CHRONIC LATERAL INSTABILITY OF THE ANKLE JOINT

Natural course, pathophysiology and steroradiographic evaluation of conservative and surgical treatment.

Richard Löfvenberg

Umeå 1994
Chronic Lateral Instability of the Ankle Joint

Natural course, pathophysiology and stereoradiographic evaluation of conservative and surgical treatment.

Akademisk avhandling

som med vederbörligt tillstånd av Rektorsämbetet vid Umeå Universitet för avläggande av doktorsexamen i medicinsk vetenskap kommer att offentligen försvaras i
sal B, byggnad 1D, 9 tr (Tandläkarhögskolan), Norrlands Universitetssjukhus, Måndagen den 16 maj 1994, kl 9.00
Fakultetsopponent: Professor Per Renström, Burlington, Vermont, USA.

av

Richard Löfvenberg

Avhandlingen baseras på följande arbeten:


Chronic Lateral Instability of the Ankle Joint

Natural course, pathophysiology and stereoradiographic evaluation of conservative and surgical treatment.

Richard Löfvenberg

From the Department of Orthopaedics, University of Umeå, S-901 85, Umeå, Sweden.

Abstract

Chronic lateral instability of the ankle (CLI), defined as frequent sprains and recurrent giving way, difficulty in walking and running on uneven surface, is often connected with pain and swollen ankles. It occurs in 10 to 20 percent after acute ankle injuries. Mechanical instability of the talocrural and subtalar joint, peroneal weakness and impaired proprioception has been suggested as etiological factors.

Aim.

To investigate the natural course in conservatively treated patients with CLI.

To assess the mechanical stability in patients with CLI by measuring the three dimensional motions in the talus, the fibula and the calcaneus in relation to the tibia during different testing procedures pre- and postoperatively.

To determine if CLI is associated with proprioceptive deficiency.

Patients and Methods.

This Thesis includes 127 ankles in 78 patients (30 women, 48 men) with CLI.

Thirty-seven patients were followed up 20 years after their first contact with the orthopaedic department because of CLI. Forty-six ankles were evaluated radiographically and the result was compared with a gender- and age - matched control-material.

The neuromuscular response to a sudden angular displacement of the ankles was studied in 15 ankles in 13 patients using EMG.

Thirty-six patients entered a prospective study using roentgen stereophotogrammetric analysis (RSA) in which the ankles were tested at manual adduction, adduction with predetermined torque, with and without external support and at drawer tests (40 N and 160N). Twenty-seven patients were followed five years postoperatively.

Result.

After 20 years 22 patients, conservatively treated still suffered from instability of the ankle and ten had recurrent giving way symptoms even on plane surface. Six ankles in the patient group and four in the control group displayed osteoarthritic changes.

Prolonged ipsilateral reaction time (m. per. long, and m. tib. ant.) was found in patients with CLI indicating proprioceptive insufficiency.

Increased talocrural adduction and a tendency toward increased total translation of the talar center was found in ankles with CLI. Concomitant fibular rotations and translations were found but with no conclusive deviation in the ankles with symptoms. The talo-calcaneal adduction reached the same level in the patient and control groups regardless of symptoms. External support (ankle brace) increased the talar stability. The use of predetermined torque and constrained testing procedure did not add information compared with the manual test.

Twenty-five patients graded the result as excellent or good five years after lateral ligament reconstruction. Talar stability (decreased adduction and translation) was increased two years postoperatively and was improved or remained the same at five years without comprising the range of motion.

Conclusion.

In more than half the cases symptoms of CLI did not resolve spontaneously. Minor degenerative changes was found after twenty years, but not to a greater extent than in a control group. CLI was associated with proprioceptive insufficiency and talocrural but not subtalar instability. Increased ankle stability can be obtained by the use of an ankle brace and by an anatomical ligament reconstruction.

Keywords. Ankle-Joint-Instability, Kinematics, Ligament, Osteoarthritis, Orthosis, Proprioception, Radiology, Reaction time, Stereo-Photogrammetry, Subtalar, Surgery.
Tillägnad Eva, Karin, Per och Britta
CHRONIC LATERAL INSTABILITY OF THE ANKLE JOINT

Natural course, pathophysiology and steroradiographic evaluation of conservative and surgical treatment.

Richard Löfvenberg
Chronic Lateral Instability of the Ankle Joint.

