatic unstable and the asymptomatic stable ankles of patients with unilateral instability, he found that the mean reaction time was 68.8 milliseconds (peroneus longus) and 69.2 milliseconds (peroneus brevis) in the stable ankles as compared to 84.5 and 81.6 milliseconds, respectively, in the unstable ankles. Using a biomechanical model he also suggested that the receptors are stimulated at a common fraction of the statically measured talar tilt angle.

Konradsen and Ravn (1990) performed a similar study. However, they also measured EMG activity of the rectus femoris and biceps femoris muscles, and in addition joint movement of the ankle, knee and hip were recorded and alternations of the body center of pressure were recorded using a force plate mounted under the trapdoor. The time from the first muscular response of the peronei to the first response over one of the upper leg muscles was defined as the central reaction time. Stable and unstable subjects showed a similar reaction pattern to sudden inversion. First a peripheral reflex action, namely contraction of the peronei, and then a centrally elicited pattern by which the vertical pressure on the ankle is relieved through flexion of the hip and knee and dorsiflexion of the ankle. The central reaction time did not differ, but a prolonged peroneal reaction time (comparable with the results of Karlsson) was found in the unstable group. These findings suggest that functional instability is not associated with disturbance of the central processing, but substantiate the theory of a proprioceptive de-afferentation being responsible for this entity.

To improve the sensitivity of one leg stabilometry, when compared with the method used by Tropp et al. (1985, see following section), Fridén et al. (1989) performed stabilometry in the frontal plane only, and they not only analyzed the distance, but also variables such as speed, and frequency. Contrary to Tropp et al. (1985b) they could well discriminate between the injured and the uninjured leg of patients with unilateral instability. Thus, their results seem to confirm the theory of Freeman.

In a study of 7 subjects with normal joints Konradsen et al. (1993) tested active and passive position sense of ankle inversion, peroneal reflex reaction time and postural control during single-leg stance. These tests were performed before and after regional anaesthetic blockade of the ankle and foot. Passive position sense was greatly impaired by anaesthesia, but active position sense, with the calf muscles activated, was preserved, and the peroneal reaction time was not altered. The stabilometric values were also unchanged by anaesthesia. The authors suggested that the afferent input from intact ankle ligaments is important in sensing correct placement of the foot while walking, but that this input can be replaced by afferent information from active calf muscles. This mechanism might also be responsible for dynamic protection against sudden ankle inversion. The authors did not believe that higher centers quickly learned to replace afferent impulses from the ankle ligaments with those from the muscles and tendons, because the results from the last tests were no better than those from the first.

Central coordination

Postural control is a complex function of cerebral, cerebellar, spinal, and peripheral afferent and efferent signals as well as muscle fiber function, all working together in order to keep the line of gravity within the area of support (Freeman et al., 1967). Freeman et al. (1965) suggested the use of the Romberg test to examine decrease of proprioception of the ankle and to evaluate functional instability. Tropp et al. (1984a; 1985a and b) maintained this assumption and used stabilometry to objectify postural control and, following Freeman, assumed this method to evaluate proprioception of the ankle and functional instability. Stabilometry is a quantitative modified Romberg test. Information from a force plate (e.g. mark Kistler) is processed on-line in a computer. The coordinates of the center of force of the subject, when standing on one leg, in the X-Y plane corresponding to the force plate are calculated and thus the total body sway in the frontal as well as in the sagittal plane is measured.

Tropp et al. (1984b; 1985a and b) observed no difference between the injured and uninjured leg in a group of soccer players after a previous ankle joint injury, thus they could not demonstrate that an injury itself produces functional instability. On the other hand, players without previous injury but showing abnormal stabilometric values ran a significantly higher risk of sustaining an ankle injury during the following season compared to players with normal values (Tropp et al., 1984b). The stabilometric values of players with functional instability were abnormal, but were not associated with a positive anterior drawer sign on clinical examination (Tropp, 1985a; Tropp et al., 1985b). Recording movements of different body segments in the frontal plane showed increased movement of upper body segments in patients with functional instability (Tropp and Odenrick, 1988). The results of stabilometry and subjective ‘giving way’ feeling and control of the movement of the body segments could successfully be improved with coordination training on an ankle disk as suggested by Freeman (Tropp et al., 1984a; Gauffin et al., 1988). Improvement reached even supranormal values, however, not only in the trained, but also in the untrained foot. In summary they found that 1) decreased postural control is associated with functional instability, 2) mechanical instability has no correlation to the degree of functional instability, 3) functional instability is associated with a higher risk for sustaining an ankle lesion and 4) a deficit of central motor control and not of peripheral proprioception is associated with functional instability.

As reported above, Fridén et al. (1989) did find a difference between the injured and uninjured leg of patients with unilateral instability, however, they also found impaired postural control of the uninjured leg of these patients as compared with the control group. Thus, they also concluded that impaired postural control is predisposing to lateral ligament injuries.

Peroneal muscles

Bonnin (1944) stressed the importance of mechanical instability. However, he also noted that hypermobility may be symptomless in people with developed muscular control. He suggested that exercise of the peroneal muscles was the method to develop muscle control. Peroneal weakness is thought to be a source of symptoms after inversion injury (Bosien et al., 1955; Staples, 1975; Trevino et al., 1994). Tropp (1986) associated peroneal muscle weakness with functional instability. They believed this weakness to be secondary to inadequate rehabilitation and to factors such as pain and immobilization. It is generally assumed that the peronei are not only involved in positioning the foot in the period about heel contact, but that they protect the foot against inversion injuries. A peripheral reflex action with contraction of the peronei is described to counteract sudden ankle inversion (Konradsen and Ravn, 1990). However, there is controversy as to whether the peroneal muscles are active at all at the time of heel contact (Glick et al., 1976; Shiavi, 1985; Mann et al., 1986; van Linge, 1988a).

Peroneal nerve palsy

Another factor which may be involved in the occurrence of functional instability is the possibility of palsy of the peroneal nerve. Peroneal nerve injuries following ankle sprains have been reported (Hyslop, 1941; Nitz, 1985). A prolonged peroneal reaction time, as described above, can also be caused by a lowered motor conduction velocity. Kleinrensink et al. (1993) measured the motor conduction velocity of both the superficial and deep peroneal nerve in a group of 22 patients. Three recordings were made starting 1 week post trauma and ending 5 weeks post trauma. A control group of 28 asymptomatic subjects was also included. The conduction velocity of both nerves was found to be lowered directly after the injury, and in the following 5 weeks both nerves recovered to a conduction velocity equal to the contralateral leg. The conduction velocity found in the patient group and control group proved to be equal with regard to the superficial nerve, however, the conduction velocity of the deep peroneal nerve in both the injured and uninjured leg of the patients was always lowered as compared to the control group. This seems to indicate that the patients are characterized by a pre-existent low motor nerve conduction velocity of the deep peroneal nerve in both legs, predisposing them to inversion injuries.

Foot build and foot positioning

Functional anatomical studies have demonstrated how the foot in the weightbearing situation moves from a neutral, more or less pronated position, into a cavovarus position during inversion (Benink, 1985; Huson, 1961 and 1991; van Langelaan, 1983). From a biomechanical point of view it is acceptable that a foot with a cavovarus configuration is more prone to lateral instability as a smaller moment of force is needed to enforce further inversion. As soon as the point of calcaneal floor contact is reached medial to the line of body-weight transmission and the axis of rotation proximal in the hindfoot an inversion lever will be produced. The relation between a cavovarus foot build and chronic lateral instability has been supported by numerous reports (Benink, 1985; Ayres et al., 1987; Bremer, 1985; Lassiter et al., 1989; Subotnick, 1985; Vidal et al., 1974; Larsen and Angermann, 1990).

Foot build will influence the position of the foot. The position of the foot and the way the foot is placed on the ground during gait, however, is probably also determined by other passive and by active factors. To our knowledge, no study in which the relationship between position of the rearfoot during gait and chronic lateral instability was examined has been reported.

General joint laxity

The range of motion at a given joint follows a Gaussian distribution throughout the population (Wood, 1971). At the extreme of range are found subjects with lax, hypermobile joints. Generalized hypermobility is associated with chronic lateral instability in numerous studies. Bonnin (1944) differentiated between patients with bilateral instability and unilateral instability. The hypermobility found in the first group was believed to be congenital and to predispose to sprains. Hypermobility of the symptomatic foot of patients with unilateral instability was found to be the result of ligamentous rupture. Increase of tibiotalar delay, which clinically results in anterolateral instability complaints, is reported particularly to be found in patients with general joint laxity (Fiévez and Spoor, 1987). Karlsson (1989) concludes that patients with generalized hypermobility of the joints should be considered as poor risks when anatomical reconstructions are planned. Many of the patients with subtalar joint instability in the study of Kato (1995) had no history of injury and he suggests that laxity of the interosseous talocalcaneal ligament may occur as one symptom of generalized joint laxity.

General joint laxity is generally associated with mechanical instability, but in a recent report it is suggested that subjects with hypermobility syndrome have poorer proprioceptive feedback than controls (Hall et al., 1995).

Tibio-fibular sprain

Tibio-fibular sprain has been reported as a cause of chronic lateral instability (Bonnin, 1965; Staples, 1975). Bonnin (1965) found persistent pain at the lower tibio-fibular joint and increased mobility of the fibula in the tibial groove at the injured side in a group of patients with chronic instability complaints. More recently, Löfvenberg et al. (1990) recorded slight increase of fibular rotations in patients with chronic lateral instability during plantar flexion and dorsiflexion, and at adduction (inversion) in some patients with bilateral symptoms and suggested that this perhaps reflects generalized joint laxity and not a separate pathophysiological entity.

Sinus tarsi syndrome

The subjective manifestations of the 'sinus tarsi syndrome' are diffuse pain on the lateral side of the foot, a feeling of hindfoot instability, especially when walking on uneven ground, and in most cases a history of a supination trauma to initiate the complaints (O'Connor, 1958; Kjaersgaard-Andersen et al., 1989; Taillard et al., 1981). At examination pain is provoked by pressure over the sinus tarsi and at attempt of supination. Meyer and Lagier (1977), in a majority of cases with sinus tarsi syndrome, observed arthrographic features corresponding with synovial inflammation and fibrous scarring tissue in the lateral talocalcaneal recess. They found no pathology at routine and stress radiographic examination. Zwipp and Tscherne (1982), however, determined talocalcaneal instability in a number of patients with this clinical syndrome and this association was also suggested by Kjaersgaard-Andersen et al., (1989).

Treatment of chronic lateral instability

Most reports in literature deal with the operative treatment of ankle instability. Some authors report that conservative treatment was undertaken prior to surgery, but little is known regarding the specific type and outcome of this treatment. It is stated that conservative treatment should be tried for all patients with chronic lateral instability and is definitely indicated for less active, low demand, and minimally symptomatic patients (Peters et al., 1991). There are no randomized studies that report on the success rate of treating individuals with chronic unstable ankles by conservative means as reported in the following (Peters et al., 1991).

The common non-operative treatment consists of physiotherapy modalities and taping and bracing. Based on the findings of the studies reported above (Tropp, 1985a; Tropp, 1986; Freeman et al., 1965; Gauffin et al., 1988) muscle strengthening and tilt board or ankle disk training are emphasized. These exercises have shown to give objective and subjective improvement. Theoretically these exercises address a whole range of the factors which seem to be involved in chronic lateral instability, at the same time.

Probably, as important as exercises to re-establish motor control, is the prevention of a reinjury and to break the vicious circle of recurrent sprains and subsequent peripheral deficits. Both ankle taping and braces are used (Drez et al., 1982) and continuation of this treatment during 3 to 6 months is propagated (Trevino et al., 1994). Taping has shown to decrease the incidence of ankle injury in basketball players (Garrick and Requa, 1973). In addition to restricting the extremes of ankle motion, it is suggested that ankle taping positively affects the proprioceptive function (Karlsson and Andreasson, 1992) and would stimulate the peroneus brevis muscle round heel contact during gait (Glick et al., 1976). However, the mechanical properties of ankle taping are dubious as it loses 40% of its effectiveness after 10 minutes (Glick et al., 1976; Laughman et al., 1984).

More mechanical support is expected to be provided by an ankle orthosis. It may act by holding the ankle in a neutral position, thus preventing initiation of inversion, and it may also give more mechanical support to ligamentous structures (Tropp et al., 1985c). Ankle orthotics, such as pneumatic ankle braces (Air-Stirrup) and lace-up braces are reported to be more effective than taping in preventing ankle injuries in football players (Rovere et al., 1988). The use of a brace was found to compensate the decrease of postural control found in the symptomatic legs of patients with chronic lateral instability (Fridén et al., 1989).

Frequently, patients with significant mechanical instability can still function when these braces are worn in situations such as sports. Patients with chronic lateral instability can improve with functional rehabilitation, and thus conservative treatment should be attempted prior to surgical intervention (Peters et al., 1991; Trevino et al., 1994). The indications for operative treatment are ill defined. Most authors report that failure of non-operative management is an indication to proceed to surgery. Generally, positive stress tests (to examine increase of talar translation and increase of inversion at the talocrural and/or subtalar level) on clinical examination are also included as a criterium. The importance of finding an increase of anterior talar translation and/or increase of talar tilt using stress radiography to demonstrate instability preoperatively is controversial. Only a few authors find a good correlation between these findings and the subjective complaints of the patients and use radiographic criteria as an indication for surgery (Karlsson, 1989). In a recent review article it was concluded that surgery is indicated when chronic lateral instability occurs in the normal day-to-day situation in which a brace is not practical (Trevino et al., 1994). Others might include patients, with higher physical demands regarding their work and/or sport.

More than 50 surgical techniques for reconstruction of the lateral ankle ligaments have been described. Roughly they can be divided into 2 groups: (1) reconstructions in which another structure or material substitutes for the injured ligament and (2) repairs in which the injured ligament is repaired secondarily with or without augmentation (anatomical repair). Based on a review of the literature, Peters et al. (1991) recommend anatomical repair of the ligaments. They recommend a non-anatomical reconstruction as described by Chrisman-Snook, based on its ability to reconstruct both the ATFL and the CFL, for the treatment of patients with generalized joint laxity, greater than 10 year time from injury to repair, significant arthritis and failed anatomical repair.

Summary of the literature review

Although most authors choose to emphasize the importance of one certain factor, they cannot, however, deny the influence of other elements. For example, hypermobility as a result of general joint laxity found bilaterally is reported to be of importance, but also hypermobility found unilaterally in an injured foot (Bonnin, 1944). Both are mechanical factors, but in one group of patients this is a predisposing factor and in the other group this is acquired. In the same study it is reported that these factors might only result in symptoms in those individuals with less developed muscular control. So, not only mechanical factors, but also muscle or motor control are involved. The same mix of different factors can be found in practically all studies. Karlsson (1989) is one of the few authors to find a strong correlation between mechanical instability and the subjective complaints of the patients. However, he also reports on the finding of a prolonged peroneal reaction time in the symptomatic legs, which is generally explained to be the result of a proprioceptive deficit. Again, both mechanical and so-called functional factors seem to be involved at the same time. Freeman (1965) introduced the term 'functional instability', found no correlation between mechanical instability and the subjective complaints and suggested proprioceptive deficit to be responsible for the symptoms. However, he also found that persistent varus instability of the talus plays a part in the etiology in a small group of patients. Tropp (1985) finds decreased central postural control to be a predisposing factor correlating with symptoms of functional instability. In addition he reports on peripheral deficits in the form of peroneal muscle weakness (Tropp, 1986). Fridén et al. (1989) were able to discriminate between the injured and the uninjured leg and found lesser postural control when patients stood on the injured leg. But, they also found the postural control in the uninjured leg to be impaired as compared with the control group. So, both central predisposing factors as well as peripheral acquired factors are involved. The same can be concluded with regard to the lowered motor conduction velocity of the deep peroneal nerve found by Kleinrensink et al. (1994).The recent finding that hypermobility and poorer proprioceptive feedback might be associated, would imply that proprioceptive malfunction can be either a predisposing or an acquired factor (Hall et al., 1995).

Listing most of the factors that are involved in the etiology of chronic lateral instability demonstrates that practically all factors have been reported both as predisposing and as acquired. Generally, two types of instability are described, mechanical and functional instability. One can now try to divide all factors into those that are involved in mechanical stability and those that determine functional stability, but from a biomechanical (and orthopaedic) point of view it is more practical to differentiate between passive and active factors (Table 1).

In conclusion, it is obvious from the previous review of the literature that multiple factors are involved in chronic lateral instability of the foot. There seems to be general consensus that numerous factors can play a role at the same time.

Table 1. Endogenous passive and active factors that determine stability of the foot.

passive	active
• axes of rotation, determined by the geometry of the bones and articular surfaces • ligaments • soft tissue characteristics, like stiffness	• muscles: muscle forces are determined by central motor control, which a.o. depends on: - proprioceptive feedback - motor nerve conduction - muscle strength - concentration - vision

Aim of the present study

In this thesis, a series of clinical-experimental and radiographic studies on the pathogenesis of chronic lateral instability of the foot is described. The onset for the study described in chapter 2 was based on a previous electromyographic study performed by van Linge (1988). In that study the function of lower leg muscles during normal walking was examined. The EMG activity of the extensor digitorum longus, tibialis anterior and peroneal muscles were registered, while walking on a treadmill, both, with a hand on the railing to ensure balance control and, without this external support. One of the main findings was that activity of the peroneal muscles was only seen when subjects had to maintain balance in a natural way, without external support. Activity of the peroneal muscles, occurring in the stance phase, was variable from step to step and seemed to alternate with activity of the tibialis anterior. No important activity of the peroneal muscles was found when balance was secured by external support. Van Linge concluded that the foot was perfectly stable without the use of the peroneal muscles and that balance control was the primary function of the peroneal muscles. Following this, van Linge suggested that the peroneal muscles could play no part in protecting the foot against an inversion injury, unless one would walk in a atypical manner, actively contracting the peroneal muscles during placement of the feet on the ground, as if one was walking through a minefield. In his study, however, only a small group of subjects were examined and the activity of the muscles was not quantified. It was decided to perform a similar study in which not only the effect of external support on peroneus longus and tibialis anterior muscle activity, but also the effect of a difference in walking speed would be examined. Peroneus longus and tibialis anterior muscle activity in the stance phase were registered electromyographically and, hereafter, the signals were further analyzed and quantified. Twenty-five patients and ten controls were examined. It was investigated whether the peroneus longus is active when the foot is at risk of sustaining an inversion injury and whether a change in muscle control can be identified in patients with chronic lateral instability of the foot.

Nearly all clinical studies concerning the investigation of passive stability of the ankle and foot have focused on the loss of integrity of the ligaments. Functional anatomical studies have been performed to investigate a.o. the role of the ligaments and the axes of rotation of the ankle and tarsal joints. No study has been performed to determine the passive stability of the foot as a whole. In view of the finding that the peroneal muscles might not be sufficiently active, or might not be active at all, to protect the foot against an inversion injury at the moment of heel contact (chapter 2), the role of passive stability of the foot might be of considerable importance. In the study, presented in chapter 3, an effort is made to determine differences of passive stability between feet under standardized conditions, using a custom-made platform that can tilt around a movable axis. It was investigated whether the feet of patients with chronic instability complaints are passively less stable than the feet of healthy controls.

In chapter 4 the role of the foot configuration in chronic lateral instability is explored. The geometry of the bones, the foot build, is one of the passive factors involved in determining the stability of the foot. It is suggested that feet with a cavovarus build are more subjective to inversion injuries. Using standardized lateral X-rays of the foot and, using four geometric indices as parameters, we investigated if a relationship between foot build and chronic lateral instability could be found. In the same study, the interrelationship between the used foot indices was evaluated.

In chapter 5 the position of the rearfoot in the frontal plane at the moment of heel contact was assessed with the help of two-dimensional video-based analysis. On the assumption that feet with a more inverted position are more prone to an inversion injury, we examined whether the feet of patients with chronic lateral instability were in a more inverted position as compared to the feet of a control group.

The great majority of studies regarding the diagnosis of mechanical instability in patients with chronic lateral instability is focused on finding pathologically increased motion in the talocrural joint. According to the simple model, described below, however, instability in the subtalar joint may also be involved. As soon as the foot is loaded, with the forcereaction acting upon the plantar aspect of the foot at a point medially to the point through which the body-weight is transmitted to the foot, this will result in a lever arm which enforces inversion. Only adequate muscle force, providing a compensatory eversion lever arm, or unloading of the leg, or change of the line of body-weight transmission will prevent an inversion injury. Inversion of the foot is a function primarily of the tarsus, not of the talocrural joint.

Movements of the tarsus are coupled to movements of the lower leg, through the talus and the ankle ligaments. If inversion is sudden, extreme and with excessive force it seems reasonable to presume that the soft tissues and ligaments at the lateral aspect of the hindfoot bypassing the subtalar joint are as much at risk of getting ruptured as the talocrural ligaments, as illustrated in a drawing by van Linge (Fig. 1). That the ATFL is, still, more often ruptured is explained by the fact that a rotation component between the talus and the ankle mortise is involved and, probably, by the less strong mechanical characteristics of this ligament. A review of the literature learned that a large spectrum of diagnostic criteria to establish abnormal subtalar tilt is being used. There is, also, no consensus regarding the method that is used to stress the subtalar joint. As a result the findings of all different studies are not comparable. In chapter 6, an investigation to determine a possible subtalar

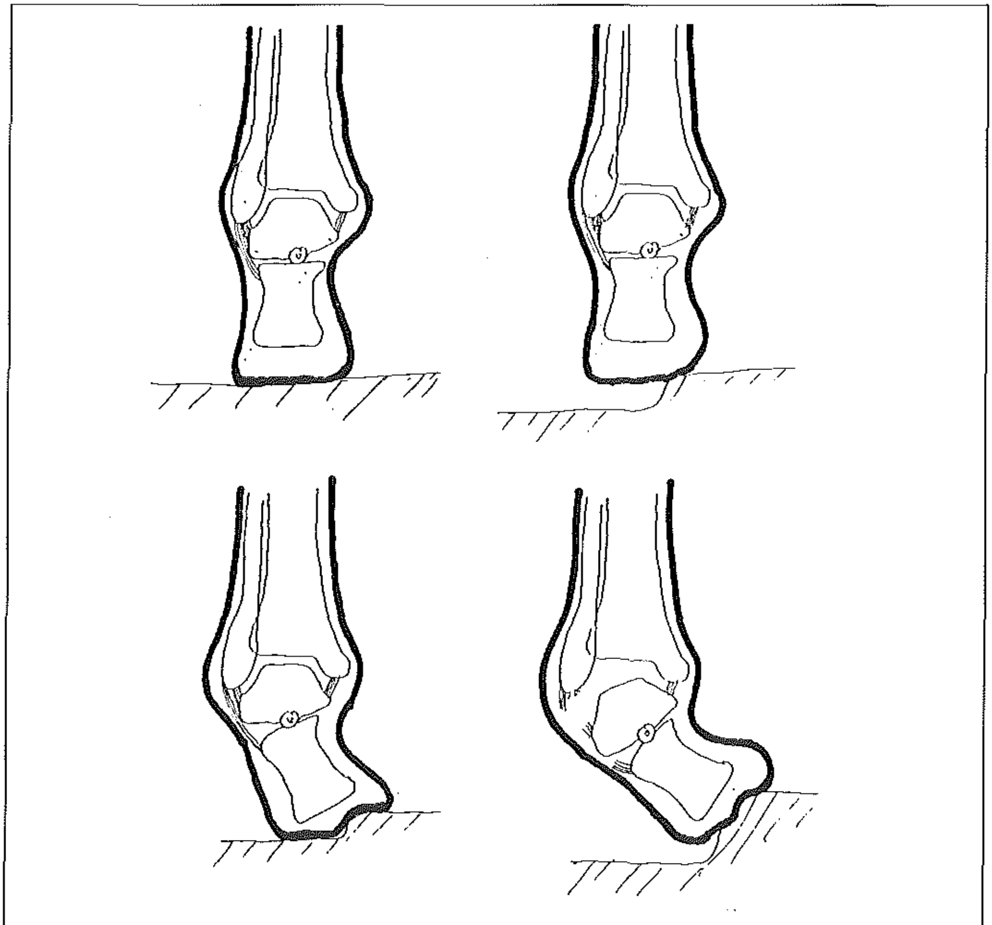

Figure 1. The mechanism of injury of the lateral ligaments of the hindfoot (B. van Linge, July 1988).

component in a group of 33 patients with chronic ankle instability, is presented. In this study a standardized radiographic assessment was made of talar and simultaneous subtalar tilt.