Natural course, pathophysiology and stereoradiographic evaluation of conservative and surgical treatment.

Richard Löfvenberg.

From the Department of Orthopaedics, University of Umeå, S-901 85, Umeå, Sweden.

Abstract

Chronic lateral instability of the ankle (CLI), defined as frequent sprains and recurrent giving way, difficulty in walking and running on uneven surface, is often connected with pain and swollen ankles. It occurs in 10 to 20 percent after acute ankle injuries. Mechanical instability of the talocrural and subtalar joint, peroneal weakness and impaired proprioception has been suggested as etiological factors.

Aim.
To investigate the natural course in conservatively treated patients with CLI.
To assess the mechanical stability in patients with CLI by measuring the three dimensional motions in the talus, the fibula and the calcaneus in relation to the tibia during different testing procedures pre- and postoperatively.
To determine if CLI is associated with proprioceptive deficiency.

Patients and Methods.
This Thesis includes 127 ankles in 78 patients (30 women, 48 men) with CLI.
Thirty-seven patients were followed up 20 years after their first contact with the orthopaedic department because of CLI. Forty-six ankles were evaluated radiographically and the result was compared with a gender- and age - matched control-material.
The neuromuscular response to a sudden angular displacement of the ankles was studied in 15 ankles in 13 patients using EMG.
Thirty-six patients entered a prospective study using roentgen stereophotogrammetric analysis (RSA) in which the ankles were tested at manual adduction, adduction with predetermined torque, with and without external support and at drawer tests (40 N and 160N). Twenty-seven patients were followed five years postoperatively.

Result.
After 20 years 22 patients, conservatively treated still suffered from instability of the ankle and ten had recurrent giving way symptoms even on plane surface. Six ankles in the patient group and four in the control group displayed osteoarthritic changes
Prolonged ipsilaterial reaction time (m. per. long. and m. tib. ant.) was found in patients with CLI indicating proprioceptive insufficiency.
Increased talar adduction and a tendency toward increased total translation of the talar center was found in ankles with CLI. Concomitant fibular rotations and translations were found but with no conclusive deviation in the ankles with symptoms. The talo-calcaneal adduction reached the same level in the patient and control groups regardless of symptoms. External support (ankle brace) increased the talar stability. The use of predetermined torque and constrained testing procedure did not add information compared with the manual test.
Twenty-five patients graded the result as excellent or good five years after lateral ligament reconstruction. Talar stability (decreased adduction and translation) was increased two years postoperatively and was improved or remained the same at five years without comprising the range of motion.

Conclusion.
In more than half the cases symptoms of CLI did not resolve spontaneously. Minor degenerative changes was found after twenty years, but not to a greater extent than in a control group. CLI was associated with proprioceptive insufficiency and talocrural but not subtalar instability. Increased ankle stability can be obtained by the use of an ankle brace and by an anatomical ligament reconstruction.

Keywords. Ankle-Joint-Instability, Kinematics, Ligament, Osteoarthritis, Orthosis, Proprioception, Radiology, Reaction time, Stereo-Photogrammetry, Subtalar, Surgery.
Contents.

Abstract 4
Original papers 7
Definitions and abbreviations 9
Background to the Thesis 11
Aims of the study 25
Patients and methods 27
Summary and Results 39
Discussion 65
Conclusions 73
Acknowledgments 75
References 76
Papers I - VII 85
Papers.

This Thesis is based upon the following papers, referred in the text by their Roman numerals.¹


¹ Complementary data not accounted for in paper I-VII are included in the results and the discussion.
## Definitions and abbreviations

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Adduction and abduction</strong></td>
<td>Rotation about the anterior-posterior or sagittal axis (z-axis). Positive value indicates adduction, or varus position (medial and distal displacement of the lateral margin of the foot)</td>
</tr>
<tr>
<td>ADS</td>
<td>Anterior drawer sign</td>
</tr>
<tr>
<td>Ankle joint</td>
<td>Talo-crural joint</td>
</tr>
<tr>
<td>AP</td>
<td>Anterior-posterior</td>
</tr>
<tr>
<td>ATF</td>
<td>Anterior talofibular ligament</td>
</tr>
<tr>
<td>ATT</td>
<td>Anterior talar translation</td>
</tr>
<tr>
<td>CF</td>
<td>Calcaneofibular ligament</td>
</tr>
<tr>
<td>CLI</td>
<td>Chronic lateral instability of the ankle. In this Thesis with a duration of symptoms for at least six months</td>
</tr>
<tr>
<td>CRT</td>
<td>Contralateral reaction time</td>
</tr>
<tr>
<td>EMG</td>
<td>Electromyography</td>
</tr>
<tr>
<td>FI</td>
<td>Functional instability, subjective complaint of ankle joint instability that could be combined with mechanical instability.</td>
</tr>
<tr>
<td><strong>Internal and external rotation</strong></td>
<td>Rotation about the longitudinal (y) axis of the tibia. Positive value indicates internal rotation corresponds to medial motion of the tip of the foot.</td>
</tr>
<tr>
<td>IRT</td>
<td>Ipsilaterial reaction time</td>
</tr>
<tr>
<td>MI</td>
<td>Mechanical instability, radiographically determined ankle joint instability</td>
</tr>
<tr>
<td>MRI</td>
<td>Magnetic resonance imaging</td>
</tr>
<tr>
<td>ms</td>
<td>Milliseconds</td>
</tr>
<tr>
<td>MTS</td>
<td>Minneapolis Testing System</td>
</tr>
<tr>
<td>Neutral position of the ankle</td>
<td>90° angle between the longitudinal axis of the lower extremity and the sole of the foot</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>N</td>
<td>Newton</td>
</tr>
<tr>
<td>Nm</td>
<td>Newtonmeter</td>
</tr>
<tr>
<td>ns.</td>
<td>Not significant</td>
</tr>
<tr>
<td>PL</td>
<td>Musculus Peroneus longus</td>
</tr>
<tr>
<td>PB</td>
<td>Musculus Peroneus brevis</td>
</tr>
<tr>
<td>RSA</td>
<td>Roentgen stereophotogrammetric analysis.</td>
</tr>
<tr>
<td>Spearman</td>
<td>Spearman's rank correlation test</td>
</tr>
<tr>
<td>Subtalar joint</td>
<td>The talocalcaneal joint</td>
</tr>
<tr>
<td>TA</td>
<td>Musculus Tibialis anterior</td>
</tr>
<tr>
<td>TT</td>
<td>Talar tilt</td>
</tr>
<tr>
<td>t-test</td>
<td>Students t-test for independent samples</td>
</tr>
<tr>
<td>paired t-test</td>
<td>Students t-test for paired samples</td>
</tr>
<tr>
<td>Wilc. match.</td>
<td>Wilcoxon Matched-Pairs Signed-Ranks Test</td>
</tr>
<tr>
<td>Wilc. rank.</td>
<td>Wilcoxon Rank Sum W Test or Mann-Whitney U Test</td>
</tr>
</tbody>
</table>
Background to the Thesis

Recurrent dislocations of the ankle was first mentioned by Wiseman (1622-1676). The condition was effectively treated by alteration of the shoe.

Today chronic lateral instability of the ankle (CLI) is a recognized condition defined as recurrent sprains and "giving way", often accompanied by pain and swelling. The patients have difficulties in walking and running even on uneven surface. They have to be observant where to walk, even indoors to avoid small objects that easily might initiate a sprain. The primary symptom that brings the patient to the physician is this feeling of insecurity and frequent "giving ways".

Residual symptoms occur in 0-48% after severe acute ankle sprains. Ankle trauma is the most frequent injury during sports. Thirteen to 56 per cent of all injuries are localized to this region, mainly as sprains. The lateral side is engaged in 85% of the cases. Based on a review of 12 prospective studies Kannus and Renström concluded that acute lateral ligament injuries should be treated conservatively even in competitive athletes. The treatment includes external support (elastic strapping, taping or ankle bracing), physiotherapy and early mobilization. Despite this regimen 10 to 20% may be expected to need elective secondary repair.

The etiology to CLI is multifactorial and controversial including functional instability and/or mechanical instability, peroneal muscle weakness, defect proprioception and subtalar instability. The majority of patients with CLI could designate a certain trauma situation as the start of the symptoms.

In 1932 Nilsson described a surgical procedure for CLI. The literature is mainly focused on the operative treatment, now with more than 50 operative procedures described (Table 3). It has been suggested that if left unoperated the condition will lead to osteoarthritis. Less attention has been paid to the results of physiotherapy, proprioceptive training and external support.