The study presented in chapter 6 provided no solution to the problem how to objectify subtalar instability. It was suggested, that increase of tilt in the talocrural or subtalar joint, found between full inversion and maximal inversion stress of this joint, could possibly help to discriminate between physiological and abnormal talar tilt. Further research, presented in chapter 7, was performed on a small group of patients with chronic unilateral instability of the foot in which CT-imaging of the stressed joints was performed, in order to find a more objective method to evaluate subtalar tilt.

Peroneus longus and tibialis anterior muscle activity in the stance phase

a quantified electromyographic study of 10 controls and 25 patients with chronic ankle instability

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Chapter 2

Summary

The electromyographic activity of the peroneus longus and anterior tibial muscles of 25 patients with chronic ankle instability (18 patients with bilateral symptoms and 7 patients with unilateral complaints) and 10 controls was registered during stance phase under different walking conditions.

With balance secured by external support, there was a variable amount of peroneal activity, most of which was found in the third quarter of stance. A high increase of peroneus longus activity starting after foot-flat was found when subjects had to maintain balance in a natural way. No difference in peroneal activity was found in relation with instability complaints. It is thought that the peroneus longus serves to maintain balance, that this function decreases with increase of speed and that one cannot rely on this muscle to prevent an inversion injury during normal walking.

The anterior tibial muscle was predominantly active in the first quarter after heel contact. An increase in activity in the second quarter as an effect of loss of secured balance suggests that this muscle plays some part in balance control, but this is not its main function. A significant increase in tibialis anterior activity was found in patients with bilateral instability. No significant difference was found between the symptomatic and asymptomatic leg of patients with unilateral instability within the same walking conditions. These findings suggest changes in central control.

Introduction

The peroneal muscles are principally evertors (pronators) of the foot and are predominantly active during the stance phase of gait. They are also plantarflectors of the foot at the beginning of push off (Sutherland, 1966; Basmajian, 1967; Jonsson and Rundgren, 1971; Ambagtsheer, 1978). However, the specific role of the peroneal muscles during gait is still unclear and has received little attention. Only once it has been described that these muscles take part in controlling the medial lateral balance in walking (Matsusaka, 1986).

Numerous factors, such as proprioceptive deficit, prolonged peroneal reaction time, increased postural sway, weakness of the peroneal muscles and damage of the peroneal nerves have been related to functional instability of the ankle/foot (Hyslop, 1941; Bosien et al., 1955; Freeman et al., 1965; Nitz et al., 1985; Tropp, 1985; Karlsson, 1989; Konradsen and Ravn, 1990). Whether these factors result in changes in the activity of the peroneal muscles during walking is still unknown. The peroneal muscles are focused on in studies of chronic instability, because it is assumed that, if they are active at the moment when the foot is placed on the ground, they will protect the foot against inversion trauma. However, it is not clear whether these muscles are always active at this moment (Glick et al., 1976; van Linge, 1988).

Function of the tibialis anterior has not been examined in studies concerning chronic instability. However, it seems interesting to include an antagonist of the peroneus longus in view of the aspect of muscle coordination. To measure activity of the tibialis posterior would obviously be the first choice. Since this muscle is located in the deep compartment, the use of intramuscular electrodes in a dynamic situation would be required and therefore examination was restricted to the tibialis anterior.

We investigated whether the peroneus longus muscle is active when the foot is at risk of sustaining an inversion injury and whether a change in muscle control can be identified in patients with chronic lateral instability. To answer these questions we examined electromyographically the activity of the peroneus longus and tibialis anterior muscles during the stance phase, 1) with and without external support, 2) under different walking speeds and 3) to find changes in activity of these muscles in patients with chronic lateral instability.

Patients and methods

Twenty-five patients (18 women) with chronic lateral instability complaints were consecutively recruited from the orthopedic out-patient department (Table 1). All

Table 1. Some characteristics of patient and control groups

Group	number	gender		age	weight	height
		M	F	m (range) sd	m (range) sd	m (range) sd
bilateral symptomatic	18	6	12	35 (21-67) 14.1	69 (54-90) 11	172 (156-186) 9.6
unilateral symptomatic	7	1	6	28 (18-43) 7.8	76 (58-101) 11	174 (165-183) 5.1
controls	10	6	4	32 (19-41) 7.5	69 (53-88) 10	177 (164-201) 11.8

M = male
F = female
m = mean
sd = standard deviation

patients complained of frequent inversion injuries and 'giving way' sensations of one or both feet. Symptoms like pain, swelling and reduced activity level were often present, but were minor complaints (for instance, only for a short period following a sprain). The patients with a possible osteochondral laesion were excluded. Patients were otherwise healthy, with no other musculoskeletal or neurological dysfunction, and could walk without limping. The control group consisted of ten subjects without any symptoms and a history without previous inversion injuries.

Muscle potentials from the peroneal and anterior tibial muscles were registered with Medicotest (Type E-100-VS, Ag/AgCl, diameter 5mm) disposable bipolar surface electrodes, spaced 17mm center-to-center. The skin was prepared to lower skin impedance to less than 10 kΩ. The electrodes were placed longitudinally to the working line of the muscle on the most prominent part of the muscle belly. An earth electrode was applied to the superior non-muscular part of the anterior surface of the tibia. Electrode gel was introduced between the skin and the electrodes before fixation. A force sensing resistor (FSR, Interlink Electronics, diameter 1.5cm, thickness 0.32mm) was placed under the heel to register heel contact. The EMG signals were preamplified (Medelec AA 63, gain 15x, impedance 100 MΩ). The raw EMG signals were then bandpass filtered (high-pass filter (HPF) 20Hz, low-pass filter (LPF) 10kHz), further amplified (Medelec AA 6T, gain 1000x) and recorded on a Racal Thermionic band recorder. The signals of the FSR were passed through a Signal Conditioner (Department of Biomedical Physics and Technology, Erasmus University Rotterdam) and collected in parallel with the EMG signals on the band recorder. During the recordings the signals were made visible with an Astromed recorder (MT 8500).

Previous experiments and pilot studies showed that strong contractions of neighbouring muscles did not interfere with the signal of the muscle that was registered. Prior to each investigation, the source of the electric signal was checked. The subjects were asked to perform specific movements in which only one of the tested muscles participated. When during these movements, activity of only this muscle was registered, the placement of the electrodes was considered appropriate. Subjects were also asked to perform a maximal effort of the muscles separately.

The subjects walked on a treadmill (Enraf Nonius TR 4009) at a speed selected as the most comfortable (range 3.7-4.3km/hr). After they felt comfortable while walking on the treadmill, 4 recordings followed. First, while walking at the chosen speed without external support and, secondly, while walking at the same speed with a hand on the railing of the treadmill to ensure balance. The same recordings were made while walking at half the chosen speed (range 1.8-2.2km/hr).

For further analysis, the EMG signals of the maximum efforts and walking sessions were filtered and amplified (HPF 20Hz, LPF 550Hz, gain 5x) and transformed into linear envelopes. This was done by first full-wave rectifying the raw signal and filtering the result (LPF 45Hz, EMG Filter). The linear envelopes signals underwent analog to digital (A/D) conversion (Dataq Instruments, inc. Model DI-420) at a sampling rate of 250Hz with a 80386 SX, 16MHz computer.

The highest peak of the linear envelope of each individual muscle was determined. This amplitude was then used as a reference value (100%) and was the normalizing factor for the linear envelope data obtained in gait for this muscle.

From each gait recording (4 recordings per leg) 20 steps and per step, only the stance phases were analyzed. The stance phase was defined as the first 60% of the stride following heel contact. For normalization in time and statistical calculations, the stance phase was defined in 4 equal quarters. These quarters of the stance phase roughly coincide with known parts of the walking cycle (as standardized in CAMARC-II project, 1993). The first quarter coincides with the part between heel contact and foot-flat at about 15% of the walking cycle, the second quarter with the part between foot-flat and mid-stance at 30%, the third quarter with the following part until heel-off and the last quarter with the part in which push-off takes place ending with toe-off at 60%.

Statistics

Statistical tests were performed using SPSS/PC+ (version 5.0.2) and BMDP (module 5V). For each test $p<0.05$ was considered significant. Differences in age, weight and height between groups were analyzed using Student t-test. To study whether the groups were comparable in gender, a chi-square-test was used.

The mean activity (m) of each muscle during each quarter of stance was determined for each step. An intra-subject mean (M) was defined as the average of the means (m) over all 20 steps.

The mean activity (m) was analyzed after logarithmic transformation using repeated measures ANOVA to determine the simultaneous influence of 1) the within-subject factors: speed, external support and quarter of stance, 2) the between-subject factor: group (patients versus controls) and 3) the relevant interactions between the factors. Simple analyses of differences of variables between patients and controls were also performed, using the Mann-Whitney U-test.

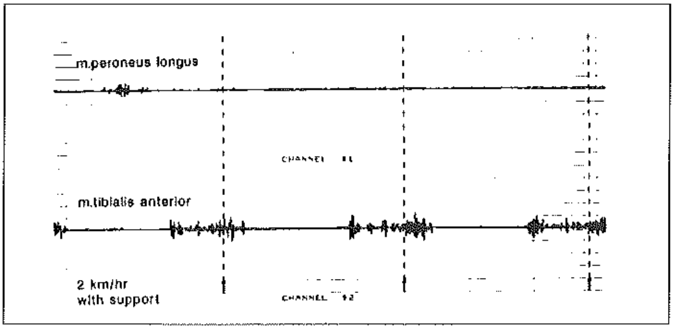
To analyze differences between the symptomatic and asymptomatic leg in patients with unilateral instability complaints, the Wilcoxon matched-pairs test, after logarithmic transformation, was used. This test was also used to study the effect of the above mentioned within-subject factors in a simple way.

Results

To illustrate our findings, a case is presented in Fig. 1. Walking at a speed of 2km/hr while balance is secured with external support, the minimal activity of the peroneus longus is striking. The tibialis anterior shows a regular activity, starting at the beginning of the sway-phase, followed by a dip in mid-swing and increasing around heel contact. As soon as the subject has no support and has to maintain balance in a natural way, there is strong activity of the peroneus longus in the stance-phase, with bursts up to 65%. However, during some steps no activity of peroneus longus is seen and during these steps the tibialis anterior is active in the stance-phase. This indicates that in this subject both muscles take part in controlling balance with alternating activity.

Comparing patients having bilateral complaints with the controls (Table2)

No statistically significant difference regarding age (p=0.6), weight (p=0.3), height (p=0.7) and gender (p=0.2) were found between the groups. (The figures in Table 2 refer to percentage activity. They seem to be low, but one must realize that they are mean values of the intra-subject means (M), which were the average of the means (m) over twenty steps.)



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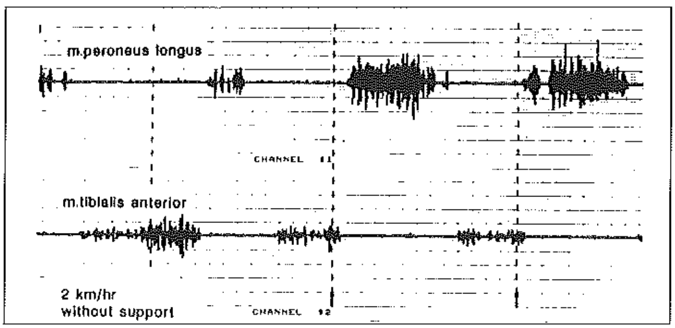

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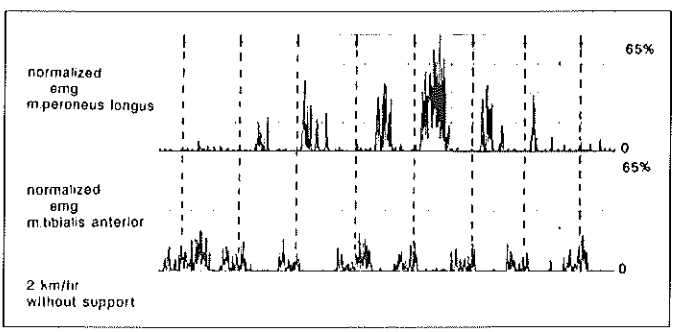

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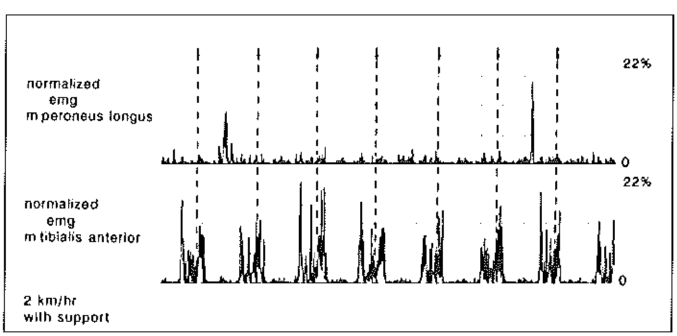


1d

Figure 1.
An example of a patient. The arrows and the dotted line indicate the time of heel contact. While walking at a speed of 2 km/hr with external support minimal activity of the peroneus longus is seen (Fig. 1a).
Without support, there is marked increase of peroneus longus activity. This activity is variable and seems to alternate with activity of the anterior tibial muscle (Fig. 1b). Normalized EMG signals with (Fig. 1c) and without support (Fig.1d). Note the high bursts of peroneal muscle activity used to maintain balance. Division 22% or 65% of highest peak activity, respectively.

Table 2. Effects of speed and external support on activity of peroneus longus and tibialis anterior measured on 18 patients with bilateral instability complaints and 10 controls.

quarter of stance		peroneus longus						tibialis anterior					
		bilateral symptomatic			controls			bilateral symptomatic			controls		
		Mn	Md	IQR	Mn	Md	IQR	Mn	Md	IQR	Mn	Md	IQR
speed													
2 km/hr	1	3.4	3.7	1.7-4.3	3.3	2.5	1.7-3.6	5.5	5.1	3.1-8.1	3.4	3.9	2.1-4.3
	2	4.4	3.7	2.7-6.1	4.7	3.7	1.9-6.4	1.8	1.5	.9-2.6	1.4	1.3	.7-1.9
	3	4.9	4.2	2.8-7.6	5.4	3.7	2.6-7.6	1.0	.9	.7-1.3	.7	.7	.5-1.0
	4	4.6	4.4	2.9-5.2	3.6	2.9	2.0-5.1	.8	.7	.7-1.0	.5	.5	.4-.6
4 km/hr	1	5.0	4.1	3.0-5.8	4.0	2.7	2.3-4.0	8.0	7.2	5.6-8.7	5.0	4.9	4.0-6.0
	2	5.0	3.6	2.6-6.3	4.6	3.5	2.6-4.8	1.5	1.5	.9-2.0	1.1	1.0	.7-1.4
	3	8.9	7.9	4.9-10.0	7.0	6.3	4.8-8.7	1.2	1.0	.8-1.7	.6	.6	.4-.9
	4	7.2	5.6	4.3-8.8	4.9	3.8	2.8-6.9	1.2	1.0	.6-1.6	.6	.5	.4-.7
ext. support													
with	1	3.0	2.0	1.7-3.9	2.4	1.6	1.3-2.5	7.1	6.0	4.6-8.6	4.4	4.5	3.6-5.5
	2	1.9	1.4	1.2-2.0	2.0	1.5	.7-2.3	1.3	1.2	.6-1.7	1.0	.8	.5-1.5
	3	5.3	4.7	3.3-5.7	4.5	3.9	1.7-5.1	.9	.9	.5-1.2	.5	.6	.4-.7
	4	5.5	4.4	3.4-6.7	3.5	3.2	1.7-4.5	.8	.7	.5-1.1	.5	.5	.3-.6
without	1	5.4	4.9	3.5-6.4	4.9	3.6	2.7-5.5	6.3	5.9	4.2-8.0	4.0	4.2	2.7-5.1
	2	7.4	5.4	4.6-11.2	7.2	5.2	4.2-9.2	2.1	1.9	1.1-2.6	1.5	1.5	.9-.8
	3	8.4	6.7	5.1-12.4	8.0	6.0	5.4-10.7	1.3	1.1	.8-1.7	.8	.8	.5-1.1
	4	6.3	5.1	4.2-7.0	5.0	4.4	2.9-7.9	1.2	.9	.7-1.3	.6	.6	.4-.7

Mn = mean; Md = median; IQR = inter quartal range (50% of all mean activity was within these limits)

Peroneus longus

Higher walking speed and loss of external support resulted in a significant increase of peroneal activity (both $p<0.0005$). Both factors also have a significant effect ($p<0.0005$) on the distribution of activity over the 4 quarters of stance. The amount of activity was highest in the third quarter of stance and was lowest in the first quarter of stance.

With increasing speed, the increase in activity was highest in the third and in the fourth quarter of stance. No major changes were found in the second quarter of stance. However, walking without support led to major increase in peroneal activity in the second quarter of stance. Nevertheless the overall activity remained highest in the third quarter.

Table 3. Simultaneous effects of speed and external support on activity of peroneus longus, averaged out over the four quarters of stance

The figures show percent activity.

patients with bilateral complaints (n = 18)			controls (n = 10)		
speed	external support		speed	external support	
	with	without		with	without
2 km/hr	2.1	5.5	2 km/hr	1.4	4.7
4 km/hr	5.0	5.5	4 km/hr	3.7	5.1

A significant (p<0.0005) interaction between speed and external support was found (Table 3). With a higher speed the effect of loss of external support was less than with a lower speed. This coincides with the finding that an increase in speed had less effect on the increase of peroneal activity when the subjects walked without external support.

There was no difference in the activity of the long peroneal muscle between the groups (p=0.5) regarding speed, the presence of external support or the distribution of activity per quarter of stance.

Tibialis anterior

Most activity of tibialis anterior under all circumstances was found in the first quarter of stance. At a higher speed, a significant increase of tibialis anterior activity was found (p<0.0005). The influence of external support on the total amount of tibialis anterior activity was not significant (p=0.3). However, external support significantly modified the distribution of activity per quarter of stance significantly (p<0.0005).

A significant difference in tibialis anterior activity was found between the groups (p<0.0005). Over all measurements, the tibialis anterior activity in the first (p=0.03) and third (p=0.04) quarters of stance was higher in symptomatic legs than in the control legs. This difference was not influenced by external support (p=0.8), but interaction with the factor speed (p=0.01) was found. At a lower speed, activity was higher in the fourth quarter while, at a higher speed, this was the case in all quarters, except the second.

Comparing the symptomatic leg with the asymptomatic leg in patients with unilateral instability complaints

Peroneus longus

Statistically, the symptomatic and asymptomatic legs did not behave differently. With secured balance, the activity of the peroneus longus increased significantly after an increase in speed (p=0.03) in all quarters except the fourth. However, without external support an increase in activity with an increase of speed was significant (p=0.04) only in the first quarter of stance. While walking with a lower speed, both symptomatic and asymptomatic legs showed more activity without than with secured balance in all quarters of stance (p=0.04). At a higher speed, this effect was significant only in the first two quarters of stance (p=0.02).

Tibialis anterior

Under the same walking conditions, no significant difference in activity was found between symptomatic and asymptomatic legs. However, while walking with secured balance, only asymptomatic legs showed an increase in activity with an increase in speed. This increase was seen in the first (p=0.02) and third quarter (p=0.02). Without support, both asymptomatic and symptomatic legs show increases in activity in the first quarter (p=0.03) with a higher speed. Walking at a lower speed, external support had no effect on tibialis anterior activity in symptomatic legs. However, in asymptomatic legs, an increase in activity was found in the second and third quarters (p=0.04). At a higher speed, this effect was seen in both symptomatic and asymptomatic legs in the second quarter of stance (p=0.02).

Discussion

Peroneus longus

There is controversy as to whether the peroneal muscles are active at the time of heel contact (Glick et al., 1976; van Linge, 1988). Ambagtsheer (1978) found activity of the peroneus longus in 2 of 11 subjects before heel contact, but described no further activity of this muscle until foot-flat. Winter and Yack (1987) found an initial peak of peroneus longus at foot-flat to control inversion. In our study a variable and relatively less amount of peroneus longus activity was found in the first part of stance and it seems that this activity is to control the position of the foot, in which the peroneus acts as a pronator.

Various investigators have reported that the peroneus longus is predominantly active during the parts of stance following foot-flat. EMG activity of the peroneus longus in gait has seldom been recorded and, when examined, the function of the

peroneus longus is related to stabilization of the foot and to acceleration about the moment of push-off (Sutherland, 1966; Ambagtsheer, 1978; Winter and Yack, 1987). Matsusaka (1986) tested gait from the viewpoint of ground reaction force, EMG activity and motion of pronation-supination in the foot. He demonstrated that the activity of the tibialis posterior and peroneus longus alternate in relation to the amplitude of the lateral component of the ground reaction force and take part in controlling balance. Ambagtsheer (1978) occasionally found the same alternation, but thought it improbable that this was to maintain balance.
We found a clear difference in all subjects between walking with and without secured balance. With secured balance, most peroneus activity takes place in the third and fourth parts of stance. This activity emerges at each step and increases as walking speed increases. We suggest that this activity is related to acceleration. However, activity of a muscle can vary considerably between individual subjects as was reported previously (van der Straaten et al., 1975; Pedotti, 1977; Arsenault et al., 1986). Without secured balance, the subjects had to maintain balance of the body in a natural way and a clear increase of peroneus activity was seen in the period following foot-flat. Great bursts of activity were found that varied from step to step (Fig. 1). This pattern of activity was present in all subjects and it is therefore suggested that balance control is the main and most common task of the peroneus longus during normal walking. The interaction found between the factors external support and speed can be explained as follows. Standing on one leg without support, all activity of the peroneus longus is used to maintain balance in the frontal plane. The slower the walking speed, the more this muscle is still used to maintain balance. However, with increase of speed, this function decreases and other activities concerning positioning of the foot, acceleration and what will later be described as active stabilization start to dominate. Medial lateral balance is probably increasingly secured by the lateral position of the foot with respect to the plane of progression; this is decided by the trajectory of the foot during swing which is mainly controlled by the hip abductors and adductors (Winter, 1994).

Tibialis anterior

Movement of the foot in the first part of the walking cycle is accompanied by major peak activity of the tibialis anterior. The tibialis anterior contracts eccentrically and acts together with other weight-accepting muscles, absorbing the shock and breaking the slight plantar flexion and pronation of the foot (Milner et al., 1971; Ambagtsheer, 1978; Nilsson et al., 1985; Ericson et al., 1986; Winter and Yack, 1987). In our study, the main very regular peak of tibialis anterior activity during stance was also found to occur in the first quarter of stance. With increase in walking speed an increase in tibialis activity occurred. These data are comparable with previous findings (Milner et al., 1971; Murray et al., 1984; Arsenault et al., 1986; Yang and Winter, 1985).

We found a far less and a variable activity of the tibialis anterior after foot-flat.

Activity of the tibialis anterior in mid-stance has received little attention. The activity varies and is believed to stabilize the tarsus (Ambagtsheer, 1978). A slight shift of activity to the second quarter of stance when subjects have to maintain balance suggests that this muscle is active for balance control, although no increase of the total amount of activity was found. An increase in activity in the period following foot-flat in the group of patients with unilateral complaints supports this finding.