Many aspects of CLI such as the natural course of CLI and the risk of osteoarthritis if left unoperated have not been completely documented.

The mechanical testing procedures (using conventional radiography) for chronically unstable ankles have been limited to two-dimensional analysis of the talocrural and the subtalar joints. The stability of the talo-calcaneal joint is
difficult to study on two-dimensional radiographs.\textsuperscript{20,34,129,131} Detailed three-dimensional \textit{in vivo} analysis of the skeletal motions of the ankle and subtalar joints have previously been performed in healthy subjects\textsuperscript{129} but not in patients with CLI.

**Bio-mechanical characteristics of the lateral ankle ligaments.**

The physiological properties of the ankle ligaments have been studied by Attarian et al.\textsuperscript{9} The observed lengths of the anterior talofibular and the calcaneofibular ligament were 1.1 and 1.8 cm, respectively. The corresponding widths were 0.8 and 0.7 cm. The maximum load before failure was 140 and 346 N with the ligaments tested separately using a MTS (Minneapolis testing system) equipment. Siegler et al.\textsuperscript{172} recorded higher loads to failure of the talofibular ligament (231 N) and smaller values of the calcaneo-fibular ligament (307 N).

Both the anterior talofibular and the calcaneo-fibular ligaments stabilizes the ankle joint but in different positions. The findings of Makhani\textsuperscript{133} was confirmed by Renström et al.\textsuperscript{153} who tested the strain in the lateral ligaments by attaching a hall effect transducer to the middle portion of the ligaments. At the plantar flexed position the anterior talofibular ligament exhibited the most strain, whereas the calcaneo-fibular ligament was the main stabilizer in the neutral and the dorsiflexed position.

**Functional instability (FI).**

Freeman et al.\textsuperscript{62} introduced the concept of functional instability (FI) of the foot (subjective feeling of instability or the foot tending to give away). Fourteen of 45 patients complained of persistent varus instability after acute ankle sprain, but had no clinical or radiographic abnormalities. Proprioceptive training was believed to reduce the symptoms. Later, the term functional instability has been denoted to the subjective feeling of joint instability regardless of mechanical instability or not.\textsuperscript{93}

Among 1300 students in a first year class at the United States Naval Academy Brand et al.\textsuperscript{18} found FI in 10%. Residual symptoms that would correspond to FI was reported by Bosien et al.\textsuperscript{16} in 33% of 113 college students 29 months after an acute sprain. Termansen et al.\textsuperscript{186} found no correlation between residual
symptoms and mechanical instability in agreement with the findings of Freeman,\textsuperscript{6,63} but in contrast to other investigations.\textsuperscript{6,22}

**Etiology**

**Muscle weakness.**

Weakness of the peroneal muscles, when tested manually, has been reported in 50 to 66\% of patients with residual symptoms after ankle sprain.\textsuperscript{16,181} These findings are in agreement with the isokinetic tests performed by Tropp\textsuperscript{188}, who recorded decreased pronator muscle strength in ankles with FI. Sidey\textsuperscript{171} showed that acute ankle sprain may induce peroneal nerve entrapment at the head of the fibula and subsequent muscle weakness causing CLI.

The importance of the intact muscular function for the stability of the ankle was investigated by Becker et al.\textsuperscript{13} They studied the anterior foot motion in healthy subjects using a holding device, in which an anteriorly directed force was applied at the heel, and recorded 1.5 mm larger anterior displacement of the foot when local anesthesia was introduced around the common peroneal nerve in the region of the head of the fibula.

Larsen and Lund\textsuperscript{118} noted increased EMG activity recorded in the peroneal muscles after operation for CLI. The muscular activity was not only on the operated but also on the unoperated side.

**Proprioceptive deficiency.**

Freeman et al.\textsuperscript{63} draw attention to impaired proprioception as an etiologic factor to CLI by using the Romberg's test in patients with functional instability. Similar results were reported by Williams\textsuperscript{197} 1988, using the same technique.

The role of intact proprioception was investigated by Konradsen et al.,\textsuperscript{107} who found altered sense of ankle joint position during changed proprioceptive conditions. They found that the passive position test was significantly altered when the ankle joint was anesthetized. The subjects could actively reposition their feet to a previous position, but not determine the ankle position when the foot was passively moved.