Passive stability

It has been reported that the peroneus longus plays no major role in the static support of the foot when balance is attained (Basmajian and Bentzon, 1954; Basmajian and Stecko, 1963) and that the foot is perfectly stable in the frontal plane as soon as the joints are axially loaded (Stormont et al., 1985). Thus, with adequate positioning, with sufficient support of the lateral aspect of the foot and with secured balance the foot is stable. This could be called passive stability. Our findings support the view that passive stability of the foot in the walking individual is not determined by the peroneus longus. Activity during stance serves to maintain balance and to achieve forward progression, but is not used to secure passive stability. This activity is not sufficient to provide stability when a sudden inversion torque unexpectedly does take place. However, in anticipation of or as reaction to torque or during higher level activities, the peroneus muscle can stabilize/protect the foot by strong additional activity. This might be called active stabilization.

Active stability

Freeman et al. (1965) first suggested proprioceptive deficit because of torn ligaments and capsule as a possible cause of functional instability. The finding of a prolonged peroneal reaction time and increased postural sway seems to substantiate this theory (Tropp, 1985; Karlsson, 1989; Konradsen and Ravn, 1990). Peroneal muscle weakness (Bosien et al., 1955; Tropp, 1985) after immobilization of the muscle or due to overstretching of the peroneal nerves at the time of inversion trauma has been described (Hyslop, 1941; Nitz et al., 1985). Kleinrensink et al. (1994) found prolonged peroneal reaction time as result of such overstretching. However, Larsen and Lund (1991), who looked at muscle activity instead of at reaction time, found no significant differences between the healthy and the diseased legs of patients with unilateral chronic instability. Konradsen et al. (1993) found that input from muscle and tendon afferents (while information from the joint and ligament mechanoreceptors was suppressed) during active movements was adequate for an accurate sense of ankle position. This could explain why in our study the activity pattern of the peroneus longus during walking remained unchanged, although ligaments and capsule have been disrupted and propriocepsis might have been disturbed. Another reason could be the fact that no active stabilization was provoked while our subjects walked on the treadmill.

Control

A correct positioning of the foot is important to avoid a possible inversion torque. Peroneal activity around heel contact was variably present, presumably to control the position of the foot. While no difference between patients and controls regarding peroneus longus activity was found, a significantly higher amount of tibialis anterior in patients with bilateral complaints was noted before the foot became fully loaded. This difference was not found between the symptomatic and asymptomatic legs of patients with unilateral symptoms. It thus seems that a difference of central control may play a part. As the increase of tibialis activity is not compensated, a more inverted position of the foot around heel contact was expected. However, this was not measurable in another study using 2-D video analysis (Louwerens and Hoek van Dijke, 1994).

Passive stability of the foot in chronic lateral instability measured with a tilting platform

Chapter 3

Summary

Multiple passive and active factors are involved in chronic lateral instability of the foot. Passive behaviour of the foot is not only determined by the integrity of the capsulo-ligamentous complex, which until now has received most attention, but also by the shape/geometry of the joint surfaces and the bones and thus by the position of the axes about which the bones rotate.

In the present study an effort was made to determine difference in passive stability of the foot between a group of 20 patients with chronic lateral instability complaints and a control group of 10 subjects. A custom-made platform under which the tilting axis could be changed was used under standardized conditions.

Although the results show a tendency of the symptomatic feet to tilt more readily, the differences were not statistically significant.

Introduction

Regardless of the form of initial treatment, around 30% of the people who sustain an inversion injury of the foot have residual complaints (Hansen et al., 1979; Thermansen et al., 1979). A number of the patients complain about pain, stiffness and swelling during or after activity, but the majority complains about instability of the ankle/foot with 'giving way' sensations, frequent sprains and problems during walking on uneven ground. This clinical syndrome, called chronic lateral instability, has been attributed to a series of passive and active factors (Bosien et al., 1955;

Freeman et al., 1965; Broström, 1965; Tropp, 1985a; Karlsson 1989). Passive factors which determine stability are the shape of the joint surfaces, the ligaments, the geometry of the bones, the position of the axes about which the bones move and also extrinsic factors such as the shoes and the ground. Active factors which may be involved are a.o. the muscles, balance/motor control, proprioception and function of the peroneal nerve.

In the present study it was investigated whether it is possible to determine differences of passive stability between feet. As explained in a model of our experimental set up (Fig. 1), the underlying thought is that the moment on which tilting/rotation of the foot starts is related to the axis around which inversion takes place. The behaviour of the foot was determined by the total of all passive factors and influence of active factors was excluded. The line/axis about which the foot of a patient with chronic lateral instability tilts was expected to be more laterally than that of someone without these complaints.

In order to test this hypothesis the tilting axis of the feet of a group of twenty patients and ten controls was examined under standardized conditions. A custom-made platform under which the tilting axis could be changed was used.

Patients and methods

Patient and control group

Twelve patients with bilateral and eight patients with unilateral chronic ankle instability were examined. The patients were recruited consecutively from the orthopaedic out-patient department. All patients included not only complained of 'giving way' sensations but also suffered frequent inversion injuries. Typically this already occurs when they misstep on a small stone or walk on uneven ground. Complaints existed for more than two years. Symptoms like pain, swelling and disability were minor. All patients could walk without pain and without limping. The control group consisted of ten subjects without any leg or ankle symptoms. Anthropometric data of the groups are summarized in Table 1.

Methods

The midline was used as the reference line for each foot, making comparison between feet possible. This line is defined as the bisecting line between the inner and external tangents to the footprint, as standardized in CAMARC-II (1993). In order to establish the midline of a foot, a special apparatus was developed (Fig. 2). Subjects were asked to place their foot on the apparatus while they were in a sitting position. Adjustable discs were placed against the medial prominence of the first metatarsal head and the lateral prominence of the fifth metatarsal head and on the inner and outer side of the broadest part of the heel. Hereafter, the midline of each

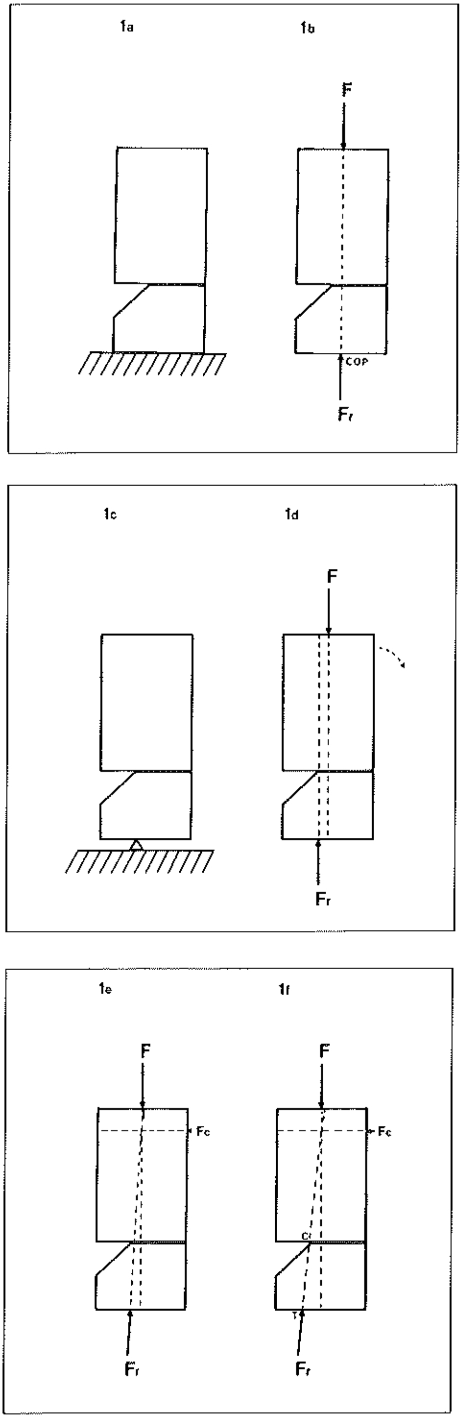


Figure 1. Model on which the present study is based.

Fig.1a. Two blocks are placed upon each other and are supported by a surface. Fig.1b. The blocks are loaded by a force (F), resulting in a reaction force (Fr). The point where Fr acts upon the blocks is defined as the center of pressure (COP). Equilibrium exists when these two forces have the same line of action. Figs.1c and 1d. When the blocks are placed on a wedge, Fr can only act through the contact point. If this point is aside the line of action of F, equilibrium will be disturbed, which results in tilting. Fig.1e. A way to maintain equilibrium, is by applying a third force (Fc) as illustrated. One of the conditions necessary for this equilibrium is that the 3 lines of action of these forces intersect in one point. Fr now has a slightly oblique direction. Fig.1f. When the wedge is moved further to the left equilibrium will be disturbed as soon as the action line of Fr passes point C. If this happens the blocks will collapse around point C.

It follows that equilibrium is not necessarily disturbed when Fr acts aside of the COP determined in Fig.1b. In the experimental set-up used in the present study an effort was made to apply this model to the lower limb in order to determine point T. Point T is thought to be related with the axis of rotation around which the foot inverts (corresponding with point C in the model).

Table 1. Anthropometric data of the patient and control groups.

	patients		controls
	bilateral symptomatic	unilateral symptomatic	
no. and gender	12 (4 M, 8 F)	8 (3 M, 5 F)	10 (6 M, 4 F)
age (yr) - mean ± sd	32 ± 13.6	28 ± 6.0	31 ± 7.3
range	21 - 67	18 - 36	19 - 41
height (cm) - mean ± sd	174 ± 7.7	175 ± 3.9	176 ± 10.5
range	160 - 186	170- 183	165 - 201
weight (kg) - mean ± sd	74 ± 10	77 ± 11	69 ± 10
range	55 - 90	65 - 101	53 - 88

M = male
F = female
sd = standard deviation

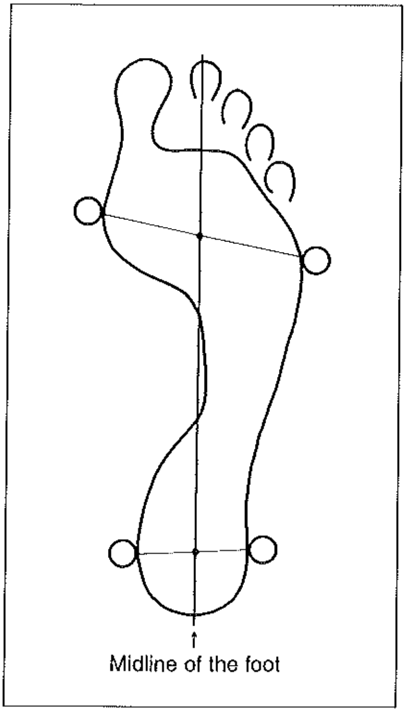
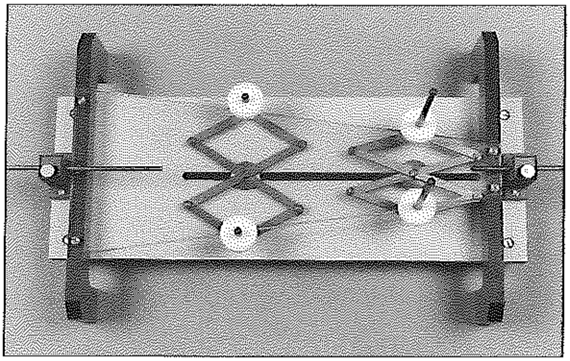


Figure 2. The axis or midline of the foot is the bisecting line between the inner and the external tangents to the footprint (left). Photograph of the used apparatus (below).



foot was marked. To test the reproducibility of this device, the midline of ten separate feet was determined twice with a period of at least a week between each occasion. Both times the midline found was indicated on a separate footprint recorded with footmats.

Of each foot the width and the length was measured in millimeters (mm) with an optical device (accuracy plus-minus 1mm in adults).

Examination using the tilting platform was performed with the subjects in an unconstrained sitting posture with the use of backrest and armrest of a chair which was adjustable in height (Fig. 3). They were instructed to look to a point on eye level while the measurements were made. The hips and knees were in a 90° flexed position and both feet were placed on the platform in a neutral position. The tip of the lateral malleolus and the head of the fibula were marked with a pencil as also the tuberosity of the tibia. The foot which was to be tested was placed on that part of the platform that could make a varus tilt. The midline of the foot was placed exactly on the zero-line of this part. The position of the lower leg in relation to the foot and the platform was controlled by two vertically projected lines provided by two slide projectors. These were projected at right angles to the sagittal and frontal plane, one line coinciding with the line between the tip of the lateral malleolus and the head of the fibula and the other with the line running from the midline of the foot to the tuberosity of the tibia. This position was maintained by a cap placed just above the knee upon the upper leg and connected to a fixed adjustable bar. This bar was loaded with a mass of 10kg as addition to the axial weight of the leg.

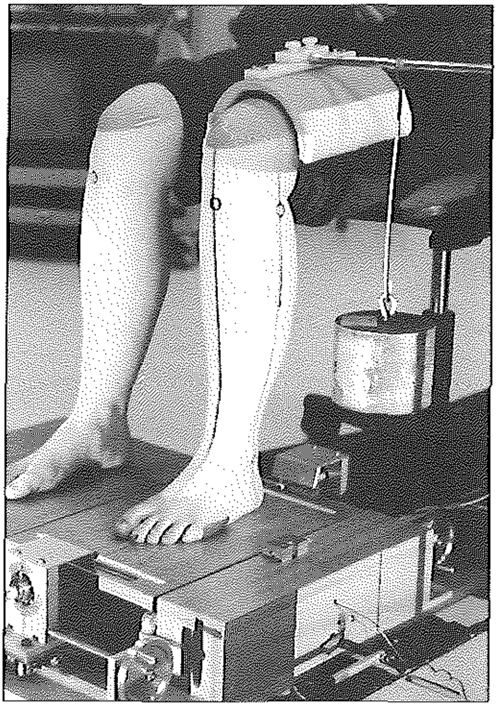


Figure 3. Photograph of the experimental set up.

Pilot surface-electromyography performed in the present study confirmed that under these conditions less than negligible activity of the peroneal and of other lower leg muscles is present, as previously found by Basmajian and Stecko (1963).

The tilting part of the platform was suspended on a low friction rotating system, constructed in such a way that the axis of rotation was movable with respect to the platform and was on the

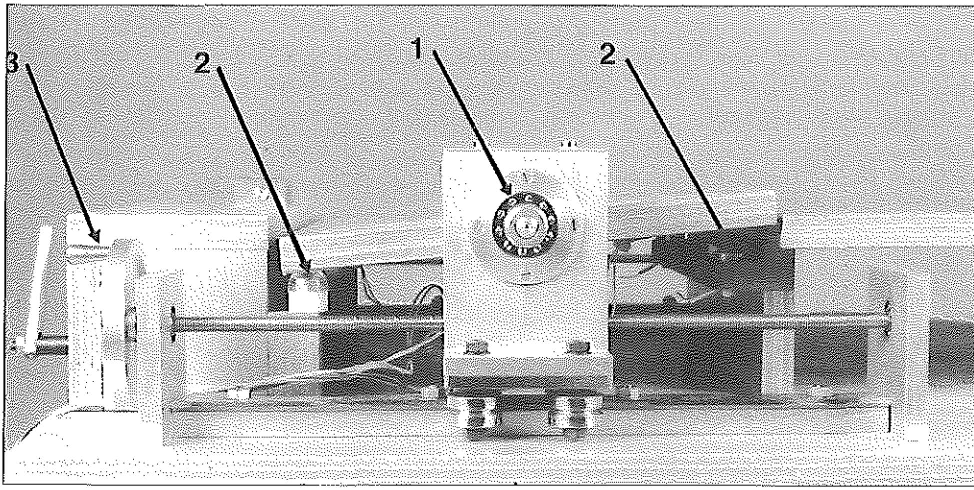


Figure 4. Photograph of the tilting platform with (1) axis of rotation (low friction), (2) force sensing resistors and (3) drive to move the axis of rotation.

same level as the surface on which the foot was placed (Fig. 4). The axis of rotation was moved in small steps (minimally 1mm) from laterally to medially remaining parallel to the midline of the foot. In this phase the surface was supported on the medial and lateral side. The support on the lateral side could be pulled away without sound or other noticeable effects. If, after pulling away the lateral support, the gravity load vector was situated medially to the axis the platform would remain in place. However, as soon as this vertical vector became laterally to the axis, after moving the axis more medially, the platform would tilt and loose contact with the medial support. This moment of tilt was registered electronically with help of force sensing resistors (FSR, Interlink Electronics) and the axis line around which this took place was defined as axis line 1 (AX 1). Possibly due to friction in the foot, it was found that the axis had to be moved somewhat more medially before the platform would turn round further until upon a safety stop on the lateral side (the maximum tilt was 5°). The axis belonging to this moment was also registered electronically and defined as AX 2. This phenomenon of a second axis disappeared with higher loads on the foot. It was verified that the friction in the apparatus is negligible.

Of each foot AX 1 and 2 were measured, being the amount of millimeters laterally (in which case the value was negative) or medially (positive value) from the midline of the foot. Measurements were made 5 repetitive times and the average values were used for further analysis. Hereafter, these values were normalized to an arbitrary foot (width 100mm and length 250mm).

All measurements were performed by the same examiner.

Statistics

The data were analyzed using SPSS/PC+, version 3.1. The variables were examined for normality. Differences in age, weight and height between groups were analyzed using Student's t-test. To test if groups were comparable in gender a Chi-square-test was used. Two comparisons were made for the variables AX 1 and 2. Firstly, all symptomatic right feet of the patients group (n=16) were compared with the asymptomatic right feet of the control group (n=10). The same was done for left feet. For analyzing differences between the patients and controls the Mann-Whitney U-test was used. Secondly, the symptomatic and asymptomatic feet within patients with unilateral complaints (n=8) were compared. For this analysis the Wilcoxon Matched-pairs test was used. For each test a p-value of 0.05 or lower was considered significant.

Results

The patient and control group (only appropriate for the first comparison) proved to be comparable regarding gender, age, height and weight.

When comparing the distance between the midline and the lateral border of ten different feet, determined on different days, the difference found was maximally 1mm as illustrated for one foot in Fig. 5. The position of the AX 1 and AX 2 found while performing the examination 5 repetitive times on one foot never differed more than 1mm as well. During the pilot studies occasionally a larger difference was found and this was found to be the result of the subject not sitting in the same position anymore. For this reason measures were taken to control the position in the standardized manner described above.

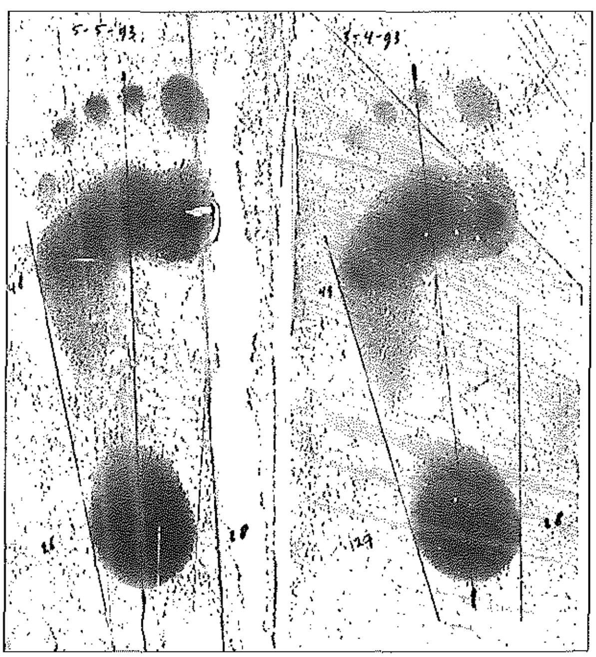


Figure 5. Comparison of the midline of a foot found at two separate occasions and marked on a footprint.

The results regarding only the first, unpaired, comparison between patients and controls are summarized in Table 2.

Table 2. Results of unpaired comparison of symptomatic right and left feet of the patients with asymptomatic right and left feet of the controls.

	no.	AX1			p-value	AX2			p-value
		mean	sd	(range)		mean	sd	(range)	
symptomatic left feet	16	-2	3.8	(-9 to 3)	.34	3	3.5	(-4 to 9)	.09
asymptomatic left feet	10	-.5	4	(-7 to 5)		6	3.5	(1 to 12)	
symptomatic right feet	16	-4.5	3.7	(-13 to 0)	.35	1	3.8	(-8 to 6)	.06
asymptomatic right feet	10	-2.5	2	(-5 to 1)		4	3.2	(0 to 10)	

sd = standard deviation

Although the mean AX 1 and AX 2 values of the patients are consequently oriented more laterally than of the controls, no statistically significant difference of AX 1 and AX 2 between symptomatic and asymptomatic feet, for neither comparison, was found. In Fig. 6 the AX 1 values of the right feet of patients and controls are plotted.

Discussion

A tilting platform has been previously used in studies concerning chronic ankle instability to establish a.o. the existence of a prolonged peroneal reaction time (Larsen and Lund, 1991; Karlsson, 1989; Karlsson and Andreasson, 1992; Konradsen and Ravn, 1990). In these studies the device was used to provoke a sudden inversion torque and to examine the active reaction of the patients. To our knowledge no earlier study has been performed using a tilting device to determine passive stability of the foot. In the present study measures were taken to exclude all active factors like muscle strength, balance/motor control and proprioception. The only point of interest was to examine if one foot would sooner invert than another under the same conditions and to find out if pure biomechanical factors are involved in chronic lateral instability. Such passive behaviour of the foot under a given loading mode is determined by the shape of the joint surfaces and the geometry of the bones and thus by the position of the axes about which the bones rotate. It is also determined by the capsules, ligaments and other soft tissues. Although the results show a tendency of the symptomatic feet to tilt more readily (Fig. 6), the differences are not statistically significant, thus we were unable to establish a difference in passive stability.

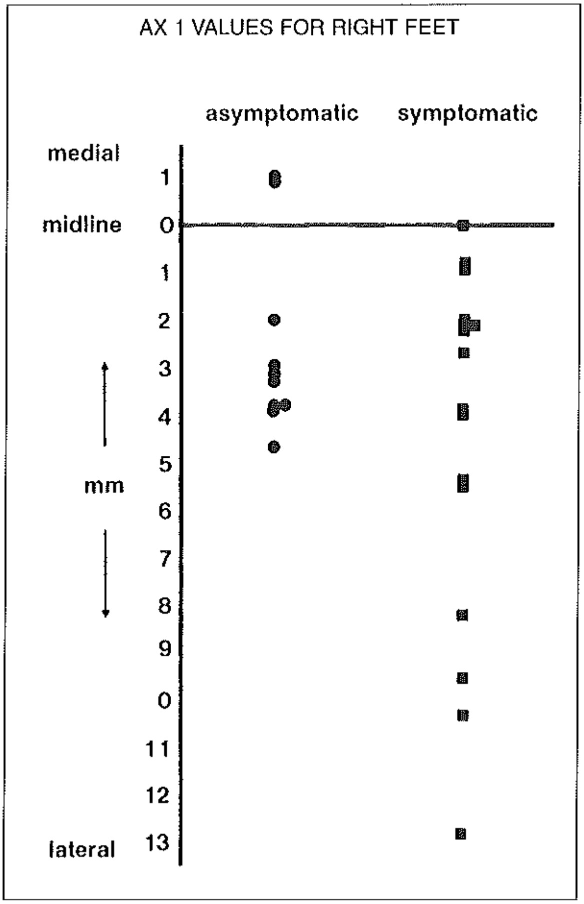


Figure 6. AX 1 values of the right feet of patients and controls in relation to the midline.

The purpose of the present study was not to provide an answer to the question as to what extent the above mentioned passive factors individually influence the moment of inversion tilt. From the model presented in the introduction (Fig. 1) it can be concluded that the position of the subtalar axis of rotation was thought to be of major importance. During the course of the study, however, it became clear that friction in or stiffness of the foot is also of interest. The factor stiffness can possibly explain why the one patient with a cavovarus foot configuration complains of instability and the other with a comparable foot does not. Many studies concerning the lateral ligaments, especially most radiological stress studies, have focussed on the establishment of pathological increase of motion in the talocrural or subtalar joints. Joints with increased mobility would be 'mechanically' unstable. However, mechanical tests cannot always verify the clinical diagnosis chronic lateral instability (Löfvenberg et al., 1989; Louwerens et al., 1995a) and it remains an enigma why a patient can have serious instability complaints about one foot and none at all about the contralateral foot, while both feet show the same amount of increased mobility. Active factors like disturbed balance/motor control could help to explain this, but it would be interesting to examine if the factor stiffness/internal friction of the foot is involved. Possibly, this passive factor might prove to be of more influence than the range of motion when evaluating instability of the foot.