Studies of the neuromuscular response to sudden angular displacement of the ankle have indicated, that the reaction time in the peroneal muscles is longer in
chronically unstable compared with stable ankles\textsuperscript{93,106} suggesting defective proprioception.

**Rupture and dislocations of the peroneal tendons.**

Spontaneous rupture of the peroneal tendons has been reported\textsuperscript{1,108} a rare cause of CLI, as well as dislocation of the peroneal tendons.\textsuperscript{175}

Mullins and Sallis\textsuperscript{137} considered widening of the ankle mortise to be a common but overlooked cause of CLI and advocated operative treatment to avoid recurrent sprains.

Anterior tibio-fibular ligament injury, osteochondritis dissecans and avulsion fractures may produce symptoms that resembles CLI.

**Osteoarthrosis**

Among others,\textsuperscript{38,71,83} Harrington\textsuperscript{80} stated that that longstanding CLI will eventually lead to osteoarthrosis. According to Jackson et al.\textsuperscript{83} 30 percent of patients submitted for arthrodesis of the ankle had a history of recurrent sprains and ankle giving way. Others have focused on the fact that ankle joints subjected to longstanding instability do not undergo severe degenerative changes to the same extent as in knee joints\textsuperscript{18}.

The definition and grading of osteoarthrosis in the ankle varies between studies. Boszotta and Sauer\textsuperscript{17} found preoperatively osteoarthrosis in 6 of 44 ankles (13.6\%) suffering from CLI using the Bargon classification\textsuperscript{10} (Table 2). At the follow-up investigation, 3.8 years after a modified Watson-Jones ligament reconstruction, osteoarthrosis was found in 29 (61.4\%) ankles. There was a positive correlation between age and occurrence of osteoarthrosis.

Zwipp\textsuperscript{204} reported arthritis in all 149 ankles with CLI before surgery (using the Bargon classification, Table 2). Fifty-two per cent of the patients had grade 0 on the Bargon scale corresponding to sclerosis in the pressure zones but intact joint space. These frequencies should be compared with those reported after ankle fractures, in which 70\% of the ankles presented with osteoarthritic changes\textsuperscript{11} using the Cedell - Magnusson classification\textsuperscript{31,132} (Table 1).
Table 1.
Osteoarthrosis in the talocrural joint classified according to Cedell/Magnusson\textsuperscript{31,132}
1 minute reduction of joint space, small osteophytes
2 as above, but more obvious, subchondral tibial sclerosis
3 joint space reduced 50%, prominent osteophytes
4 obliterated joint space.

Table 2.
Osteoarthrosis in the talocrural joint classified according to Bargon\textsuperscript{10}.
0 sclerosis in the pressure zones but intact joint space.
I sclerosis in the pressure zones, small osteophytes, slight decrease in joint space.
II sclerosis in the pressure zones, osteophytes, decreased joint space, blurring of the subchondral bone-structure.
III obliterated joint space, subchondral cysts and deterioration of the subchondral bone structure.

Ankle instability - Mechanical instability (MI).

Ankle motion beyond the physiological range of motion is defined as mechanical instability (MI) of the ankle.\textsuperscript{148} The static mechanical stability of the ankle joint depends on the architecture of the stabilizing ligaments, skeletal anatomy and the capsular structures. Muscle tone contributes to the dynamic stability. The initiation of CLI can usually be traced to a particular trauma situation. The typical position in which the sprain occurs is in "plantarflexion, inversion and adduction" of the foot and ankle according to Grace\textsuperscript{73} and Renström and Cannus.\textsuperscript{154} In this position the anterior talo-fibular ligament (ATF) is the main lateral stabilizing ligament.\textsuperscript{21,77,154,179} Consequently, the ATF is the most commonly torn ligament in acute ankle sprains. According to Broström\textsuperscript{21} the ATF was ruptured in 87% of 239 patients with acute sprains. Simultaneous rupture of CF or deltoid ligaments occurred in 17 and 2.5%, respectively. Rupture of all three ligaments was found in 3%.