Chronic instability of the foot and foot geometry

a radiographic study

Chapter 4

Summary

Multiple factors are involved in chronic lateral instability of the foot. The geometry of the foot may be of importance. A cavovarus foot may predispose to lateral ligament injuries. In the present study, standardized lateral X-rays were obtained of the feet of patients with chronic instability complaints and of a control group. Four parameters were used: 1) the tarsal index as described by Benink (1985), 2) the talocalcaneal angle, 3) the talometatarsal angle and 4) the calcaneal angle. No relationship between lateral instability of the foot and foot geometry was found. The talocalcaneal angle as defined in this study was found to be a less appropriate parameter in measuring the longitudinal footarch.

Introduction

Twenty to forty percent of patients who injure the lateral ligament complex of the ankle have residual complaints (Freeman et al., 1965; Hansen et al., 1979). These include 'giving way' sensations, often associated with frequent inversion injuries and a variable amount of pain and swelling. While many factors may be involved in chronic instability , it has been suggested that a foot with cavovarus build is more prone to lateral ligament injuries (Benink, 1985; Larsen and Angermann, 1990). From a biomechanical point of view it seems likely that a foot with a cavovarus configuration inverts more readily than a plantigrade foot.

In this study, four geometric foot indices were measured on standardized lateral X-rays in order to 1) establish a relationship between foot build and chronic lateral instability and 2) evaluate the interrelationship between these foot indices.

Patients and methods

Patient and control group

Twenty-two patients with bilateral and eleven patients with unilateral chronic ankle instability symptoms were examined. The patients were recruited consecutively from the orthopaedic out-patient department. All patients complained of frequent inversion injuries with variable amount of 'giving way', swelling, pain and reduced level of activity. In twenty-eight patients, symptoms had existed for more than three years and in five patients more than one year. 'Giving way' was present while walking on even ground in twenty-eight feet, and while walking on uneven ground in twenty-two more feet. In three feet problems existed only during sporting activity and in two feet pain was constantly present. The control group consisted of ten subjects with no such symptoms. The number, age, sex, height and weight of the patient and control groups are shown in Table 1.

Methods

A special device was used to obtain standardized lateral radiographs of the foot in neutral position with full weightbearing (Fig. 1).

Table 1. The number, age, sex, height and weight of the patient and control groups.

	Patients		Controls
	bilateral symptomatic	unilateral symptomatic	bilateral asymptomatic
number and gender	22 (7 M, 15 F)	11 (3 M, 8 F)	10 (4 M, 6 F)
age (mean ± sd and range) years	31 ± 13.6 (19 - 66)	30 ± 9.5 (19 - 45)	30 ± 7.4 (18 - 40)
height (mean ± sd and range) cm	172 ± 10.6 (165 - 201)	176 ± 6.6 (162 - 185)	177 ± 12.9 (165 - 200)
weight (mean ± sd and range) kg	75 ± 16.1 (62 - 107)	78 ± 15.7 (61 - 110)	68 ± 10.1 (52 - 86)

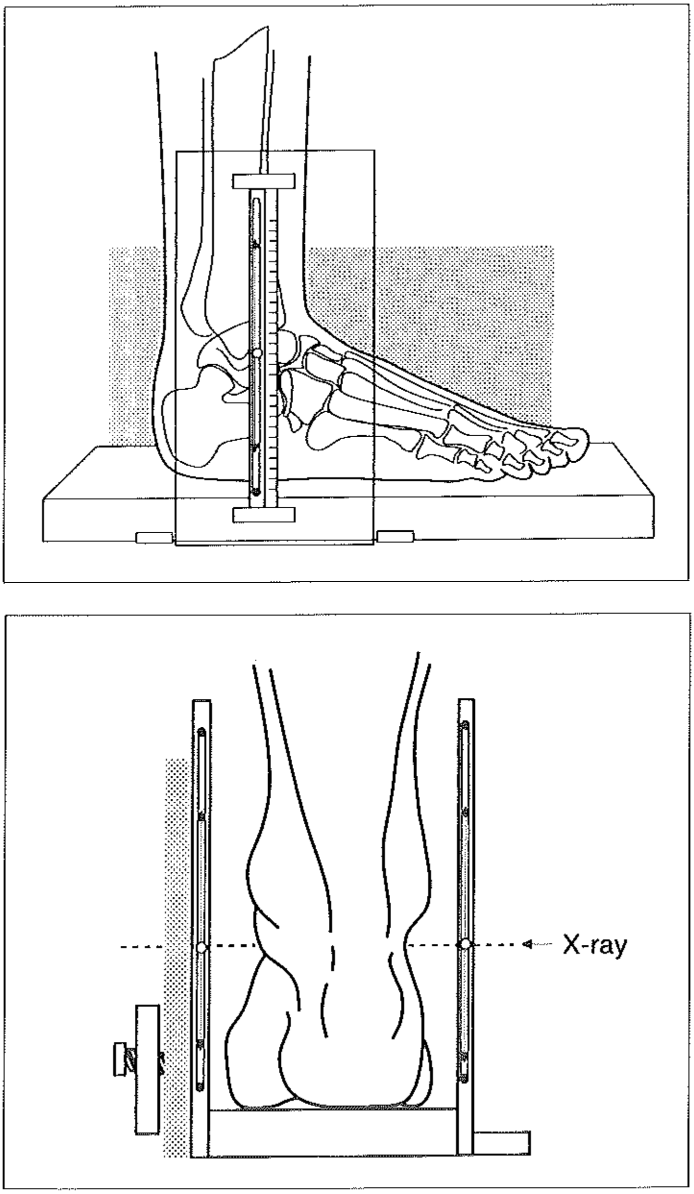


Figure 1. Lateral and frontal view of the set-up used in order to obtain standardized lateral radiographs of the foot. Pellets on both sides of the foot are adjusted to the same height as the talar neck and the X-ray beam is centered on these pellets.

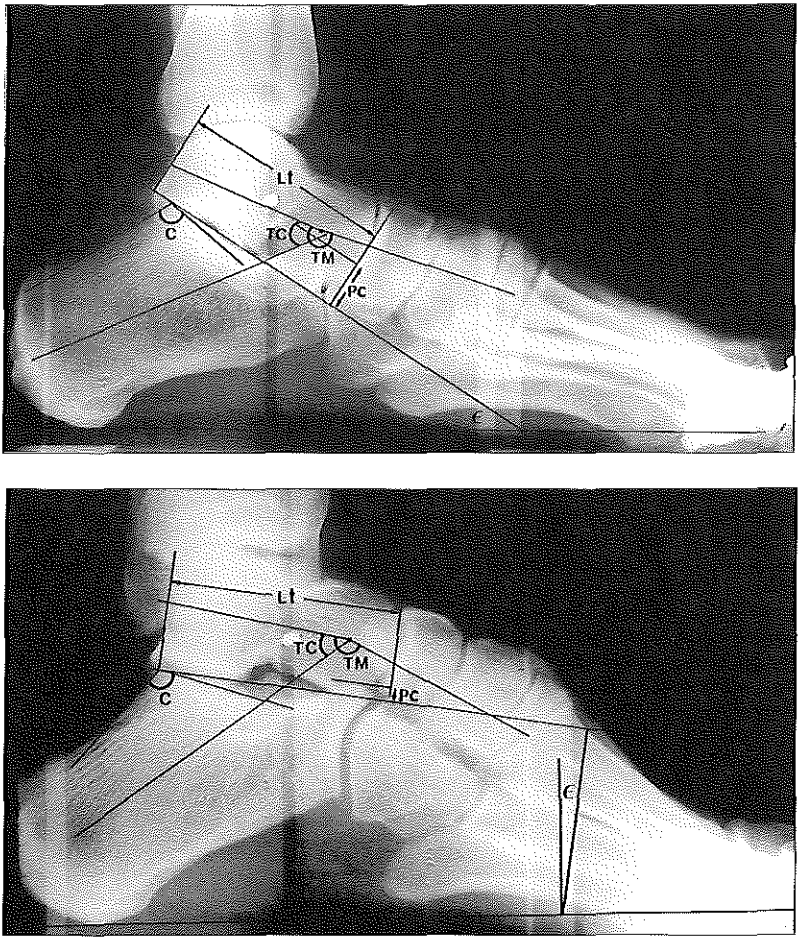


Figure 2. Radiographs of a foot with a slightly flattened longitudinal arch (above) in comparison with a foot with a high longitudinal arch (below).

A low platform was provided with a cassette holder. Parallel to the cassette were two transparent perspex plates between which the foot was placed on a 2cm elevation with the lateral border parallel to the plates. In each perspex plate a small pellet (diameter 2mm) could be adjusted in vertical direction along a scale. These pellets were adjusted to the same height as the talar neck after palpation of the sinus tarsi. The X-ray beam was centered on the pellets. The distance between focus and film was one meter. Radiographs were taken of each foot. They were accepted if the two pellets were completely aligned and when no part of the first metatarsal bone or the tarsus was outside the film. In a few cases a new radiograph had to be made.

The tarsal index was determined and three angles 1) the lateral talocalcaneal, 2) the talometatarsal and 3) the calcaneal angle were measured (Fig. 2).

Benink's (1985) tarsal index (TI) is based on the angle of inclination of the talocalcaneal joint and on the overlap of the head of the talus and the calcaneus (Pc). The angle of the talocalcaneal joint (E) is determined by the line drawn tangential to the posterior articular surface of the calcaneus and the anterior articular surface at the underside of the head of the talus and a line parallel to the platform. Pc in mm is divided by the length of the talus (Lt) in mm. The tarsal index is given as TI=100xPc/LtxtgE. As will be discussed later an increase of inversion (cavovarus) of the tarsus results in a decrease of Pc and decrease of the angle E and thus results in a decrease of TI.

The lateral talocalcaneal angle (TC) was defined as the angle between the line through the posterior articular margin of the talar trochlea and the midpoint of the caput tali (the talar line) and the longitudinal line through the calcaneus. Hindfoot cavus is characterized by a more vertical position of the calcaneus, thus a large angle is measured on feet with a high arch (Samilson and Dillin, 1983).

We used the modification as Larsen and Angermann (1990) of the talometatarsal angle (TM) proposed by Gould (1983). TM is the angle between the talar line, described above, and a line through the midpoint of caput tali and the midpoint of the base of the first metatarsal. A small angle implies a high arch.

C represents the angle between the posterior subtalar articular margin and the posterosuperior surface of the calcaneus. A large angle would be seen in feet with high arches (Gamble and Yale, 1966).

All the measurements were performed by the same examiner.

Statistics

The data were analyzed using SPSS/PC+, version 3.1. The variables were examined for normality. For each test, a p-value of 0.05 or lower was considered significant. A logarithmic transformation was applied on variables with a distribution that was skewed to the right before analyses with parametric tests were performed.

Differences in age, weight and height between groups were analyzed using Student's t-test. To test if groups were comparable in gender a Chi-square-test was used.

When analyzing differences between groups for TI, TC, TM and C, the symptomatic feet of all patients (unilateral as well as bilateral) were compared with asymptomatic feet of the controls (Student's t-test or Mann-Whitney U-test; this was done for left and right feet separately). Secondly, a comparison was made between the asymptomatic feet and the symptomatic feet of patients with unilateral instability, using the asymptomatic feet as controls.

Correlations between age, weight, height and the measured variables (TI, TC, TM, and C) were evaluated by means of Pearson's correlation coefficient. The same test was used to determine correlations between the variables TI, TC, TM and C. Relationship between these variables and gender were tested using Student's t-test.

Results

The patient and control groups were comparable regarding gender, age, height and weight. No statistically significant differences between symptomatic and asymptomatic feet regarding TI, TC, TM and C were found (Table 2), neither between the patient and control group, nor within the unilateral group.

Table 2. TI, TC, TM and C angles, comparing the symptomatic feet of patients (both unilateral and bilateral) with feet of the control group. Differences were never statistically significant.

		symptomatic			asymptomatic		
		mean	sd	range	mean	sd	range
TI	R	5.9	4.1	0.6-16.7	6.3	2.8	2 -11.2
	L	6.8	3.4	1.4-15.2	6.7	2.7	0.4-9.8
TC	R	46.8	4.3	38-54	47.8	4.1	42-54
	L	44.6	4.5	36-54	45.0	5.6	35-56
TM	R	171	10.9	160-184	174	5.9	166-186
	L	174	6.0	160-186	174	5.3	162-183
C	R	111	7.8	98-125	112	9.5	98-128
	L	110	10.3	96-125	111	8.8	98-125

Table 3. Correlations between the different variables TI, TC, TM and C.

	right feet			
	TI	TC	TM	C
TI		.38 p=.011*	.66 p=.000*	-.57 p=.000*
TC	-.04 p=.790		.25 p=.110	-.55 p=.000*
TM	.71 p=.000*	.12 p=.430		-.36 p=.018*
C	-.36 p=.017*	-.29 p=.059**	-.30 p=.054**	
	left feet			

* = statistically significant
** = tendency towards significancy

Statistically significant positive correlations were found for both right feet and left feet between TI and TM and for right feet between TI and TC (Table 3). For right feet statistically significant negative correlations existed between C and all three other variables and the same was found between C and TI for left feet. A tendency towards statistically significant negative correlations between C and TC and between C and TM was found for left feet.

There was no significant correlation between the variables age, height and weight and the measured variables TI, TC, TM and C. A statistically significant difference was found between men and women for the variable TC for both left ($t=2.62$, $df=41$, $p=0.012$) and right feet ($t=2.35$, $df=41$, $p=0.023$). Women were found to have lower values of TC.

Discussion

Functional anatomical studies have demonstrated how the foot in the weightbearing situation moves from a neutral more or less pronated position into a cavovarus position during inversion (Huson, 1961 and 1991; van Langelaan, 1983; Benink, 1985). The talus rotates posterolaterally out of the socket of the navicular bone and 'mounts' the calcaneus (Fig. 3). On a lateral view, the overlap of the head of the talus and the front of the calcaneus will decrease and the talo-calcaneal angle will also decrease. From a biomechanical point of view it is likely that a cavovarus foot is more prone to lateral instability as a smaller momentum is needed to enforce further inversion. This was proposed by Benink (1985) who introduced a tarsal index based on a lateral X-ray for evaluating cavovarus; others have also supported this relationship (Vidal et al., 1974; Subotnik, 1985; Bremer, 1985; Ayres et al., 1987; Lassiter et al., 1989).

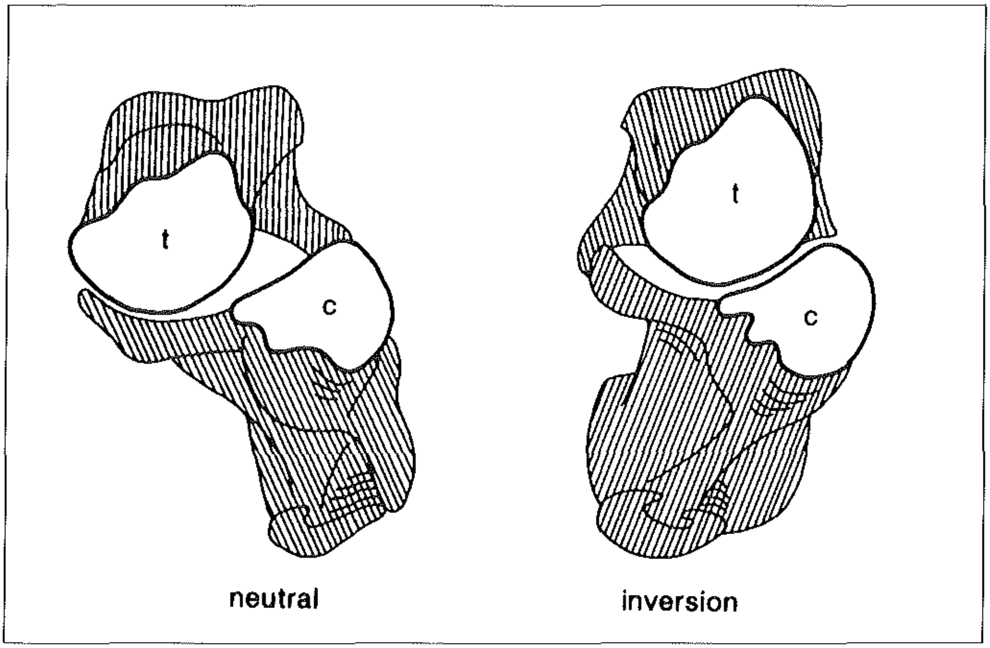


Figure 3. Frontal view on the talocalcaneal joint complex in a neutral position (left) and after inversion of the foot (right).

On clinical examination we found that cavovarus feet were more frequent in the patient group and we expected to find radiological differences between the patient and control group. In six out of fifty-five symptomatic feet a TI beneath 2.0 was measured, while in all twenty feet of the control group the TI was higher than 2.0. However, no statistically significant difference between the groups could be demonstrated (Table 2). As far as the values of TI are concerned our data were comparable with those of Larsen and Angermann (1990). In contrast with our results, they found lower values of TI for their patients and statistically significant difference between the groups. Possibly this can be explained by the facts that they performed their measurements on the feet in a non-weightbearing position and with a different patient selection.

Three of the six symptomatic feet with a TI beneath 2.0 were the symptomatic foot of a patient with unilateral complaints. Two of the three asymptomatic feet of these patients also had a high arch with a TI beneath 2.0 (i.e. 0.9 and 0.4). Thus it seems that a cavovarus build is not a dominant factor and is only one of the multiple factors playing a role in chronic instability.

As the medial foot arch lowers, the TI will increase and a positive correlation with TM which also increases is to be expected (Table 3). A higher C-angle is said to be related with a high arch of the foot and the negative correlation between this angle and both TI and TM is thus understandable. While others (Larsen and Angermann, 1990) report that the TC angles in feet with higher arches are to be found higher, implying a negative correlation between TC and both TI and TM and a positive correlation between TC and C, our findings are closer to finding the contrary. With cavovarus the calcaneus most often assumes a vertical position, but as illustrated (Fig. 2) also the talus moves upward and as a result the TC angles of a foot with a lower arch and of a foot with a high arch can be equal. With increase of varus, the TC angles might even become smaller as reported by Keim and Ritchie (1970), who find an increase of the 'lateral TC angle' when the patient has a valgus heel or a calcaneus foot.

In conclusion, we are unable to establish a relation between chronic lateral instability of the foot and foot geometry. The TC angle as defined in the present study is a dubious parameter in measuring the longitudinal arch of the foot. In daily orthopaedic practice the TM angle seems to be a better measure of cavus of the foot.

The position of the rearfoot at the moment of heel contact and chronic lateral instability

a video analysis

Chapter 5

Summary

Multiple factors are involved in chronic lateral instability of the foot. In the present study, a possible relationship between the way the foot is placed on the ground during walking and instability complaints was searched for. This position is determined by both passive and active factors. Examination was performed under different walking conditions, in order to examine the effect of walking speed and the influence of secured balance. The position of the rearfoot in the frontal plane was assessed with help of two-dimensional video-based analysis.

The conclusions of the present study are 1) that a relationship between the position of the rearfoot at the moment of heel contact and chronic lateral instability of the foot was not found, and 2) that no significant influence of walking speed or external support (secured balance) could be established.

Introduction

From a (bio)mechanical point of view it is understandable that if a foot is loaded in an inverted position a varus torque will soon occur. An inversion lever will be produced as soon as the point of calcaneal floor contact is medial to the line of body-weight transmission and to the axis of rotation in the hindfoot. In literature it is suggested that a relation between a varus posture of the tarsus and occurrence of lateral ligament injuries exists (Ayres et al., 1987; Bremer, 1985; Larsen and Angermann, 1990; Lassiter et al., 1989; Subotnick, 1985; Vidal et al., 1974). In the preceding radiographic study (chapter 4) we did not succeed in finding a significant relation between foot configuration and instability complaints. The position of the foot, however, is not only the result of the passive factor 'foot build', but is also determined by active factors such as motor control and concentration. The following question arose: if it is not the 'foot build', could it then be the 'way of walking' that is involved in chronic lateral instability? To answer this question, a dynamic analysis of rearfoot motion during walking of a group of twenty-one patients with bilateral instability complaints and of fourteen healthy subjects was performed. Recordings were also made under different walking conditions in order to examine whether change in walking speed and the presence of external support (secured balance) had an effect on the rearfoot position. To our knowledge, such an assessment in patients with chronic lateral instability has not been reported previously.

Patients and methods

Patient and control group

Twenty-one patients with bilateral chronic ankle instability symptoms were examined. The patients were recruited consecutively from the orthopaedic out-patient department. All patients included not only complained of 'giving way' sensations but also suffered frequent inversion injuries. Typically, this already occurs when they misstep on a small stone. Complaints had existed for more than two years. Symptoms like pain, swelling and disability were minor. All patients could walk without pain and without limping. The control group consisted of a total of fourteen subjects without any leg or ankle symptoms. Patient and control groups are shown in Table 1.

Table 1. Patient and control groups

	number (M/F)	age (yrs)	height (cm)	weight (kg)
		m (range) sd	m (range) sd	m (range) sd
symptomatic	21 (7/14)	32 (18-67) 13	173 (156-186) 8	71 (51-100) 13
asymptomatic	14 (7/7)	29 (19-41) 7	178 (164-201) 11	68 (53-82) 8

M = male
F = female
m = mean
sd = standard deviation

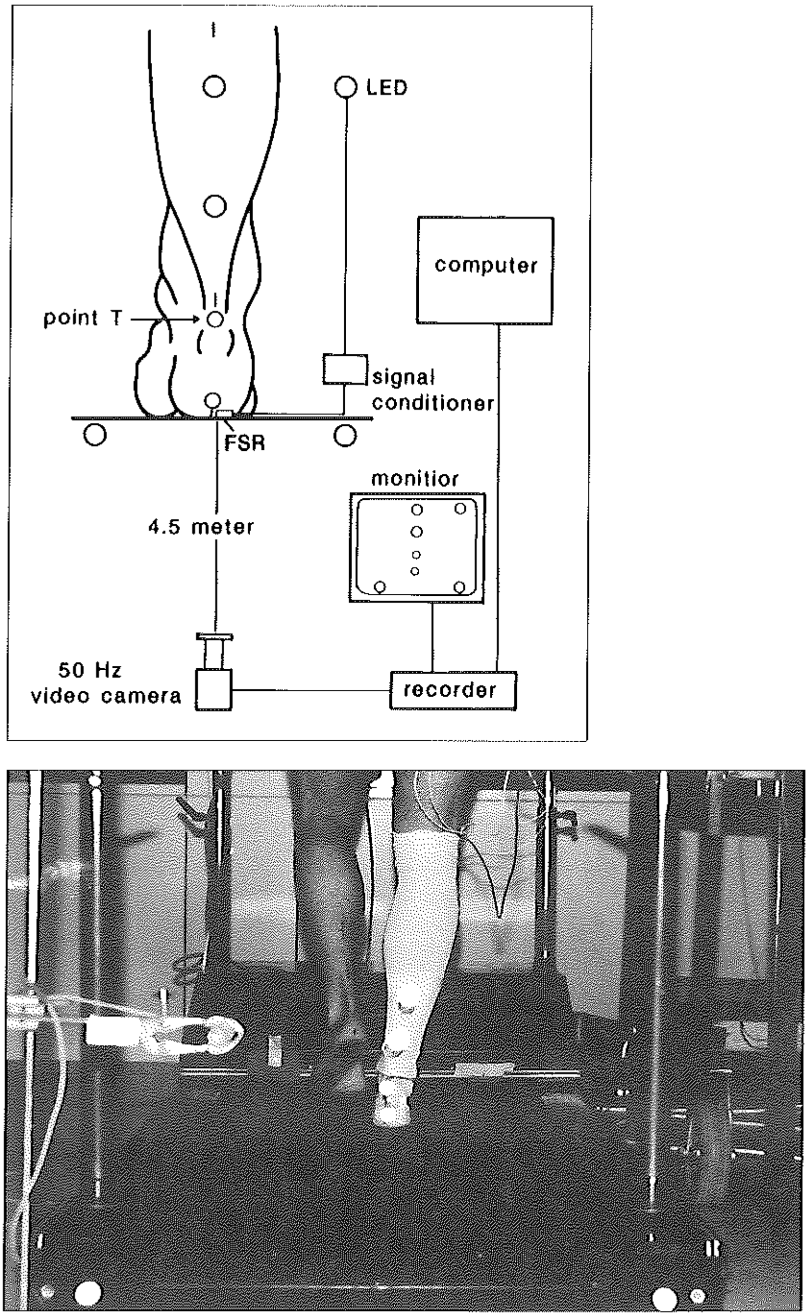


Figure 1.
A diagram and a photograph of the set up.