Measurements of mechanical instability

Talar tilt

Nilsson\textsuperscript{e140} pointed out that "it is necessary to take pictures in different positions of pronation and supination to demonstrate the undue play in the astragaloid 'fork'." Later Dehne\textsuperscript{44} introduced the lateral stability test (Talar Tilt), since then frequently used to radiographically demonstrate talar instability.\textsuperscript{41,33,65,88,93,116,121,167}
During the test the foot is adducted manually or by means of a device. One of the first standardized testing procedures was described by Rubin and Witten\(^{158}\) (Figure 1). The talar motions are measured on conventional radiographs in terms of rotations about an arbitrary chosen anterior-posterior axis, or as distal translation of the upper lateral corner of the talus (Figure 2).

Brand et al.\(^{18}\) found talar tilt more than 10° in 14% among 175 athletes and a strong correlation between instability and symptoms. Rubin and Witten\(^{158}\) registered normal talar tilt between 0° and 23° (Figure 1) with a load of about 11 pounds at the lateral aspect of the ankle. Sedlin\(^{167}\) found maximum talar tilt of 14° in normal ankles and a range between 8° and 15° in ankles with CLI. Laurin et al.\(^{121}\) recorded the talar tilt in 92 normal subjects and registered no difference in talar tilt when comparing a standardized testing procedure with manual adduction. The average was in their study 7° (range: 0° to 27°).

**Anterior talar translation, anterior drawer sign or test**

Johnson and Markolf\(^{90}\) found considerable variation in anterior talar laxity of intact specimens (3.1 - 12.3 mm at 100 N) when tested in the MTS apparatus. The displacement increased 3.5 to 7 mm (100 N) after sectioning the FTA confirming the importance of the anterior talofibular ligament to prevent anterior subluxation of the talus.

Clinically, anterior talar stability may be assessed by applying anterior stress at the heel.\(^{21,64,114,122,179}\) Increased anterior displacement of the talar trochlea could be felt in front of the lateral malleolus which as been called the anterior drawer sign (ADS).
Radiographically anterior displacement or subluxation of the talus (anterior talar translation (ATT) has been measured by several authors.4,5,6,7,8,9,10,11,12,13

The value of testing the mechanical stability of the ankle has been debated, because TT and ATT have a wide range in normal subjects.18,41,169 Some authors28,40,56,77,145 claim that in patients with unilateral symptoms the side to side difference is the most important objective criterion (TT more than 6-10°, ATT more than 3 mm). Seligson et al.169 stated that "inversion stress test" (TT-test) for evaluation of the lateral ligament is less helpful than the anterior talar translation under standardized conditions. Johannsen88 concluded after examining 244 acutely injured patients that "the anterior drawer sign cannot replace the talar tilt examination or vice versa."

The use of standardized testing procedures have become more frequent after the introduction of the TELOS® apparatus, (Figure 4). designed for stress-evaluation of both talar tilt and anterior translation.59,93 Using this apparatus Karlsson93 defined mechanical instability in the talocrural joint, when ATT was 10 mm or more and the TT was 9° or more. The average ATT was 5.1 mm (2.0 mm to 10.0 mm) in normal ankles and 6.3 mm (3.0 mm to 10.0 mm) in ankles with acute rupture of the ATF in a study by Sauser et al.161 who also used the TELOS® apparatus. The average talar tilt in their study was 2.6° in normal and 8° in the injured ankles.
Others found the radiological stress tests to be of little diagnostic help and relied on the symptoms of instability as told by the patients and on the physical examination using the anterior drawer sign.

Subtalar instability

Rubin and Witten suggested that subtalar instability could be of clinical relevance in CLI and developed a stress tomographic technique. They estimated the normal tibio-calcaneal angle between 40° and 50°. However, they could not demonstrate obviously increased subtalar instability in any of the 27 tested patients. In one of the few studies in which this method has been used, Harrington showed subtalar tilt (55°, 50°) in two patients of 36 with CLI.

Using the Brodén exposure Heilman et al. demonstrated increased talo-calcaneal distance after sectioning of the calcaneo-fibular ligament. However, Harper did not find significantly increased subtalar opening in ankles with symptoms compared with the contralateral side and controls using the same method. Some of the studies suggesting subtalar instability to be one of the underlying causes to CLI did not perform any testing of the subtalar joint.

Roentgen stereophotogrammetric analysis (RSA)

Joint kinematics have previously been studied using RSA in vitro and in vivo, however, not in CLI.

Alternative diagnostic methods for ligament injuries

Lindstrand and Mortensson and Biegler et al. described methods using an index for measuring the actual ATT. These methods do not seem to have come into general use.

Computed tomography of the ankle joint has been used experimentally in diagnosing ligament lesions, but is not widely used in clinical praxis. Schricker et al. found sonography reliable for detecting acute lesions of the lateral ligaments of the ankle, which was confirmed by Ernst et al., who also included eight ankles with chronic instability.

Magnetic resonance imaging (MRI) has been used in diagnosing the soft tissues in ankles sprains. Using this method Verhaven et al. observed 93% accuracy
in diagnosing acute tears of the FTA and FC. The value of the MRI in the
diagnosis of chronic lesions in the lateral ligaments has not been studied.

Ankle arthrography and stress-tenograms have mainly been used as diagnostic
procedures in acute ankle injuries\textsuperscript{24,54,58} and their value in CLI is questionable.\textsuperscript{166}

**Chronic lateral instability - treatment**

**Non operative treatment**

*Physiotherapy*

Freeman et al.\textsuperscript{63} stated that "the incidence of proprioceptive deficit and the
symptom of give way can be reduced by coordination exercises" in recent
sprains. This statement was confirmed in athletic populations with FI by
Tropp\textsuperscript{187} and Gauffin et al..\textsuperscript{69} These studies showed improvement of the postural
sway and decreased number of recurrent sprains after coordination training and
strengthening of the peroneal muscles using ankle disk for 10 weeks.

Karlsson et al.\textsuperscript{97} treated 100 patients with physiotherapy for three months, and
concluded that low grade mechanical instability should be treated
conservatively, whereas early surgical reconstruction was recommended in high
grade mechanical instability (TT more than nine degrees and ATT more than ten
mm).

Harrington\textsuperscript{80} did not observe any improvement in the "heel inversion gait" in a
group of patients, who had had a home program for peroneal strengthening and
attributed this to the longstanding instability of these patients. Harper\textsuperscript{79} found 11
of 14 ankles refractory to the physiotherapy program.

Shoe modification with a lateral wedge has been used but the results are not
discussed in detail.\textsuperscript{66,80,116,122}

*External support.*

The efficacy of external support in the prevention of recurrent and acute sprains
has been investigated,\textsuperscript{57,68,72,117,187} but the overall results in patients with CLI have
not been documented.\textsuperscript{148}
In a prospective randomized study on functional treatment for acute grade III ankle sprains Neumann et al.\textsuperscript{138} compared ankle bracing (Aircast) with elastic wrapping. They found that both treatments provided excellent results with no residual functional instability. Other prospective studies on acute ankle sprains treated with ankle braces have come to the conclusion that ankle sprains could be treated conservatively even in athletes.\textsuperscript{92,207,206}

The role of taping in the prevention of ankle sprains was studied by Garrick and Requa\textsuperscript{68} in 1228 basketball players with previous history of sprain. They observed 24 cases (5.5\%) with repeated sprains in the untaped group and 13 cases (16.4\%) in the taped group.

According to Wilkerson\textsuperscript{196} "the goal of taping is to achieve greatest possible restriction of the foot motion in the frontal plane and permit full range of motion in the sagittal plane." However, the stabilizing effect of the taping will decrease during exercise, although the remaining stability is greater than in the untaped ankle.\textsuperscript{196,117} Glick et al.\textsuperscript{72} suggested that taping beside the mechanical support has a stimulating action on the peroneus brevis muscle compared with the untaped ankle. The effect on the proprioception using ankle taping has been studied by Karlsson and Andreasson,\textsuperscript{98} who found significantly shorter reaction times in the peroneal muscles using tape when the ankles were subjected to sudden twist.

The mechanical properties and the effectiveness of adhesive taping have been studied more extensively than orthotic devices.\textsuperscript{75,76,117,119,128,157} In an experimental comparison between laced stabilizers and adhesive taping, Bunch et al.\textsuperscript{25} concluded, that some of the ankle braces could be equal to or better than tape for ankle support. Based on comparative studies on a semi-rigid orthosis and adhesive taping, Greene and Hillman\textsuperscript{75} suggested the orthosis a better alternative for persons with CLI.