Methods

From research performed by Stormont et al. (1985) it is known that with physiologic axial loading of the foot, the articular surfaces of the ankle and subtalar joints will account for complete inversion stability no matter what the condition of the lateral ligaments. The most critical phase during walking seems to be the moment that the foot touches the ground, when the foot is not yet loaded and when the activity of the peroneal muscles is not sufficient to provide stability to withstand a sudden unexpected inversion torque (Louwerens et al., 1995b). For this reason it was decided to restrict our study of the position of the rearfoot to what this position is at the time of heel contact.

Retroflective markers were placed, on the midportion of the triceps tendon where it attaches to the calcaneus (point T), on the line that bisects the calf 7.5 and 15cm above point T and on the heel just above the axis line of the foot (Fig. 1). The diameter of the two proximal markers was 3cm and of the two distal markers 2cm. In order to establish the axis of the foot, defined as the bisecting line between the inner and external tangents to the footprint, as standardized in CAMARC-II (1993), a special device was used (see Fig. 2., chapter 3). A knee brace fitting system (Innovation Sports) was used to mark the posterior median point at the knee joint level. The line drawn from this point to point T was used as the line bisecting the calf.

A diagram and a photograph of the set up are given in Fig. 1. Subjects walked on a treadmill (Enraf Nonius, TR 4009). Recordings of each foot separately were started after the subjects were accustomed to walking on the treadmill. The frontal view of the rearfoot was filmed with a 50Hz video camera (HCS MX5, 56470) from a distance of approximately 4.5m. Infra-red filters confined the incoming light to the infra-red region, while infra-red LED strobes mounted around the lens (Ernitec TV zoom lens) supplied the necessary light. Heel contact was registered with a force sensing resistor (FSR, Interlink, thickness 0.032cm). Signals from the FSR were passed through a custom-made Signal Conditioner and activated an infra-red LED which was also filmed. A monitor (Bosch M38 BA) was used to control the filming. Recordings were stored on a video recorder (Panasonic NV-FS 100 HQ, Fuji Pro-S videotapes). The video data were reduced to coordinates using a video digitizing system (VME) and a custom-made computer program was used for further analysis, similar to the program used in previous research (Keemink et al., 1991).

The placement of the markers and all recordings were performed by one investigator.

Of each foot, four separate gait recordings, under different walking conditions, were made. Recordings were made while walking at a speed which was chosen to be comfortable (3.7-4.3km/hr), first walking without external support and secondly walking with a hand on the railing of the treadmill in order to secure balance.

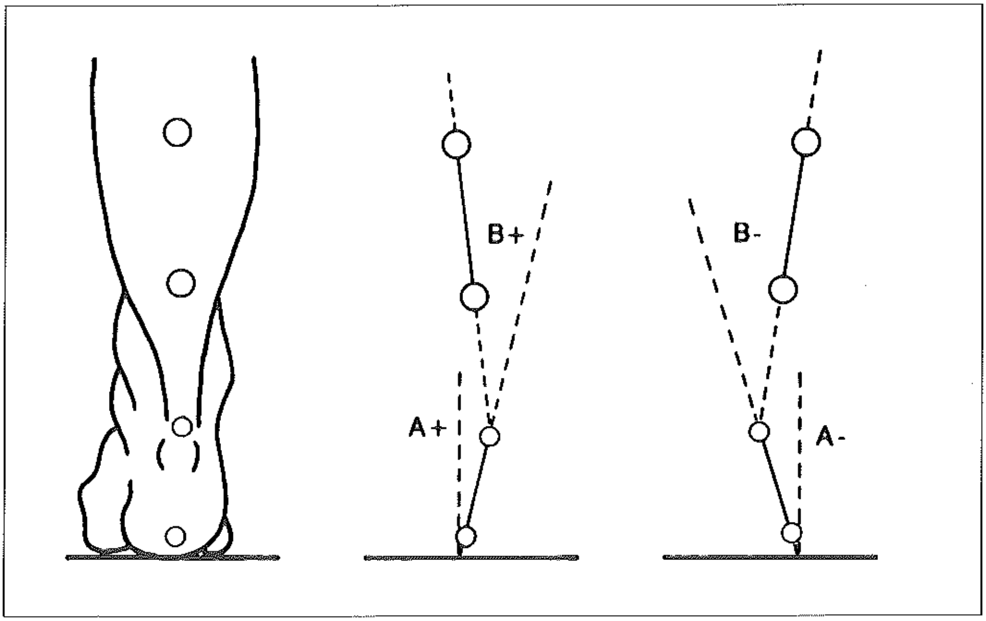


Figure 2. The angles A and B. With an inversion configuration the angles were defined as positive and in eversion as negative.

Similar recordings were made while walking at a slow speed, which was 2km/hr less than the firstly chosen speed (1.7-2.3km/hr). Of each recording all steps during one minute of walking were analyzed.

Two angles were calculated (Fig. 2): the angle between the vertical and the calcaneus (A) and the angle between the calcaneus and the lower leg (B). With an inversion configuration the angles were defined as positive and in eversion as negative. With a sampling rate of 50Hz, heel contact will often take place between two following samples. The last sample prior to heel contact was used for further analysis.

The mean values and standard deviations of the angles were determined. Of each recording the five steps at which the foot was most inverted were also analyzed, because the possibility exists that a 'normal' mean value is found while during some individual steps an extreme amount of inversion was present.

Statistics

The data were analyzed using SPSS/PC+, version 3.1. The variables were examined for normality. A logarithmic transformation was applied on positively-valued variables with a distribution that was skewed to the right before analyses with parametric tests were performed. Differences in age, weight and height between groups were analyzed using Student's t-test. To test if groups were comparable in gender a Chi-square-test was used. For analyzing differences of at least ordinally scaled variables between groups the t-test if appropriate or Mann-Whitney U-test was used. For each test a p-value of 0.05 or lower was considered significant.

Results

The patient and control group proved to be comparable regarding gender, age, height and weight.

The data of the angles for all steps and of the angles with the feet in the most inverted position (max) for each separate recording are listed in Table 2. No statistically significant differences were found between the patient and control group, neither between the separate recordings (under different walking conditions) within the same foot.

For the total group of subjects the A- and B-angles were found to be quite variable. The results for all left feet are plotted in Fig. 3.

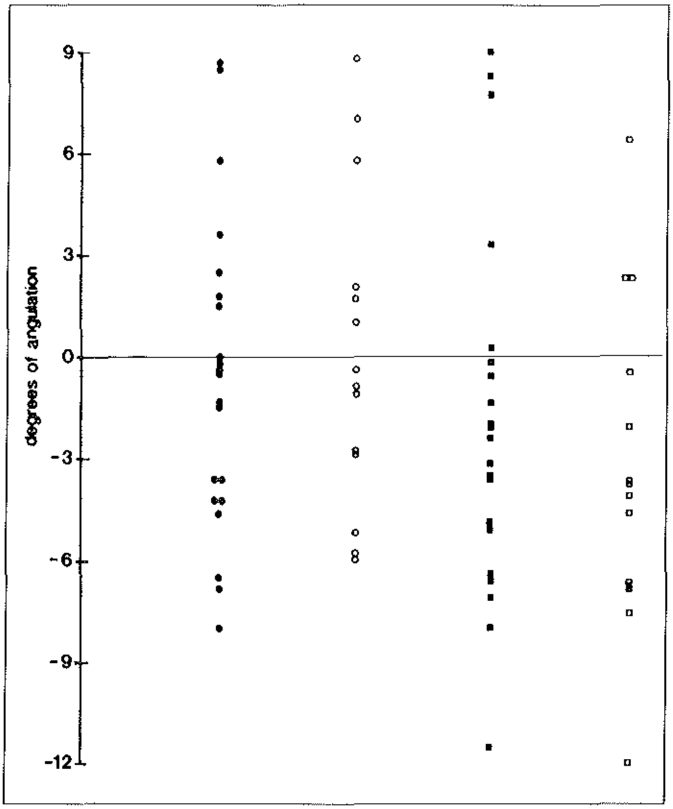


Figure 3. Calcaneo-to-vertical (A) angles of patients (●) and controls (○) and calcaneo-to-lowerleg (B) angles of patients (■) and controls (□), of all left feet.

Table 2. Angles at heel contact found during four separate gait recordings

		angle A			max A			angle B			max B		
patients with bilateral instability (n = 21)													
		m	sd	range	m	sd	range	m	sd	range	m	sd	range
4 W	L	-.3	4.3	-8.5 - 8.1	2.9	4.8	-5.8 - 11.4	-2.5	4.9	-12.4 - 8.4	1.1	5.1	-7.9 - 12.1
	R	.6	4.6	-7.7 - 8.3	3.7	4.6	-5.6 - 10.5	-1.2	5.1	-9.7 - 7.5	4.0	7.0	-4.6 - 21.2
4 O	L	-.7	4.5	-7.4 - 8.0	2.6	4.6	-4.6 - 10.7	-2.6	5.1	-10.7 - 9.4	.8	4.7	-5.6 - 10.5
	R	.5	4.7	-8.4 - 8.2	4.0	4.7	-3.6 - 13.2	-1.0	4.6	-9.9 - 6.9	2.7	4.9	-5.5 - 13.8
2 W	L	-.3	4.7	-8.8 - 8.2	2.9	5.2	-5.3 - 18.6	-2.4	5.2	-11.9 - 9.3	1.5	5.1	-5.1 - 16.1
	R	.9	4.5	-7.4 - 9.8	3.5	4.8	-5.3 - 12.5	-.7	5.2	-10.3 - 10.1	2.2	5.6	-6.1 - 12.9
2 O	L	-.8	4.6	-8.2 - 9.7	1.9	4.6	-5.3 - 12.0	-1.9	5.2	-11.0 - 11.3	1.0	5.3	-8.9 - 13.9
	R	.2	5.0	-9.8 - 10.5	3.2	5.6	-7.2 - 16.7	-3.7	5.4	-11.4 - 11.8	4.4	9.0	-9.3 - 17.5
controls with no complaints (n = 14)													
4 W	L	.5	4.6	-5.2 - 8.9	2.9	4.9	-3.4 - 11.8	-3.3	4.7	-11.8 - 6.2	-.4	4.9	-7.0 - 8.0
	R	3.3	2.6	-7.0 - 9.6	5.6	2.9	.7 - 12.2	-.4	2.6	-3.6 - 5.3	2.1	2.8	-2.2 - 7.4
4 O	L	-.3	4.6	-6.2 - 8.5	2.1	4.8	-3.8 - 11.9	-3.6	.8	-12.5 - 5.9	-1.2	5.0	-8.5 - 8.3
	R	2.7	2.9	-1.7 - 9.1	5.2	3.2	.4 - 11.6	-.1	2.9	-4.1 - 5.2	2.3	2.7	-1.2 - 6.3
2 W	L	.1	5.1	-5.3 - 9.3	2	4.8	-4.6 - 11.8	-3.8	4.8	-12.1 - 6.1	-1.6	5.4	-10.4 - 7.5
	R	3.0	2.9	-1.6 - 9.3	5.3	3.0	.2 - 11.3	-.6	3.4	-6.4 - 5.6	1.9	3.7	-2.9 - 8.4
2 O	L	.1	5.1	-7.0 - 8.8	2.1	5.3	-4.9 - 11.7	-3.0	5.1	-11.7 - 7.3	-.7	5.6	-9.6 - 9.3
	R	2.6	2.9	-3.7 - 8.8	4.8	2.6	-1.7 - 9.8	.2	3.2	-4.5 - 5.7	2.4	3.0	-2.6 - 6.7

m = mean
sd = standard deviation
L = left feet
R = right feet
4 W = speed 4 km/hr with external support
4 O = speed 4 km/hr without external support
2 W = speed 2 km/hr with external support
2 O = speed 2 km/hr without external support

Discussion

The use of a treadmill may be the cause of alteration of gait. It is assumed that these differences are unmarkedly as, in general, is also the case regarding EMG-patterns (Murray et al., 1984). Although the markers were all placed as accurately as possible by one investigator, slight deviations between subjects will occur. Further unreliability results from movements between the skin and the underlying structures, but these movements were thought to be minimal in the frontal plane and were neglected. In previous studies, to investigate rearfoot pronation (Clarke et al., 1983) and running limb varus (Tristant and Blake, 1991) the midline of the calcaneus was measured with help of two markers placed vertically on the rear of a shoe. However, as movements of the foot within the shoe probably occur, it was thought in the present study preferable to perform measurements with markers placed directly on the rearfoot. The angles in the present study are not meant to be regarded as a precise description of ankle and foot joint movements, but we trust the method allows a comparison between the individual subjects.

For the total group of subjects the calcaneus to vertical (A) angles and the angles (B) between the rearfoot and the lower limb were found to be quite variable. Also within the same subject, variations were found, for instance an inverted position of the right foot and an everted position of the left foot at the time of heel contact. All combinations of rearfoot and lower limb position occurred, but this was never characteristic for one of both groups.

No statistically significant differences, which would indicate a different placement of the foot, between the symptomatic and asymptomatic feet were found. The results, in particular for right feet, even suggest a higher mean calcaneus to vertical angle (more inversion) for the control group (Table 2). It is imaginable that increased speed or loss of the presence of secured balance might provoke changes in motor control and of rearfoot position, however, these factors had no influence on the position of the rearfoot.

In conclusion, it could not be established that the amount of inversion of the rearfoot at the moment the foot contacts the ground during normal walking is a predictive discriminating factor involved in chronic lateral instability of the foot.

Stress radiography of the talocrural and subtalar joint

Chapter 6

Summary

The object of this investigation was to determine a possible subtalar component in a group of 33 patients with chronic ankle instability. A group 10 subjects without ankle/foot symptoms acted as controls. A standardized radiographic assessment of talar and simultaneous subtalar tilt was made. A hinge device to stress the joints and a specific subtalar stress view (Brodén view) were used under fluoroscopic control. Radiographs were made with the feet: 1) in neutral position, 2) after inversion with moderate force until the point of fair restraint (step 1), and 3) after inverting with more force as far as the conditions would allow (step 2).

An increase of talar tilt between step 1 and step 2 was only found in feet that were symptomatic. This suggests that this increase is only possible when lateral ligaments are damaged. Further research is necessary to determine whether this finding can serve as a parameter to discriminate between physiological and abnormal talar tilt.

A wide range of subtalar motion was found in both symptomatic and asymptomatic feet. With the present method, practically all subtalar joints showed some loss of congruity and medial shift of the calcaneus in relation to the talus. This could not be correlated with ankle instability at the talocrural joint. The consequence of the use of different subtalar stress methods has so far received little attention and is discussed.

Introduction

Twenty to forty percent of patients who suffer an injury of the lateral ligament complex of the ankle have residual symptoms (Freeman et al., 1965; Hansen et al., 1979; Thermansen et al., 1979) often with functional instability. This term was introduced by Freeman (1965) to define symptoms such as 'giving way' sensations and sprains with or without pain and swelling. Multiple factors seem to play a role in the pathophysiology of functional instability. Some authors believe that mechanical instability due to rupture or elongation of capsule and ligaments is an important factor (Staples, 1975; Broström, 1966b; Karlsson, 1989) and others state that there is no correlation between mechanical instability and residual symptoms (Freeman, 1965a and b; Freeman et al., 1965; Hansen et al., 1979; Thermansen et al., 1979; Tropp, 1985a; Tropp et al., 1985c). Mechanical instability is most often located at the talocrural level. Since Rubin and Witten (1962) for the first time suggested the clinical significance of subtalar instability, this topic has received a considerable amount of attention (Laurin et al., 1968; Vidal et al., 1974; Brantigan et al., 1977; Zwipp and Tscherne, 1982; Zollinger et al., 1983, 1984; Cass et al., 1984; Zwipp, 1986; Zwipp and Kretek, 1986; Zell et al., 1986; Kjaersgaard-Andersen et al., 1987a and b; Kjaersgaard-Andersen et al., 1988; Harper, 1992). Clanton (1989) concludes that subtalar instability must be considered as a cause of symptoms in a patient who sustains an inversion type of injury to the ankle and hindfoot, particularly if other causes of instability have been excluded.

Identifying subtalar instability (often in conjunction with talocrural instability) has important consequences in relation to the technique of reconstruction to be used in patients who undergo surgical treatment (Vidal et al., 1974; Brantigan et al., 1977; Riegler, 1984; Zwipp, 1986; Zwipp and Kretek, 1986). Subtalar instability may also have clinical importance in the sinus tarsi syndrome (Kjaersgaard-Andersen et al., 1988; Zwipp and Tscherne, 1982; Zollinger et al., 1983). Although Taillard et al. (1981) as well as Meyer and Lagier (1977), defined specific abnormalities using arthrography of the subtalar joint in patients with sinus tarsi syndrome, they were unable to find convincing increase in the talocalcaneal (subtalar) angle on forced supination of the heel.

Specific subtalar stress views (Huggler, 1978; Zwipp and Tscherne; 1982; Zwipp, 1986; Zwipp and Kretek, 1986; Bruns and Dahmen, 1989; Machan and Oelrich, 1989; Heilman et al., 1990) and stress tomography (Brantigan et al., 1977; Zollinger et al., 1983; Zollinger et al., 1984) have been used to identify subtalar instability. The generally used subtalar stress view is a 40° Brodén view (Brodén, 1949) with inversion stress applied to the calcaneus and forefoot as proposed by Laurin et al. (1968). Most investigators apply stress manually (Laurin et al., 1968; Huggler, 1978; Zwipp and Tscherne, 1982; Zwipp, 1986; Zwipp and Kretek, 1986; Clanton, 1989) as illustrated in Fig. 1.

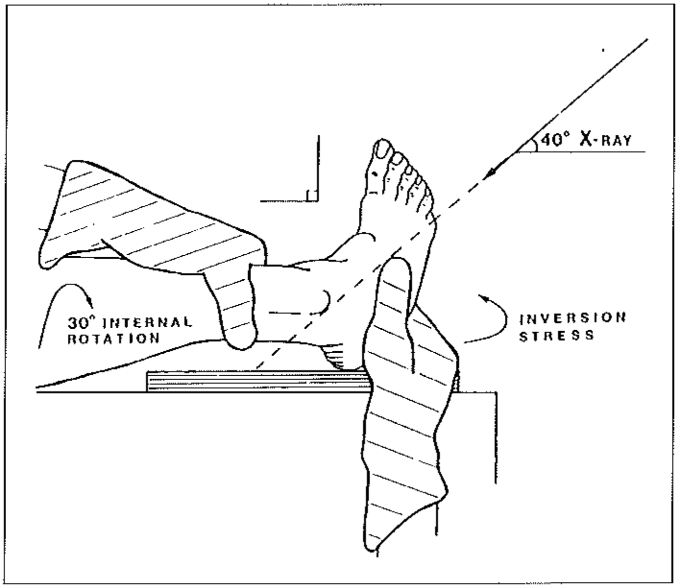


Figure 1. Diagram illustrates the technique commonly used to take a manual stress radiograph of the subtalar joint.

Although a stress device is commonly used for measuring talocrural instability, the use of a device to standardize measurements for evaluation of subtalar instability has been suggested only once in an experimental study (Bruns and Dahmen, 1989). The use of fluoroscopy for correct positioning has been reported only sporadically (Anderson et al., 1952; Zell et al., 1986; Clanton, 1989).

In the present study, all patients complained of chronic lateral instability. To evaluate possible mechanical instability, we examined talocrural and, in particular, subtalar motion stepwise under standardized conditions with a 40° Brodén view using fluoroscopy and a hinge device to apply symmetrical inversion stress. We found significant differences with individuals with ankle instability at the talocrural joint, but not at the subtalar joint.

Materials and methods

Patient and control groups

Twenty-two patients with bilateral and 11 patients with unilateral chronic ankle instability symptoms were examined (group A, Table 1). The patients were recruited consecutively from the orthopaedic out-patient department. All patients complained

Table 1. Number, age, sex, height, and weight of patient and control groups.

	GROUP A		GROUP B (control)
	bilateral symptomatic	unilateral symptomatic	
number and gender	22 (7 M, 15 F)	11 (3 M, 8 F)	10 (4 M, 6 F)
age (yr)			
mean ± sd	31 ± 13,6	30 ± 9.5	30 ± 7,4
range	19-66	19-45	18-40
height (cm)			
mean ± sd	172 ± 10.6	176 ± 6.6	177 ± 12.9
range	162-201	162-185	165-200
weight (kg)			
mean ± sd	75 ± 16.1	78 ± 15.7	68 ± 10.1
range	62-107	61-110	52-86

of frequent inversion trauma with variable amount of 'giving way' sensation, swelling, pain and reduced level of activity. In 28 patients, symptoms existed for more than 3 years, and in five patients, symptoms existed for more than 1 year. 'Giving way' sensation was present while walking on even ground in 28 feet, and while walking on uneven ground in 22 more feet. In three feet, problems existed only during sporting activity, and pain was constantly present in two feet.

The control group consisted of 10 subjects without any leg or ankle symptoms (group B, Table 1). The number, age, sex, height and weight of the patient and control groups are shown in Table 1.

A general physical examination was performed on all patients including examination of the ankle and foot joints, range of motion, and ankle stability. Hypermobility was defined on the basis of standard tests (Biro et al., 1983) during examination. In the present study, the term joint laxity is used when subjects exhibit idiopathic general joint laxity according to these tests. Sporting activities were evaluated by means of a questionnaire.

Stress examination

To apply an equal moment of force to both feet, a hinge device similar to the one used by Rubin and Witten (1960) and Brantigan et al. (1977) was used. The feet were strapped to the device and placed in neutral position. The hinge device also controlled the neutral position, during further examination. The integrity of the

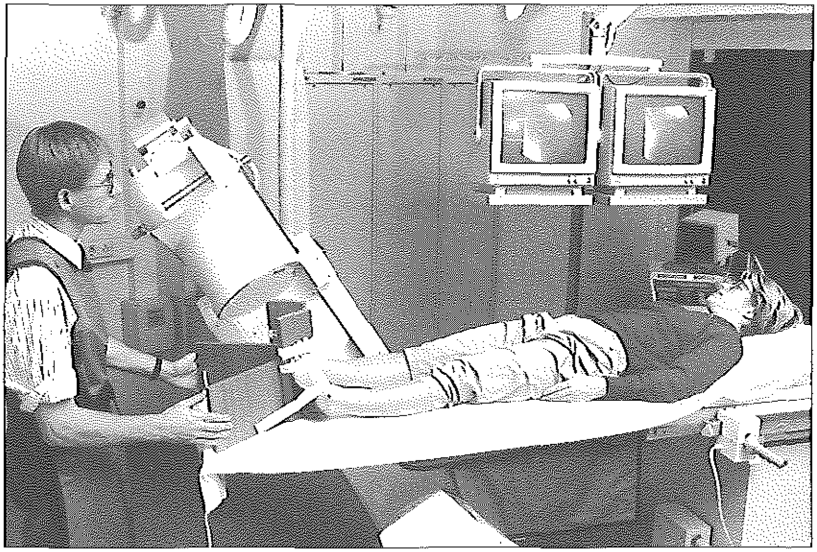


Figure 2. Photograph shows the technique used in the present study. Stress was applied with a hinge device. An apparatus with an image intensifier was used. Radiographs were taken with the x-ray beam centered on the subtalar joint with an angle of 30° latero-medially and 40° caudo-cranially.

calcaneofibular ligament can best be examined with the ankle perpendicular to the tibia (Laurin et al., 1968; Rasmussen, 1985; de Vogel, 1970). A hold upon the calcaneus was maintained by a shoe-contrefort. Examination was performed with the subjects in supine position on the table of a prototype of the Philips Integris 3000 apparatus (Fig. 2). Using this apparatus, the x-ray beam was centered with the image intensifier on the subtalar joint, with an angle of 30° latero-medially and 40° caudo-cranially (Brodén at 40°). A constant focus-film distance was used and a view of the talocrural joint and more than three fourths of the calcaneus was obtained. A stepwise examination was performed. After a non-stressed radiograph (Fig. 3a) was obtained, the feet were inverted until there was fair restraint (no one complained of any discomfort during this first step). Movements were visualized with the image intensifier. The feet were held in this inverted position for 30 seconds, subjects were encouraged to relax, and a radiograph was then made (Fig. 3b). Thereafter, actual inversion stress was applied, again under fluoroscopic control. The feet were inverted as far as possible to the point of pain or until no further closure of the device was possible (step 2). This position was held for 1 minute, to ensure full relaxation, before a third radiograph was taken (Fig. 3c).

Measurements were made directly on the radiographs. The talar tilt was measured using a standard method (Rubin and Witten, 1960; Laurin et al., 1968; van Moppes and van den Hoogenband, 1982; Karlsson, 1989). Lines were drawn across the

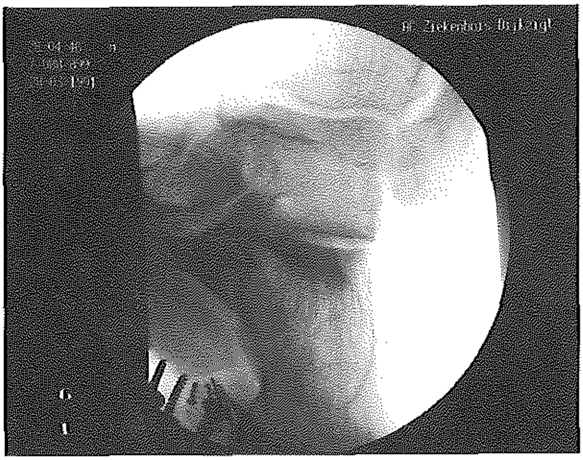


Figure 3a. The radiograph shows the talocrural and subtalar joints with the foot in neutral position without stress being applied.

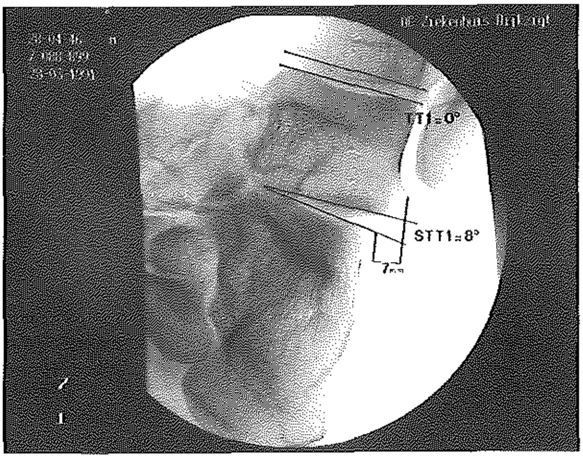


Figure 3b. This radiograph was taken after the foot had been inverted (step 1). The talus has made no tilting motion. Loss of congruency with tilt and shift in the subtalar joint can be seen.

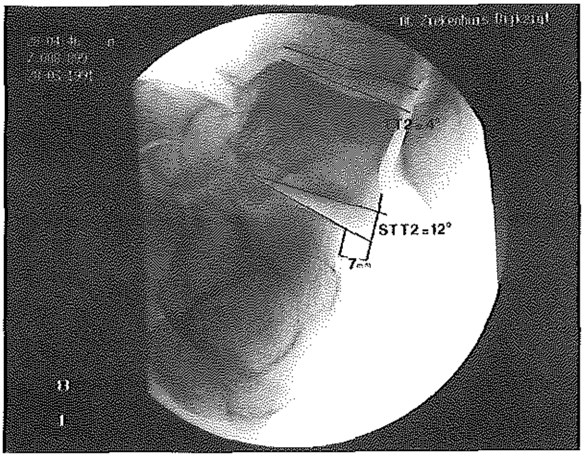


Figure 3c. In this radiograph taken after actual stress has been applied (step 2), a small degree of talar tilt and increase of subtalar tilt can be seen.

domes (the two most proximal points) of the lower articular surface of the tibia and the corresponding eminences of the talus. The reference points used for the measurements were clearly visible on the oblique views of the ankle. The angle between these lines after inversion of the foot (step 1) was defined as talar tilt (TT)1 and after actual inversion stress (step 2) , TT2 (Figs. 3b and c).

In measuring subtalar changes the following procedure was used: a first line was drawn across the two most lateral margins of corpus tali and a second line through the lateral border of the calcaneal side of the subtalar (posterior talocalcaneal) joint surface running parallel to the first. The distance between these lines, being the shift of the calcaneus relative to the talus, was thus measured in millimeters, and defined as shift 1 after inversion and shift 2 after inversion stress (Figs. 3b and c). Lines were drawn across the articular surfaces of the talus and the calcaneus of the subtalar joint. The angle between these lines was defined as subtalar tilt (STT) 1 after inversion and STT2 after further inversion stress (Figs. 3b and c).

Statistics

The data were analyzed using SPSS/PC+, version 3.1. The variables were examined for normality. For each test, p-values of 0.05 or lower were considered significant. A logarithmic transformation was applied on quantitative variables with a distribution that was skewed to the right before analyses with parametric tests were performed.

Differences in age, weight and height between groups were analyzed using Student's t-test. To test whether groups were comparable in gender, for sporting activities and joint laxity, a chi-square-test was used.

Correlations between age, weight, height and the measured variables (TT, STT and shift) were evaluated by means of Pearson's correlation coefficient. The relationship between these variables and gender and joint laxity were tested using Student's t-test.

When analyzing differences in TT, STT and shift between groups, the symptomatic feet of all patients (unilateral as well as bilateral, group A) were compared with asymptomatic feet of controls (group B) (Student's t-test or Mann-Whitney U-test; this analysis was done for both right feet and left feet).

A separate analysis was performed on patients with unilateral instability complaints (n=11). Of these patients, the symptomatic feet were compared with the asymptomatic feet, using the asymptomatic feet as controls (paired t-tests). Increases in TT, STT and shift between step 1 and step 2 that were found to be significantly different from zero (paired t-test) were compared between groups using the t-test for independent samples.

Results

Clinical

The symptoms found during examination of the 55 symptomatic feet are summarized in Table 2. Of all asymptomatic feet, two contralateral feet of patients with unilateral instability were found to have a positive anterior drawer test and positive tilting; in control group B, one foot with a positive anterior drawer test was found. None of the asymptomatic feet exhibited swelling, decreased mobility or pain. No statistical differences regarding age, sex, weight and height distribution or sporting activities were found between groups.

Table 2. Clinical findings of examination of 55 symptomatic feet.

symptoms	number of feet
positive anterior drawer sign	17
increased inversion tilting	14
local capsular/synovial swelling	8
reduced dorsiflexion of the ankle	1
tenderness of the sinus tarsi region	6
crepitus talocrural joint	2
peroneal tendinitis	1

Table 3. Comparison of TT, STT (°), and shift (mm) in symptomatic feet of patients with feet of controls[a].

	N	TT2	STT2	Shift 2
left feet				
asymptomatic	10	2.5 ± 3.7[b]	9.7 ± 3.8	6.5 ± 3.2
symptomatic	27	5.8 ± 4.0[b]	10.7 ± 3.3	6.6 ± 2.1
right feet				
asymptomatic	10	2.7 ± 4.1[c]	10.5 ± 2.9	7.4 ± 2.4
symptomatic	28	6.6 ± 5.5[c]	9.9 ± 4.2	6.7 ± 2.4

[a] Data are expressed as mean ± sd
[b] Mann-Whitney U-test: U = 69.0, P = .0223
[c] Mann-Whitney U-test: U = 69.5, P = .0176

Radiological

Statistically significant differences in TT2 were found between the symptomatic feet of patients (group A) and the controls (group B) (Table 3). The difference in TT2 between the symptomatic and asymptomatic feet of patients with unilateral complaints was not statistically significant (p=0.4). Of the 55 symptomatic feet (group A), 13 feet were found to have a talar tilt of 10° or higher. This was also the case in two of the 11 asymptomatic feet belonging to patients with unilateral complaints and two of the 20 control feet (groupB).

With increase of moment of force TT between step 1 and step 2, TT increased statistically significantly in the symptomatic feet ($p<0.007$). An increase of TT of 2° or more (the maximum increase was 6°) was found in 18 out of 55 symptomatic feet. In 15 of these feet, increase of the TT was present or was higher on the side with most symptoms. Increases in TT of 2° and 4° were found in only two asymptomatic feet (in the same two obviously 'mechanically unstable' feet of two patients with unilateral complaints that also demonstrated increased TT [>10°] and positive anterior drawer tests). Actual inversion stress after inversion of the foot (step 2) never resulted in the increase of TT in a foot of the control group B.

Radiologically, a mean subtalar tilt of 10° (range 3-20°) and a mean medial shift of 7mm (range 2-12.5mm) was found. No statistically significant differences were found between symptomatic and asymptomatic feet regarding STT and shift (Table 3), nor regarding increase of STT and shift during step 2. A clear increase (4°) of STT was seen only once in the symptomatic foot of a patient with unilateral instability (Fig. 3). The difference of STT between the two feet of the same person was 4° in four healthy controls, 4° in one patient with unilateral complaints, and 4° in three patients and 5° (the maximum difference) in one patient with bilateral complaints. All other differences were less.

A positive relation was found between general joint laxity and both talar and subtalar tilt. For left feet, a significant relation also existed regarding medial shift; however, this relation was not confirmed for right feet (Table 4).

Table 4. Effect of general joint laxity on TT, STT, and shift.

	laxity (mean ± sd)	no laxity (mean ± sd)	t	df	P[a]
left feet					
TT2	7.3 ± 4.4	3.9 ± 4.7	2.22	40	.032*
STT2	11.6 ± 3.6	9.1 ± 3.2	2.21	39	.033*
shift 2	7.5 ± 2.4	5.8 ± 2.2	2.32	39	.025*
right feet					
TT2	8.2 ± 4.9	3.2 ± 4.8	3.09	40	.004*
STT2	11.8 ±3.6	8.9 ± 3.1	2.73	40	.009*
shift 2	7.0 ± 2.5	6.7 ± 2.2	0.36	40	.724

P[a] = two-tailed probability. Asterisk indicates significance.

No significant correlation was found between the age, sex, height and weight and the measured variables TT, STT and shift.

Discussion

Talocrural joint

It has been reported that the results of stress-radiography are very closely related to 1) the mechanical device and the amount of load used, 2) the position of the foot and 3) whether the examination was carried out under anaesthesia (Lindstrand and Mortensen, 1977; Rasmussen, 1985; Larsen, 1986; Bleichrodt, 1987). Thus, it is difficult to compare our results with those in the literature, as various investigators have used different materials and methods.

Examining TT with our method was simple. The force applied to both feet of the same patient is equal, but is different for each individual, due to reasons such as stiffness which is different for each individual and changing moments of force when the amount of inversion changes. However, the criteria for each step were the same for all subjects. In our view, the use of the same absolute force on each foot would have definite drawbacks for reasons mentioned above. In the present study, patients primarily complained of instability; pain, if present, was always minor. None of these patients experienced pain while inversion of the foot (step 1) was performed. We believe that if patients do experience pain during normal inversion of a foot, the increase of talocrural or subtalar tilt will no longer give reliable information, as is also the case in other methods when no anaesthetic is used.

Radiological results showed statistically significant differences in talar tilt between symptomatic feet (group A) and control feet (group B). This seems to confirm the suggestion made in the literature that 'mechanical' instability is a factor predisposing to chronic lateral instability.

However, the relationship between talar tilt and 'mechanical' instability is not straight forward. We also found a wide range of TT (0-18°) in the asymptomatic feet during inversion of the feet (step 1). It was noteworthy to see under fluoroscopic control how effortlessly the talus started to tilt, in subjects of the control group (group B) as well, from the first moment of inversion onward. In some cases, mere inverting the foot without force was sufficient to produce talar tilt of up to 18°.

The large individual variation in TT also is reported in the literature (Rubin and Witten, 1960; Inman, 1976; Seligson et al., 1980) and makes it difficult to differentiate between normal and a pathologically increased talar tilt within the ankle mortise.

Stepwise examination of talar tilt might help to make this differentiation. During the first step, the foot is fully inverted and passive structures, such as ligaments, become increasingly tight until they block further motion. It seems possible that increasing inversion stress hereafter, as done during step 2 will only show increase of TT in feet with damaged lateral ligamentous structures.

Further research is necessary to demonstrate whether the increase of talar tilt that occurs between steps 1 and step 2 can serve as a new parameter in diagnosing mechanical instability of the talocrural joint.

Subtalar Joint

Rubin and Witten (1962) were the first to evaluate the clinical significance of subtalar instability using a footholding device to produce inversion stress while tomograms were taken. Brantigan et al. (1977) used the same method and demonstrated subtalar instability in three patients with persistent instability as a result of nonreconstructed, ruptured calcaneofibular ligament. It has been suggested that subtalar instability is a cause of the clinical symptoms of ankle instability wether or not there is instability in the talocrural joint.

When trying to detect abnormal tilt on basis of a clinical examination, it was difficult to appreciate whether tilt was caused by talocrural motion together with subtalar motion, or solely by subtalar motion. In three patients with joint laxity, the tilt during inversion stress was clinically considered to be equally positive in both feet; however, radiological differences of 10° of talocrural talar tilt were measured between these feet. Furthermore, the same problem recurs as it does for the talocrural joint, namely, to what extent is the inversion of the foot physiological and when does it become pathologic?

Radiologically, no differences between symptomatic and asymptomatic feet concerning subtalar tilt and medial shift were found. A high intersubject variation was found, as previously reported by others (Inman, 1976; van Langelaan, 1983). The statistically significant relationship between higher values of both talar ($p < 0.03$) and subtalar tilt ($p < 0.03$) and joint laxity suggests that joint laxity is one of the factors causing this variation.

Comparing our results regarding the subtalar joint with those reported in literature proved to be more difficult then doing so for the talocrural joint.

Various methods have been described to evaluate subtalar instability radiologically. Stress has most often been applied manually (Zwipp and Tscherne, 1982; Huggler, 1978; Zwipp, 1986; Clanton, 1989). However, we prefered to use a stress device, because we find this method to be more reliable in producing an equal moment of force on both feet. A large spectrum of diagnostic criteria to establish abnormal subtalar tilt has been reported in literature. Criteria vary from only a few degrees of tilt in the subtalar joint, based on the results of kinesiologic studies (Kjaersgaard-Andersen et al. 1987a and b) to subtalar tilt above 20° (Machan and Oelrich 1989).

The consequence of the use of different subtalar stress methods in regard to the difference of findings which can be found has received insufficient attention. If, for example, we were to use the criteria as proposed by Zwipp (1986), in which case a subtalar tilt more than 5° and a medial shift of the calcaneus of more than 5 mm are to be considered abnormal, practically all feet we examined would show abnormal movement. However, different stress methods were used. Zwipp applied inversion force specifically to the calcaneus in relation to the talus while blocking rotation of the lower leg (Fig. 1). In the present study, inversion stress was applied to the foot as a whole, and was accompanied by exorotation of the lower leg. It is known from functional anatomical studies that loss of congruency and shift in the subtalar joint is normal under these conditions (Huson, 1961 and 1991; van Langelaan, 1983; Benink, 1985).

Another problem in interpreting subtalar stress radiographs is how to differentiate between normal and pathologic subtalar motion. As also reported by Harper (1992), a wide range of subtalar tilt and shift was found in asymptomatic feet. As a consequence, finding a subtalar tilt, for example, of 15° will give no information with regard to abnormal motion in this joint. A difference of subtalar tilt of up to 5° with the contralateral foot will give no further information, because this can also be normal. Possibly, similar to the situation described for the talocrural joint, finding an increase of subtalar tilt in one foot and no increase in the contralateral foot during stepwise or dynamic examination might be of clinical importance. In the present study, a clear increase of subtalar tilt between step 1 and step 2 could only be demonstrated once in a patient who was free of symptoms after conservative treatment. Thus, it is still to be demonstrated wether this assesment can be of help.

From the present study, it can be concluded that: (1) a statistically significant difference of talar tilt was found between symptomatic and asymptomatic feet, (2) an increase in talar tilt between steps 1 and 2 was only present in symptomatic feet, which suggests the existence of ligamentous damage, and (3) no difference of subtalar tilt or shift could be demonstrated between asymptomatic and symptomatic feet.

Stress radiology and stress examination of the talocrural and subtalar joint on helical computed tomography

Chapter 7

Summary

The main objective of this study was to compare subtalar inversion stress views using the Brodén view with inversion stress views on helical Computed Tomography (CT). One of the drawbacks of routine radiography is the imaging of 3-dimensional structures in a 2-dimensional plane. We investigated if the use of helical CT would lead to a more objective and clearer measurable method to determine the amount of tilt in the subtalar joint. A group of 15 patients with unilateral chronic instability complaints and clinically suspected subtalar instability was examined. The contralateral asymptomatic foot was used as control.

A variable amount of subtalar tilt (4-18°) was demonstrated in all cases on stress radiographs, without finding significant difference between the symptomatic and asymptomatic feet. However, contrary to the findings at the talocrural level, subtalar tilt was found in none of the patients using helical CT. Thus, we now doubt that the tilt seen during stress examination using the Brodén view is the true amount of tilt. It may be that the lateral opening, seen on these radiographs, for a major part results from imaging two planes that have made a translatory and rotatory movement relative to each other in an oblique direction. It is concluded that the Brodén stress examination might not be useful for screening patients with subtalar instability.

Associated anomalies not visible on the roentgenographs were detected by helical CT. In four cases narrowing of the articular cartilage and irregular and hypertrophic

bone formation at the middle facet joint of the subtalar joints was found. Likely these changes cause disturbance of function in this joint and it is suggested that the subjective complaint of instability with 'giving way' complaints is not only caused by hypermobility, but can be caused by other disturbances of normal motion.

Introduction

Chronic lateral instability of the ankle/foot may be present in as many as 10% to 30% of people who have sustained an injury of the lateral ligament complex (Freeman, 1965; Hansen et al., 1979; Linde et al., 1986). It is a clinical condition with frequent inversion injuries/sprains, 'giving way' sensations, difficulties in walking on uneven ground and sometimes pain and swelling. Multiple factors are involved. Abnormal or increased motion in the talocrural joint due to lateral ligamentous damage is believed to be one of these factors (Broström, 1966; Staples, 1975; Karlsson, 1989). Damage of the anterior talofibular ligament results in increased motion in the sagittal plane (de Vogel, 1970; Rasmussen, 1985). This ligament, with its more horizontal orientation, plays an important part in transmission of motion between the leg and the foot (Prins, 1978; Huson, 1991). After severing this ligament tibiotalar delay will increase markedly (Fiévez and Spoor, 1987; Huson, 1991). The term anterolateral/internal rotatory instability has been used to describe the resulting clinical symptoms (Anderson et al., 1952; Glasgow et al., 1980; Rasmussen, 1985). More severe trauma of the lateral ligament complex may cause injury of both the anterior talofibular and the calcaneofibular ligament. Damage of both these ligaments results in an increase of varus tilting of the talus within the ankle mortise (Rubin and Witten, 1960; Rasmussen, 1985). The calcaneofibular ligament is rarely injured alone, but with or without a combined lesion of the anterior talofibular ligament, rupture of this ligament is reported to result in an increase of motion in the subtalar joint (Rubin and Witten, 1962; Laurin et al., 1968; Vidal et al., 1974; Brantigan et al., 1977; Zwipp and Tscherne, 1982; Zollinger et al., 1984; Zell et al., 1986; Kjaersgaard-Anderson et al., 1987a and b; Heilman et al., 1990). Subtalar instability must be considered as a cause of symptoms in chronic lateral instability particularly if other causes of instability have been excluded (Clanton, 1989).

In a previous study (Louwerens et al. 1995a, described in chapter 6) we found that an increase of talar tilt (in the talocrural joint) between two steps of inversion was present in symptomatic feet only. It was suggested that the increase of tilt between these steps, might serve to distinguish between normal and pathologically increased tilt. However, because increase of tilt was found only once in the subtalar joint, no conclusions could be drawn as to the use of this method in diagnosing mechanical instability of the subtalar joint. We also concluded that no consensus existed as to the best method and the criteria to be used for evaluation of abnormal motion in the subtalar joint.

In the present study a further effort is made to objectify a possible subtalar component in a group of 15 patients with unilateral chronic instability complaints. An identical standardized radiographic assessment of talar and simultaneous subtalar tilt was made, using a 40° Brodén view. This time, the same stress examination was also performed using CT-imaging.

Patients and methods

Patients

Fifteen patients, 12 men and 3 women, with chronic unilateral foot instability were consecutively recruited from the orthopaedic out-patient departments of the Central Military Hospital and the University Hospital of Utrecht. All patients complained of frequent unilateral inversion injuries and instability (with 'giving way' sensations) of the foot. Typically sprains already occurred when they walk on a uneven surface. Sometimes a short period of pain and swelling followed such a sprain, but otherwise the patients were without pain. At clinical examination an increase of inversion tilt was found and there was suspection for the presence of subtalar instability on the symptomatic side. The asymptomatic feet of these patients served as a control group. The number, age, height and weight of the subjects are shown in Table 1.

Methods

A detailed description of the standardized radiographic assessment of talar and simultaneous subtalar tilt and of the measurements used in the present study has been given previously (Louwerens et al., 1995a). The hinge device to stress the joints in the present study was identical to the one previously described with exception that all ironwear was replaced by other materials in order to make the apparatus suitable for helical CT or MRI (Fig. 1). A specific subtalar view (Brodén

Table 1. Age, sex, height and weight of patient group (12 M, 3 F).

	mean ± sd	range
age (yr)	25 ± 5.3	18 - 36
height (cm)	181 ± 7.0	166 - 192
weight (kg)	82 ± 9.7	64 - 99

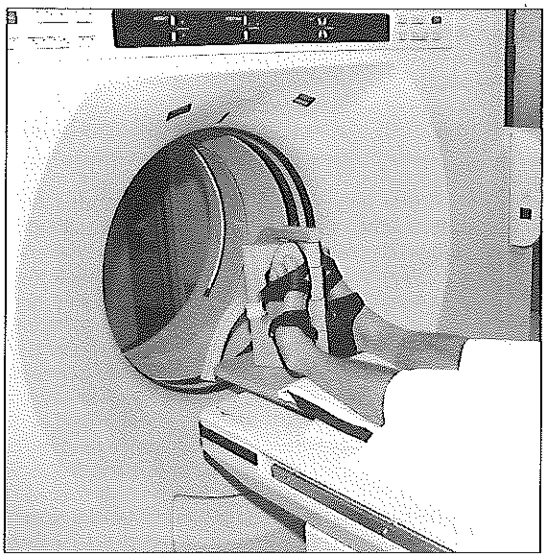


Figure 1. Photograph showing the hinge device used in this study.

view) was used under fluoroscopic control, this time, using a Philips angiodiagnostics 96 apparatus (Shelton, CT, USA).

Radiographs were made of the feet in neutral position (step 0), after inversion with moderate force until the point of fair restraint (step 1) and after inverting as far as possible to the point of pain or until no further closure of the device was possible (step 2). This position was held for 1 minute, to ensure full muscle relaxation, before the third radiograph was made.

The amount of talar tilt found after step 1 was defined as TT1 and after step 2 as TT2. The corresponding subtalar tilt angles were defined as STT1 and STT2 respectively. The difference/increase of tilt found between (S)TT1 and (S)TT2 was calculated for each foot and defined as TTd and STTd. TTd and STTd were used as parameters for comparison between symptomatic and asymptomatic feet.

In the stress device, computed tomography of the inverted hindfeet was performed with a high resolution technique on a helical CT scanner (Tomoscan SR 7000, Philips Medical Systems, Best, the Netherlands). Stress was gradually increased in order to compensate for the effect of ligamentotaxis and the hinge device was closed to the same amount of degrees as previously found after step 2. This position was held during a period of 4 minutes, the time required to perform CT scanning. Contiguous axial slices (thickness 3mm) from 2cm above the talocrural joint to the calcaneocuboid joint were obtained. After acquiring the raw data, separate coronal reconstructions were made of the hindfoot with a bone algorithm. Measurements were made analogously to those on the Brodén view.

Table 2. Results regarding TT1 and 2, TTd, STT1 and 2, STTd, TTct and STTct.

Case	S/A	TT1	TT2	TTd	STT1	STT2	STTd	TTct	STTct
1	S	3	3	0	14	14	0	0	0
	A	1	8	7	12	12	0	0	0
2	S	10	10	0	8	8	0	0	0
	A	7	7	0	7	7	0	0	0
3	S	10	12	2	8	10	2	6	0
	A	9	9	0	7	7	0	0	0
4	S	0	0	0	8	8	0	0	0
	A	1	1	0	6	6	0	0	0
5	S	0	0	0	8	8	0	0	0
	A	0	0	0	10	10	0	0	0
6	S	10	14	4	8	10	2	0	0
	A	8	8	0	10	10	0	0	0
7	S	8	12	4	10	10	0	5	0
	A	4	6	2	6	6	0	0	0
8	S	5	5	0	5	5	0	0	0
	A	5	5	0	5	5	0	0	0
9	S	4	4	0	7	10	3	0	0
	A	9	9	0	5	5	0	0	0
10	S	4	8	4	12	12	0	9	0
	A	3	3	0	12	12	0	0	0
11	S	11	18	7	16	18	2	9	0
	A	10	16	6	7	10	3	0	0
12	S	7	7	0	10	10	0	0	0
	A	7	7	0	6	6	0	0	0
13	S	9	12	3	8	8	0	12	0
	A	11	11	0	4	4	0	10	0
14	S	1	1	0	10	10	0	0	0
	A	1	1	0	8	8	0	0	0
15	S	8	10	2	6	6	0	0	0
	A	3	3	0	7	7	0	0	0

S = symptomatic
A = asymptomatic

	TT1	TT2	TTd	STT1	STT2	STTd	TTct	STTct
mean	5.63	7.07	1.43	8.33	8.73	0.40	1.70	0
St.D.	3.72	4.93	2.22	2.81	3.03	0.93	3.62	0
range	11.00	18.00	7.00	12.00	14.00	3.00	12.00	0
min.	0	0	0	4	4	0	0	0
max.	11	18	7	16	18	3	12	0

Statistics

The data were analyzed using SPSS/PC+, version 6.0. P-values of 0.05 or lower were considered significant. TTd and STTd of the symptomatic feet were compared with those of the asymptomatic feet using a one-tailed sign-test. The same test was

used comparing the results obtained with CT imaging.

Results

Results regarding TT, STT, TTd, STTd, TTct and STTct are summarized in Table 2.

Brodén stress examination

Talocrural

Increase of talar tilt was found in 7 of the symptomatic feet (range 2-7°), but also in 3 of the asymptomatic feet. In one case, increase of talar tilt was found only in the asymptomatic foot and in two patients increase was found in both feet. Seven out of the 15 patients showed no increase of talar tilt between step 1 and step 2, neither in the symptomatic nor in the asymptomatic foot. Regarding the increase of talar tilt (TTd) the difference between symptomatic and asymptomatic feet was found to be statistically significant ($p=0.04$).

Subtalar

An increase of subtalar tilt was found in the symptomatic foot of 3 patients and in both feet of 1 patient. Differences between the symptomatic and asymptomatic feet were not significant.

CT stress examination

Talocrural

Tilting of the talus within the ankle mortise was found in the symptomatic foot of 5 patients (range 5-12°). A talar tilt of 10° was also found in the asymptomatic foot of one of these patients. The difference of talar tilt (TTct) between the symptomatic and asymptomatic feet was statistically significant ($p=0.03$). The 5 feet with talar tilt during CT stress examination also demonstrated an increase of talar tilt during Brodén stress examination. In two symptomatic feet no talar tilt was found during CT examination, while these feet did demonstrate increase of TT during Brodén stress examination.

Subtalar

Tilting within the subtalar joint was never found using CT stress examination.

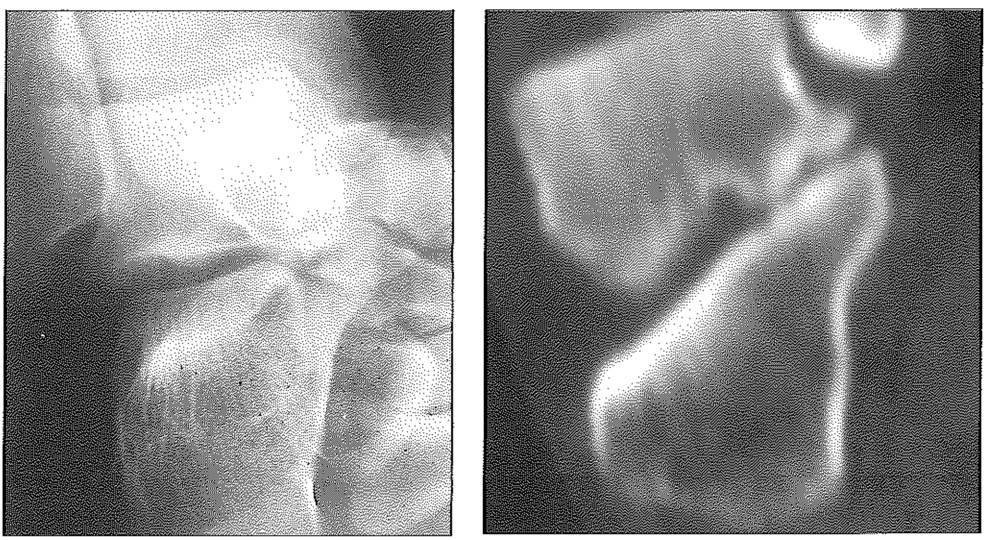


Figure 2. On the Brodén stress view no talocalcaneal coalition can be seen. Only slight 'lateral opening' suggests minimal motion in this joint (left). CT examination shows the presence of a fibrous coalition (right).

Other findings

Four patients showed changes in the middle facet of the subtalar joints (Fig. 2). Loss of cartilage space and irregular and hypertrofic bone formation is seen, suggesting the existence of a fibrous coalition. One patient showed a large posterior calcaneal cyst in the symptomatic foot. No other disorders or signs of osteochondral lesions were found.

Discussion

Talocrural joint

The association between chronic lateral instability of the foot and mechanical instability (increased mobility as a result of ligamentous damage) is under debate. While some authors stress the importance of mechanical stability (Broström, 1966b; Karlsson, 1989), there are others who believe that factors like proprioception, muscle and balance control are of more importance (Freeman et al., 1965; Tropp, 1985a). Freeman et al.(1965) and Tropp (1985a) found no correlation between the patient's subjective complaints, for which the term functional instability was introduced by Freeman (1965) and mechanical instability. Obviously, the more importance is attributed to mechanical instability, the more interesting it becomes to be able to differentiate between normal physiological and pathologically increased range of motion of the joints. In the previous chapter increase of talar tilt (between steps 1 and 2, as also performed in the present study) was only found in symptomatic feet. This was interpreted with the possibility that during the first step the foot is fully inverted and passive structures, such as the ligaments, become increasingly tight until they block further motion. Increasing stress hereafter, as done during step 2, will only show increase of tilt in feet with damaged lateral ligamentous structures. It was suggested that this increase might serve as a new parameter in diagnosing mechanical instability of the talocrural joint.

In the present study a statistically significant difference was found between symptomatic and asymptomatic feet with regard to increase of talar tilt (TTd), however, an increase of tilt was also found in 3 asymptomatic feet and in one case a clear talar tilt and increase of talar tilt was found in the asymptomatic foot only (Table 2). The use of increase of tilt as a definite parameter has therefore become doubtful. The relation between the radiographic diagnosis of mechanical instability and chronic lateral instability complaints remains questionable. Both mechanical as well as functional instability are involved, they may be parallel phenomena, as described by Tropp (1985a). In our patient group mechanical instability was not a dominant factor.

To our knowledge, no previous investigation has been published combining stress examination of the foot and CT-scanning. One of the drawbacks of routine radiography is the imaging of 3-dimensional structures on a 2-dimensional plane. When motion takes place in rather complex geometrical structures like the subtalar joint, the articular surfaces loose congruency. It may become a problem to draw the lines that represent the tangents to these surfaces and thus to measure the amount of tilt. This problem does not occur when CT scanning is used.

In only 6 feet an angulation was found in the talocrural joint during CT stress examination (Table 2). In 5 cases this was in the symptomatic foot and in these feet this was associated with increase of tilt with Brodén stress radiography. In the sixth case, it concerned an asymptomatic foot in which a TT of 11° was found and no TTd. Increase of tilt is not always associated with a tilt during CT scanning. Although explanations can be found for differences in the amount of tilt between the two examinations, we cannot explain why not all feet that exhibit an evident talar tilt with stress radiography also show tilting during CT scanning. It cannot be excluded that slight concessions were made regarding the amount of stress applied during CT examination, although subjectively both the examiner and the subjects experienced the amount of stress and closing of the hinge device to be equal. Another explanation for the difference would be that the talocrural joint was cut in a different plain, but this still does not explain why in some feet no tilting at all is seen with CT examination, while they do show a talar tilt of 10° and sometimes more. In conclusion, there seems to be some relation between chronic lateral instability, increase of talar tilt and CT angulation of the talocrural joint during stress examination, but the results are inconsistent and none of these examinations are found to be more specific for the radiographic assessment of mechanical instability.

Subtalar joint

A wide range of motion (4-18°) of the subtalar joint was found during Brodén stress radiography. These results are comparable with those found in previous studies (Rubin and Witten, 1962; Harper, 1992; Louwerens et al., 1995a). Increase of subtalar tilt was found in only 4 symptomatic feet and in 1 asymptomatic foot. This increase was never more than 3° and it is open to discussion as to what extent slight 'errors' in drawing the lines representing the articular surfaces, are of influence. As mentioned above this can be a problem for the subtalar joint with its undulated geometry. It was hoped that CT scanning would bring clarity and make measurements more reproducible. However, not once was an actual opening of the subtalar joint on the lateral side found. One would have expected such at least in one of the patients, similar to findings at the talocrural level.

Incongruity, occurring between the bones of the tarsus during motion has been noted as early as the second half of the 19th century and has been extensively described by Huson (1961, 1991). Roentgen-stereo-photogrammatic studies have demonstrated translation and rotation of the talus and calcaneus in relation to one and other during inversion of the injured foot. As a result, the calcaneus inverts in relation to the talus (van Langelaan, 1983; Lundberg, 1988). However, a tilting motion between the two bones is not mentioned. Kjaersgaard-Andersen et al. (1987a) found increase of adduction in the talocalcaneal joint to a maximum of 5° after cutting the calcaneofibular ligament. Smaller increases were found after cutting of the ligaments of the sinus and canalis tarsi only (Kjaersgaard-Andersen et al., 1988). The results of a study performed by Heilman et al. (1990) in which the calcaneofibular and talocalcaneal ligaments were selectively cut, suggest that this increase is a result of tilting, and Clanton (1989) in a review article, concludes that it appears that any loss of parallelism is indicative of instability. In fact practically

Fig. 3. Brodén stress examination shows both talar tilt and subtalar tilt (above). CT stress examination confirms the existence of a talar tilt, however, no tilt is found at the subtalar level (below).

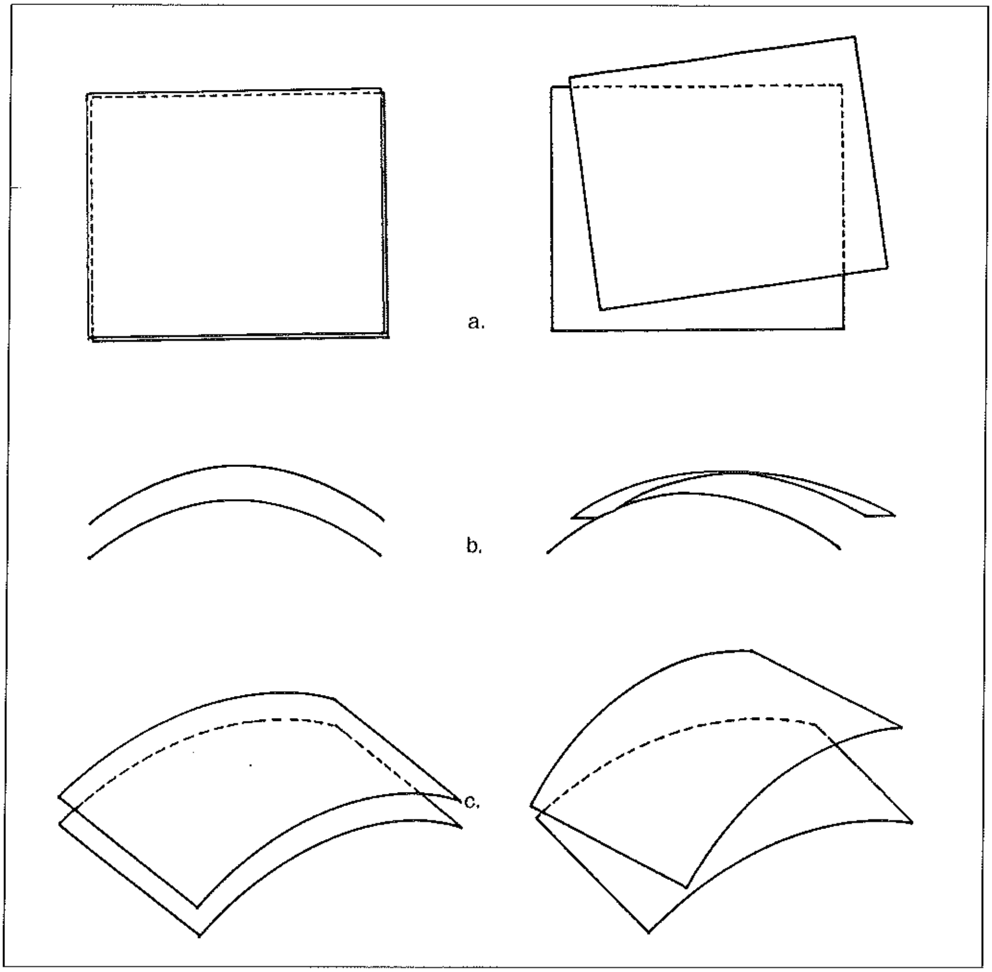


Figure 4. Two curved parallel surfaces seen from above (a), from aside (b) and in an oblique direction (c). On the left side before (the surfaces are still fully congruent) and on the right side after translation and rotation relative to each other.

all clinical radiographic studies on this matter, including the present study, have focused on finding a subtalar tilt in order to establish mechanical instability.

We now doubt that the tilt seen during Brodén stress examination (Fig. 3) is the true amount of tilt. If surfaces have a curved geometry as drawn in Fig. 4 some amount of tilt will occur when these planes translate and rotate upon each other (Fig. 4b), but the angulation which seems to occur (Fig. 4c) is the result of viewing two planes that have made such movements relative to each other in an oblique direction.

Obviously there is a direct relation between the amount of motion and the so-called tilt, but we suggest that determining the amount of translation and rotation in a direct manner might prove to be more helpful in objectifying abnormal motion in the subtalar joint. Recently, Kato (1995) described a method to measure anterior displacement of the calcaneus in relation to the talus. This translation is only one of the components. Harper (1992) suggested that the assessment of the rotational component of hindfoot inversion might help to document subtalar instability. Possibly a combination of both above mentioned components occurs, resulting in anterolateral rotatory instability of in the subtalar joint. Further research must be performed to confirm these suggestions.

Finally, CT examination of the hindfoot itself might prove to be helpful in diagnosing problem cases with chronic lateral instability. Quite unexpectedly a fibrous talo-calcaneal coalition was found in four patients (Fig. 2). So in these patients the subjective complaints seem to be caused by disturbance of the coupling between foot and leg (possibly abnormal motion at the talocrural level) as a result of loss of motion in the tarsus, rather than of hypermobility.

Summary and discussion

Chapter 8

This thesis describes a series of clinical-experimental and radiographic studies on the pathogenesis of chronic lateral instability of the foot. Chronic lateral instability is a clinical syndrome in which patients complain of instability and/or the feeling of instability of the ankle/foot. They have, so-called, 'giving-way' sensations and often suffer recurrent inversion sprains. Typically, the patients say that they already give-way or sprain the foot when they step on a small stone or walk on an uneven surface. Reinjuries occur during normal activities of daily life or during sports. These complaints may be accompanied by pain and swelling. In the first chapter it is pointed out that multiple active and passive factors are involved in this clinical syndrome. There seems to be consensus that numerous factors can play a role at the same time. Two main thoughts were of influence during the onset of the present studies.

The firstone is the thought that the peroneal muscles do not protect the foot against an inversion injury during normal walking. If this was to be the case, then all the emphasis given to this active stabilizing factor in the treatment of chronic instability would seem to be a little misplaced and more attention should be given to protection of the foot by providing more passive stability. Following this thought the studies described in chapters two, three and four were started. The study presented in chapter five is a continuation of these studies.

The second thought is that, initially, not the ankle but the foot sustains an inversion injury. There seems to be a tendency to neglect the fact that inversion and thus inversion injuries also concern the joints within the tarsus. In common daily language it is, for example, said: 'I sprained my ankle' and also in the medical literature the terms 'ankle sprain' and 'instability of the ankle' are most commonly used. Also, most of the research concerning instability has focused on the involvement of the ankle ligaments and on injury to the ankle joint. Far less is known about the role of the tarsal joints. The studies presented in chapters six and seven concern this issue.

In the present chapter a brief summary of the above mentioned chapters is given. A few issues will be discussed in a general context in the second part of this chapter.

Summary

Chapter 2 describes a study in which the electromyographic activity of the peroneal longus and anterior tibial muscles of 25 patients with chronic lateral instability and 10 controls was registered during the stance phase of gait. We investigated whether the peroneus longus muscle is active when the foot is at risk of sustaining an inversion injury and whether a change in muscle control can be identified in patients with chronic lateral instability. Activity of the muscles was registered while walking under a series of different walking conditions in order to analyze the role of these muscles in relation to the functions balance control (by walking with and without a hand on the railing/secured balance) and propulsion (by walking with a normal and much slower speed).

With regard to the peroneus longus a clear difference was found in all subjects between walking with and without ensured balance. With ensured balance, there was a variable amount in peroneal activity, most of which was found in the third quarter of stance. A high increase in peroneus longus activity, in particular in the second quarter of stance, was found when subjects had to maintain balance in a natural way. This peroneal activity varied from step to step and alternation with activity of the anterior tibial muscle was registered. This was found in all subjects and it is thus thought that the peroneus longus serves to maintain balance and that the activity to provide this balance mainly takes place in the period between foot-flat and midstance.

The interaction between the factors of external support and speed was another finding in this study. This can be explained as follows. When standing on one leg without support, all activity of peroneus longus is used to maintain balance in the frontal plane. The slower the walking speed the more this muscle is still used to maintain balance. However, with increase of speed, this function decreases and other activities which might concern positioning of the foot, acceleration and active stabilization start to dominate.

The anterior tibial muscle was predominantly active in the first quarter following heel contact. Loss of secured balance was of no influence on the activity of this muscle during this phase. However, with increase in walking speed an increase in tibialis anterior activity occurred. Thus, activity of this muscle seems to be mainly related to locomotion. A far less and variable activity was found in the phase after foot-flat. A slight shift in activity to the second quarter of stance when subjects have to maintain balance suggests that this muscle, at least in some individuals, works actively for balance control.

No difference in peroneal activity was found in relation to instability complaints. A significant higher activity of the tibialis anterior muscle was found in patients with bilateral instability, while no significant difference was found between the symptomatic and asymptomatic legs of patients with unilateral instability. These findings suggest changes in central control and not a peripheral pathogenesis of the instability complaints.

Because the higher amount of tibialis activity is not compensated by peroneus longus activity, a more inverted position of the foot around heel contact might occur. As explained elsewhere, this is biomechanically unfavourable in connection with lateral instability of the foot. Increase of inversion was, however, not measured in these patients. The study in which this was investigated is presented in chapter 5.

Chapter 3 concerns a study in which an effort is made to measure the passive stability of a foot. An experimental set-up is described in which the findings are not influenced by muscle activity, thus excluding the factor active stability. A custom-made platform, which could tilt around a movable axis, was used under standardized conditions. It is suggested that the axis around which the foot is found to tilt is determined by passive factors, only. This axis does not reflect which passive factor in particular is of importance, but is thought to be related with passive stability of the foot as a whole. It was presumed that the feet of 20 patients with chronic lateral instability might tilt sooner (around an axis more laterally) than the feet of 10 controls. Although the results show a tendency of the symptomatic feet to tilt more readily, the differences were not statistically significant.

One of the passive factors that influences the stability is the foot configuration. Biomechanically a foot with a varus position of the hindfoot is more prone to an inversion injury, because a smaller moment of force is needed to enforce inversion. As described in chapter 4 we examined the foot build of 33 patients with chronic instability complaints and 10 controls using standardized lateral radiographs. Four different parameters were used: 1) the tarsal index as introduced by Benink, 2) the talocalcaneal angle, 3) the talometatarsal angle and 4) the calcaneal angle. No significant differences were found between the two groups, thus we were unable to establish a relation between chronic lateral instability of the foot and foot geometry. Positive and negative correlations between the four parameters used in this study were roughly as presumed before the study, with exception of the talocalcaneal angle. This angle was found to be a dubious parameter in measuring the longitudinal footarch. It is suggested that the talometatarsal angle is the most practical angle to use in order to evaluate the amount of cavus of the foot in daily orthopaedic practice.

Two of the above mentioned findings provide a reason to undertake the study which is presented in chapter 5. These are the following. Firstly, a significantly higher (not compensated) activity of anterior tibial muscle was found in patients with bilateral instability. As suggested previously this might render a more inverted position of the foot. Other findings, described in chapter two, are of additional importance namely, that stance phase activity of the tibialis anterior is predominantly between heel contact and foot-flat, which is the phase when the foot is most at risk of sustaining an inversion injury (because it is not fully loaded) and which is also the phase in which the peroneus longus muscle is least active. In the second place, after finding no significant relation between foot geometry and instability complaints, the following question arose: if it is not the 'foot build', could it then be the 'the way of walking' that is involved in this clinical syndrome? For the position of the foot is not only the result of the architecture of the foot, but is also determined by active factors such as motor control and attention.

To answer this question a dynamic analysis of rearfoot motion during walking of a group of 20 patients with bilateral instability complaints and of 14 healthy subjects was performed. The position of the hindfoot in the frontal plane was assessed with the help of 2-dimensional video-based analysis. Recordings were also made under different walking conditions in order to examine whether change in walking speed and the presence of external support (ensured balance) had any effect on the rearfoot position. Again, we could not demonstrate a significant difference between the patients and the controls. It was concluded 1) that a relationship between the position of the rearfoot at the moment of heel contact and chronic lateral instability of the foot could not be confirmed and 2) that no significant influence of walking speed or external support (ensured balance) on this position could be established.

The object of the investigation presented in chapter 6 was to determine a possible subtalar component in a group of 33 patients with chronic ankle instability. A group of 10 subjects without ankle/foot symptoms acted as controls. A standardized radiographic assessment of talar and simultaneous subtalar tilt was made. A hinge device to stress the joints and a specific subtalar view (Brodén view) were used under fluoroscopic control. Radiographs were made with the feet: 1) in neutral position, 2) after inversion with moderate force until the point of fair restraint (step 1), and 3) after inverting with more force as far as the conditions would allow (step 2).

A wide range (3-20°) of subtalar motion was found, with a mean of 10°, in both symptomatic and asymptomatic feet. With the present method, practically all subtalar joints showed some loss of congruity and medial shift of the calcaneus in relation to the talus. This could not be related with chronic instability of the foot. The consequence of the use of different subtalar stress methods has so far received no adequate attention and is discussed in this chapter.

An increase of talar tilt between step 1 and step 2 was found in feet that were symptomatic only. During the first step, the foot is fully inverted and passive structures, such as ligaments, become increasingly tight until they block further motion. It was suggested that increasing inversion stress hereafter, as done during step 2, might only result in increase of the talar tilt when lateral ligaments are damaged. Further research was thought necessary to determine whether this finding can serve as a parameter to discriminate between physiological and abnormal talar tilt and do likewise for the subtalar joint.

One of the objectives of the study described in chapter 7 has been put forward in the previous paragraph. Another purpose of this study was to compare subtalar inversion stress views using the Brodén view with inversion stress views on helical CT. One of the drawbacks of routine radiography is the imaging of 3-dimensional structures in a 2-dimensional plane. Helical CT was used to investigate if this method would lead to a clearer measurable and thus to a more objective way to determine the amount of tilt in the subtalar joint. A group of 15 patients with unilateral chronic instability complaints and suspected subtalar instability was examined. The contralateral asymptomatic foot was used as control.

Using the Brodén view a variable amount of subtalar tilt (4-18°) was demonstrated, without finding significant difference between the symptomatic and asymptomatic feet. However, contrary to the findings at the talocrural level, subtalar tilt was found in none of the patients using helical CT. Thus, we now doubt that the tilt seen during Brodén stress examination is the true amount of tilt. It may be that the lateral opening, which is seen on the radiographs, for a major part results from imaging two planes in an oblique direction that have made a translatory and rotatory movement relative to each other. It is concluded that the Brodén stress examination might not be as useful for screening patients with subtalar instability as generally assumed.

The finding that increase of tilt between step 1 and step 2 in the talocrural joint only occurs in symptomatic feet could not be confirmed in this study. There seems to be some relation between increase of talar tilt, angulation in this joint found on helical CT and chronic lateral instability, but the results are not consistent. The problem how to discriminate between normal and abnormally increased motion is still unsolved.

Finally, changes not visible on the roentgenographs were detected by helical CT. In four cases narrowing of the articular cartilage and irregular and hypertrofic bone formation at the middle facet joint of the subtalar joints was found. It is probable that these changes result in disturbance of the function of this joint and thus it is suggested that the subjective complaint of instability with 'giving way' complaints is not only caused by hypermobility, but can be caused by other disturbances of normal motion.

Discussion

Probably everyone sustains an inversion injury of one of his feet/ankles at least once in his lifetime. The natural history of this injury is benign. However, even long after the injury, when asked for, quite a number of people still experience some discomfort. For the great majority of these patients these complaints are not enough reason to consult a physician. Those patients that do visit the clinics often complain of instability, 'giving way' feelings and sometimes suffer reinjuries. In this research multiple factors that have been described to be involved in this clinical condition were examined in a series of clinical-experimental and radiological studies. In daily orthopaedic practice it is easily assumed that these factors are indeed of influence. However, the influence of the peroneal muscles, foot geometry, foot positioning, the subtalar joint and of passive stability of the foot could not be demonstrated in this study. This can be caused by numerous facts.

First of all, the methods or the patient groups that were used in the various studies might have been inadequate. The methods used in this series of studies were based on the present literature. In practically all studies efforts were made to improve the accuracy and objectivity of the methods thus far used. Computer programs were made to quantify EMG-signals and for video-analysis. Apparatus were developed to determine the midline of a foot and for tilting the foot under standardized conditions. The last two chapters in fact concentrate on the lack of clear criteria and a standardized method to demonstrate subtalar instability. The patients who participated in the study were representative of patients with chronic lateral instability of the foot as seen at the clinics. With exception to the study described in chapter 7 (in which it was our intention to select patients with unilateral subtalar instability), symptoms found at physical examination like cavovarus foot build, laxity in the talocrural joint and such were not used as selection criteria, in order to prevent bias.

Another reason can be that the factors examined are not dominant enough on itself. For example a cavovarus foot configuration might be of importance, but it is not the only factor involved. Other factors like hypermobility or difference in motor control seem to determine that a patient with symmetrical bilateral cavovarus can have complaints on one side and none whatsoever on the other side.

The finding of no statistically significant differences between the groups that were examined, with exception regarding activity of the tibialis anterior muscle, does not imply that our study has no relevance. Clinicians might have the tendency to overemphasize the importance of certain findings at physical examination such as a positive talar tilt, hypermobility of the tarsus or a varus hindfoot. The present study illustrates that such symptoms on itself might mean little and warns against overtreatment of these patients. It is often questionable if all kinds of treatment commonly applied are of more benefit to the patient than advice and reassurance.

List of abbreviations

ATFL	anterior talofibular ligament
ATT	anterior talar translation
AX	axis line
C angle	calcaneal angle
COP	center of pressure
CFL	calcaneofibular ligament
CT	computed tomography
EMG	electromyography
FSR	force sensing resistor
HPF	high-pass filter
LPF	low-pass filter
PTFL	posterior talofibular ligament
STT	subtalar tilt
TC angle	talocalcaneal angle
TM angle	talometatarsal angle
TI angle	tarsal index
TT	talar tilt

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Samenvatting

Dit proefschrift behandelt een reeks van klinisch-experimentele en radiologische onderzoeken betreffende de pathogenese van chronische laterale instabiliteit van de voet. Chronische laterale instabiliteit is een klinisch syndroom waarbij patiënten klagen over instabiliteit en/of een instabiliteitsgevoel van de enkel/voet. Ze klagen over het gevoel van doorzakken en kenmerkend is de klacht van deze patiënten dat ze bij het minste of geringste al 'door hun enkel gaan' of de enkel echt verzwikken. Hierbij treedt dikwijls enige mate van pijn en zwelling op. In het eerste hoofdstuk wordt aangegeven dat een veelheid van actieve en passieve factoren bij deze klachten een rol speelt. Men is het er over eens dat verschillende factoren tegelijkertijd van invloed kunnen zijn. Bij de aanloop tot dit onderzoek speelden twee basisgedachten een rol.

In de eerste plaats de gedachte, dat de peroneusspieren de voet tijdens normaal lopen niet beschermen tegen een inversieletsel. Indien dit het geval zou zijn, zou alle aandacht die word geschonken aan het actief oefenen van deze spieren bij de behandeling van chronische laterale instabiliteit weinig nut hebben en zou meer aandacht moeten worden geschonken aan het beschermen van de enkel door middel van het aanbieden van passieve (mechanische) steun. Naar aanleiding van deze gedachte werden de onderzoeken, zoals beschreven in hoofdstukken 2 tot en met 4 opgezet. Het onderzoek beschreven in hoofdstuk 5 sluit op deze studies aan.

De tweede gedachte betreft het feit dat iemand niet de enkel maar eigenlijk, om te beginnen, de voet verzwikt. De zwikbeweging wordt initieel gemaakt in de voetwortel. Er bestaat een tendens om de rol van de voet bij het zwikletsel over het hoofd te zien. Er wordt gezegd 'ik heb mijn enkel verzwikt' en ook in de medische literatuur worden de termen 'enkelverstuiking/distorsie' en 'enkelinstabiliteit' alom gehanteerd, hetgeen mogelijk ten onrechte de nadruk legt op het enkelgewricht.

Voorts blijkt vrijwel al het onderzoek betreffende instabiliteit gericht te zijn op de ligamenten van de enkel en op letsel van het enkelgewricht. Weinig is daarentegen bekend over de rol van de voetwortelgewrichten. De onderzoeken als beschreven in de hoofdstukken 6 en 7 gaan hier nader op in.

In de volgende tekst wordt een samenvatting van bovengenoemde hoofdstukken gegeven.

Hoofdstuk 2 betreft een studie naar de electromyografische activiteit van de peroneus longus en tibialis anterior spieren tijdens de standfase van het lopen bij 25 patiënten met chronische laterale instabiliteitsklachten en 10 controlepersonen. Onderzocht werd of de peroneus longus spier wel actief is op het moment dat de voet gevaar loopt op een inversieletsel en of veranderingen in activiteit van deze spier kunnen worden aangetoond bij patiënten met chronische laterale instabiliteit. Activiteit van de spieren werd geregistreerd onder verschillende loopomstandigheden om inzicht te krijgen in de rol van deze spieren bij het verzorgen van balans (door middel van lopen met en zonder externe steun) en ten aanzien van het voortbewegen (door middel van lopen met verschillende snelheden).

Er werd een markant verschil in activiteit van de peroneus longus spier gezien tussen het lopen met en zonder externe balans. Externe balans werd verzorgd doordat de proefpersonen een hand aan de reling mochten plaatsen, zonder op de reling te leunen. Met balans op deze manier aangeboden wordt een variabele hoeveelheid peroneus activiteit gezien, waarvan de meeste in het derde kwartaal van de standfase. Wanneer personen balans moesten houden op een natuurlijke wijze werd een grote toename van peroneus longus activiteit met name in het tweede kwartaal van de standfase gevonden. Deze activiteit varieerde van stap tot stap en afwisseling met activiteit van de tibialis anterior spier werd geregistreerd. Dit bleek het geval bij alle proefpersonen en derhalve wordt aangenomen dat de peroneus longus dient voor het behoud van balans en dat de activiteit hiertoe voornamelijk plaatsvindt in de periode tussen 'foot-flat' en het midden van de standfase.

Voorts kwam uit dit onderzoek naar voren dat er een interactie bestaat tussen de factoren externe steun en loopsnelheid. Deze interactie kan als volgt worden uitgelegd. Bij het staan op één been zonder externe balansverzorging wordt alle activiteit van de peroneus longus aangewend voor het behoud van balans in het frontale vlak. Hoe langzamer de loopsnelheid hoe meer activiteit van deze spier nog steeds wordt gebruikt voor het houden van balans. Echter, met toename van de loopsnelheid vermindert deze functie en beginnen andere activiteiten, mogelijk verband houdende met positionering van de voet, met acceleratie en actieve stabiliteit te domineren.

Activiteit van de tibialis anterior spier werd voornamelijk gevonden in het eerste kwartaal van de standfase. Verlies van uitwendig verzorgde balans had geen invloed op de activiteit van deze spier in deze fase. Echter, toename van de loopsnelheid ging gepaard met een toename van tibialis anterior activiteit. Derhalve wordt aangenomen dat activiteit van deze spier met name gerelateerd is aan het voortbewegen. Een veel geringere en variabele activiteit werd gevonden in de fase na 'foot-flat'. Een kleine verschuiving van de activiteit naar het tweede kwartaal van de standfase wanneer de proefpersonen zonder externe steun liepen suggereert dat deze spier, in ieder geval bij sommige personen, actief is ten behoeve van het houden van balans.

Er werd geen relatie gevonden tussen peroneus activiteit en instabiliteitsklachten. Wel werd bij patiënten met bilaterale instabiliteitsklachten een significant hogere activiteit van de tibialis anterior spier aangetroffen, terwijl geen significant verschil werd gevonden tussen het symptomatische en het asymptomatische been van patiënten met unilaterale instabiliteit. Dit suggereert dat eerder verstoring van centrale controle dan perifere stoornissen een rol speelt bij deze instabiliteitsklachten.

Daar de grotere activiteit van de tibialis anterior niet gecompenseerd lijkt te worden door de peroneus longus zou het gevolg kunnen zijn dat de voet een meer geïnverteerde stand heeft op het moment dat de hiel met de grond in aanraking komt ('heel contact'). Zo'n stand is biomechanisch gezien ongunstig in relatie met laterale instabiliteitsklachten. Een toegenomen inversiestand kon, zoals beschreven in hoofdstuk 5, echter niet bij deze patiënten worden aangetoond.

Hoofdstuk 3 betreft een onderzoek waarin gepoogd werd de passieve stabiliteit van de voet te meten. Een proefopstelling wordt beschreven waarbij de resultaten niet worden beïnvloed door spieractiviteit, teneinde de factor actieve stabiliteit uit te sluiten. Een speciaal hiervoor ontwikkeld plateau, dat kan kantelen om een verplaatsbare as, werd hiervoor onder gestandaardiseerde omstandigheden gebruikt. Aangenomen werd dat de gevonden as waarover de voet kantelt uitsluitend van passieve factoren afhankelijk is. Deze as geeft geen informatie over de mate waarin de passieve factoren afzonderlijk een rol spelen, maar verondersteld werd dat er verband bestaat met de passieve stabiliteit van de voet in zijn geheel. Verwacht werd dat de voeten van 20 patiënten met chronische laterale instabiliteit eerder zouden kantelen (rond een meer naar lateraal georiënteerde as) dan de voeten van 10 gezonde controlepersonen. Hoewel de resultaten een neiging hiertoe lijken aan te geven, waren de verschillen statistisch niet significant.

De bouw van de voet is een van de passieve factoren die bij stabiliteit een rol speelt. Vanuit biomechanisch oogpunt zal een inversieletsel eerder optreden bij een voet met een varusstand van de achtervoet, omdat een kleiner krachtmoment nodig is om inversie te veroorzaken. In hoofdstuk 4 wordt een onderzoek beschreven waarin bij

33 patiënten met chronische instabiliteitsklachten en 10 controlepersonen de vorm van de voet werd onderzocht, gebruik makend van gestandaardiseerde laterale röntgenopnamen. Vier verschillende parameters werden gebruikt: 1) de tarsale index zoals beschreven door Benink, 2) de talocalcaneale hoek, 3) de talometatarsale hoek en 4) de calcaneale hoek. Aangezien tussen de twee groepen geen significante verschillen werden gevonden, kon geen verband worden aangetoond tussen chronische laterale instabiliteitsklachten en voetbouw. De positieve en negatieve correlaties gevonden tussen de vier parameters kwamen in grote lijnen overeen met de verwachtingen, met uitzondering van de talocalcaneale hoek. Deze hoek blijkt een minder geschikte parameter te zijn voor het vaststellen van de hoogte van het lengtegewelf van de voet. In de dagelijkse orthopaedische praktijk zal de talometatarsale hoek de meest bruikbare zijn om een idee te krijgen van de mate van holling van de voet.

Twee van de eerder genoemde bevindingen vormen een aanleiding om het in hoofdstuk 5 gepresenteerde onderzoek te verrichten. Ten eerste de mogelijk toegenomen inversiestand van de voet als gevolg van hogere, niet door de peroneus longus gecompenseerde, tibialis anterior activiteit. Meer in hoofdstuk 2 beschreven bevindingen zijn hierbij van aanvullend belang, namelijk dat de standfaseactiviteit van de tibialis anterior optreedt in het kwartaal aansluitend op 'heel contact', hetgeen de fase is waarin het grootste risico bestaat op het optreden van een inversieletsel (omdat de voet nog niet volledig belast wordt) en tevens dat juist in deze fase de peroneus longus spier het minst actief is. In de tweede plaats leidde het feit dat geen significante relatie werd gevonden tussen voetbouw en instabiliteitsklachten tot de vraag of dan misschien de manier van lopen van invloed zou kunnen zijn. Immers, de positie van de voet wordt niet alleen bepaald door de bouw van de voet, maar ook door actieve factoren, zoals spiercontrole en concentratie.

Om dit te onderzoeken werd een dynamische analyse gemaakt van de positie van de achtervoet tijdens lopen bij een groep van 20 patiënten met bilaterale instabiliteitsklachten en 14 controlepersonen. De positie van de achtervoet in het frontale vlak werd bepaald met behulp van 2-dimensionale video-analyse. Opnamen werden gemaakt onder verschillende loopomstandigheden teneinde te onderzoeken of loopsnelheid en extern verzorgde balans van invloed zijn op de resultaten. Wederom werd geen significant verschil tussen de patiënten en de controlegroep gevonden. Geconcludeerd werd dat 1) de relatie tussen een varuspositie van de achtervoet op het moment van 'heel contact' en laterale instabiliteit van de voet niet kon worden bevestigd en dat 2) geen significante invloed van loopsnelheid of externe balansverzorging op deze positie kon worden aangetoond.

Het doel van het in hoofdstuk 6 beschreven onderzoek was om een mogelijke subtalaire component bij een groep van 33 patiënten met chronische laterale instabiliteit aan te tonen. Een groep van 10 personen zonder enkel/voetklachten diende als controle. Kanteling van de talus binnen de enkelvork tegelijkertijd met kanteling in het subtalaire gewricht werden met behulp van een gestandaardiseerde radiologische methode bepaald. Er werd van een scharnierend apparaat om de gewrichten open te spouwen, van een speciale subtalaire opnamerichting (volgens Brodén) en tevens van doorlichtingsapparatuur gebruik gemaakt. Röntgenopnamen werden gemaakt met de voeten: 1) in neutraal stand, 2) na inversie met gematigde kracht tot het punt dat een zekere hoeveelheid weerstand werd gevoeld en de voeten volledig geïnverteerd leken (stap 1), en 3) na verdere inversie met meer kracht zover als de omstandigheden toelieten (stap 2).

Er werd een grote spreiding (3-20°) van subtalaire beweeglijkheid gevonden met een gemiddelde kantelhoek van 10° in zowel de symptomatische als de asymptomatische voeten. Met de gebruikte methode werd in praktisch alle gewrichten een zekere mate van verlies van congruentie en van mediale translatie van de calcaneus in relatie tot de talus gevonden. Deze bevindingen waren niet gerelateerd aan de klachten van de patiënten. Aan de consequenties van het gebruik van verschillende spouwtechnieken is tot op heden nog onvoldoende aandacht geschonken en dit wordt besproken in dit hoofdstuk.

Alleen bij symptomatische voeten werd tussen stap 1 en stap 2 een toename van de mate van kanteling gevonden. Tijdens de eerste stap wordt de voet volledig geïnverteerd en komen passieve structuren, waaronder de ligamenten, op spanning totdat zij verdere beweging blokkeren. Verondersteld werd dat toename van kanteling hierna, tijdens de tweede stap, alleen zou optreden als gevolg van beschadiging van de ligamenten. Verder onderzoek werd nodig geacht om te bepalen of het vinden van een toename van kanteling kan dienen als een parameter waarmee onderscheid kan worden gemaakt tussen normaal en abnormaal toegenomen kanteling in zowel het talocrurale als subtalaire gewricht.

Het bovengenoemde was een van de beweegredenen om het onderzoek beschreven in hoofdstuk 7 te verrichten. Een andere reden was om de resultaten van het spouwonderzoek, gebruik makend van de Brodén opname, te vergelijken met die waarbij hetzelfde in beeld werd gebracht met behulp van computer-tomografie (CT). Een van de nadelen van het routine röntgenonderzoek is dat 3-dimensionale structuren worden afgebeeld op een 2-dimensionaal vlak (er treedt overprojectie op). De reden om gebruik te maken van CT was om te onderzoeken of met deze methode een meer duidelijke en daardoor objectievere bepaling van de subtalaire kantelhoek mogelijk zou zijn. Het onderzoek werd uitgevoerd bij een groep van 15 patiënten met unilaterale chronische instabiliteitsklachten, waarbij op grond van het klinisch onderzoek suspectie bestond op een subtalaire component. De contralaterale asymptomatische voet diende als controle.

Er werd een variabele mate van kanteling (4-18°) in het subtalaire gewricht gevonden bij gebruik van de Brodén opname. Er werd geen significant verschil tussen symptomatische en asymptomatische voeten gevonden. Echter, in tegenstelling tot de bevindingen ter hoogte van het talocrurale gewricht, werd op het niveau van het subtalaire gewricht niet éénmaal kanteling gevonden wanneer gebruik was gemaakt van CT. Er wordt nu betwijfeld of de kanteling die wordt gezien op de Brodén opname wel een werkelijke kanteling is. Mogelijk is de laterale opening welke lijkt te ontstaan bij deze opnamen het gevolg van projectie in een schuine richting van twee gebogen vlakken die een translatie en rotatie ten opzichte van elkaar hebben gemaakt. Geconcludeerd wordt dat het spouwonderzoek, gebruikmakend van de Brodén opname, mogelijk minder geschikt is voor het analyseren van subtalaire abnormale beweeglijkheid dan tevoren werd aangenomen.

De bevinding dat toename van kanteling in het talocrurale gewricht tussen stap 1 en stap 2 alleen optreedt in symptomatische voeten kon in dit onderzoek niet worden bevestigd. Er lijkt enige relatie te zijn tussen, toename van talaire kanteling, kanteling in het talocrurale gewricht, zoals gevonden met CT en chronische laterale instabiliteit, maar de resultaten zijn niet eenduidig. Het probleem hoe onderscheid gemaakt kan worden tussen normaal en abnormaal toegenomen beweeglijkheid is nog niet opgelost.

Tot slot zij vermeld dat met behulp van CT afwijkingen werden gevonden die op de röntgenopnamen niet herkend werden. In 4 gevallen werden ter plaatse van het middelste facetgewricht (subtalair) onregelmatige versmalling van de gewrichtsspleet en hypertrofische veranderingen gevonden. Het is aannemelijk dat deze veranderingen de gewrichtsfunctie verstoren. Mogelijk dat subjectieve instabiliteitsklachten en doorzakklachten het gevolg kunnen zijn niet alleen van hypermobiliteit, maar ook van andere verstoringen van de normale gewrichtsfunctie.

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Curriculum Vitae

Jan Willem Karel Louwerens werd op 8 november 1955 te Bogota (Colombia) geboren. Hij volgde zijn middelbare schoolopleiding aan de Rooms Katholieke Scholengemeenschap Katwijk de Breul te Zeist (1968-1971) en het Aloysius College te Den Haag (1971-1974). Hij studeerde psychologie aan de Rijksuniversiteit te Leiden (R.U.L.) tot 1976. In dat jaar kon zijn studie geneeskunde aanvangen aan dezelfde universiteit. Van 1978 tot 1981 was hij als student-assistent verbonden aan de afdeling Immunopathologie van het Pathologisch Anatomisch Laboratorium van de R.U.L. en betrokken bij onderzoek naar neuroendocriene cellen in ovariumtumoren, onder leiding van prof.dr. F.T. Bosman. In 1983 werd het artsexamen afgelegd en werd gestart met de opleiding tot orthopaedisch chirurg. De chirurgische vooropleiding werd gevolgd in het Eudokia Ziekenhuis te Rotterdam (opleider A. Zwaan). Onder leiding van prof.dr. B. van Linge volgde vanaf 1985 de verdere opleiding aan de afdeling Orthopaedie van het Academisch Ziekenhuis Rotterdam, Dijkzigt. Na zijn inschrijving in het Specialisten Register op 1 maart 1990 bleef hij op deze afdeling werkzaam als junior specialist. In samenwerking met de afdeling Biomedische Natuurkunde en Technologie van de Erasmus Universiteit Rotterdam, onder supervisie van prof.dr.ir. C.J. Snijders en prof.dr. B. van Linge, werd begonnen aan het onderzoek waarvan dit proefschrift verslag doet. In de jaren 1991 en 1992 was hij werkzaam als orthopaedisch chirurg in het Ruwaard van Putten Ziekenhuis te Spijkenisse.
Vanaf 1 maart 1993 is hij in dienst van de Koninklijke Luchtmacht in de rang van kolonel en als staflid van het Academisch Cluster Orthopaedie werkzaam in het Centraal Militair Hospitaal en het Academisch Ziekenhuis te Utrecht. In 1995 werkte hij gedurende 3 maanden in het Harborview Medical Center te Seattle, Verenigde Staten, teneinde zich verder te bekwamen in reconstructieve voet- en enkelchirurgie en orthopaedische traumatologie.