**Operative treatment**

Nilsson\textsuperscript{e140} introduced the surgical treatment for CLI referring to Gallie\textsuperscript{66}, who in 1913 described a technique for prevention of deformity in infantile paralysis. Over 50 different (Table 3) operative procedure have been described although many of them are modifications of four concepts published by Elmslie\textsuperscript{50,33} (1934), Watson-Jones\textsuperscript{194,195} (1940,1955), Evans\textsuperscript{53} (1953) and Broström\textsuperscript{23} (1965). Generally the operative procedures can be classified as non anatomic or
A majority of the operative procedures include tenodesis; most frequently involving one of the peroneal tendons (Table 3).

The short-term outcome of the different procedures are generally satisfactory (good or excellent 80%), but long-term results and prospective and or randomized randomized studies are rare.

The Evans procedure (using the peroneus brevis tendon) addresses mainly the ATF-ligament, but the tendon used for reconstruction is positioned between the ATF and CF. The frequency of satisfactory long-term results varies between 50% and 82%.

The long-term results of the Watson-Jones procedure is more disappointing. Van der Rijt et al. reviewed the results 22 years after the operation, and reported complete relief of symptoms of instability in three of nine patients. Postoperative complications occurred in two (1 had an infection and one developed a neuroma).

Contrary to the disappointing long-term results above, Snook reported satisfactory results in 36 of 48 ankles in a 10 year follow up study after Chrisman-Snook reconstruction; five of 48 ankles displayed hypersensitivity, neuroma or numbness.

Mapes et al. compared 40 patients randomized to either the Chrisman-Snook or modified Broström procedure. The mean age was 26 years, and the TT tested with the TELOS apparatus was 14 degrees preoperatively. At follow up at 28 months (6 to 49 months) the frequency of good or excellent results was 80% in both groups. The talar tilt was slightly less (five degrees) in the Chrisman-Snook group compared with 7 degrees in the Broström group. However, the number of complications was smaller in the Broström group. (Chrisman-Snook group: 5/20 wound healing problems, 8/20 nerve complication; Broström group: no complication).

Based on a study on 347 reconstructive operations of the fibular ligaments performed 1971-1986, Zwipp recommended direct suture or tensioning of the ligaments when possible and concluded that tenodesis should be considered when neither direct reconstruction with ligaments nor indirect reconstruction with periosteal flap is possible.
Table 3. Reconstructive procedures for chronic lateral instability of the ankle. Pb = M. peroneus brevis, pl = M. peroneus longus, ext. dig. brevis = M. extensor digitorum brevis.

Some operative procedures quoted from other authors are indicated as follows: *= Broström, 23 ** = Saltrick, 160 *** = Machan et al., 131 # = Wirth, 199 ## = Scröder et al., 165 ### = St. Pierre et al., 179 ⎠ = Stöhr and Huberty, 183 PDS = polydioxanon band.

Reconstructions using tendons

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Procedure</th>
<th>Year</th>
<th>Author</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1932</td>
<td>Nilsonne</td>
<td>pb</td>
<td>1980</td>
<td>Goldner***</td>
<td>ext. dig. long.</td>
</tr>
<tr>
<td>1940</td>
<td>Watson-Jones</td>
<td>pb</td>
<td>1981</td>
<td>Keller</td>
<td>pb</td>
</tr>
<tr>
<td>1945</td>
<td>Hambley*</td>
<td>pi</td>
<td>1981</td>
<td>Leach</td>
<td>pb</td>
</tr>
<tr>
<td>1948</td>
<td>Kiäer*</td>
<td>pb</td>
<td>1982</td>
<td>Epstein</td>
<td>pb</td>
</tr>
<tr>
<td>1952</td>
<td>Watson-Jones</td>
<td>pi</td>
<td>1982</td>
<td>Pieron</td>
<td>pb</td>
</tr>
<tr>
<td>1953</td>
<td>Evans</td>
<td>pb</td>
<td>1982</td>
<td>Wilson</td>
<td>pb</td>
</tr>
<tr>
<td>1953</td>
<td>Windfeld*</td>
<td>pb</td>
<td>1983</td>
<td>Hendel</td>
<td>pb</td>
</tr>
<tr>
<td>1954</td>
<td>Pouzet*</td>
<td>pi</td>
<td>1984</td>
<td>Spirig</td>
<td>plantaris longus</td>
</tr>
<tr>
<td>1957</td>
<td>Lee**</td>
<td>pb + fascia lata</td>
<td>1985</td>
<td>Anderson</td>
<td>plantaris longus</td>
</tr>
<tr>
<td>1959</td>
<td>Stören*</td>
<td>achilles</td>
<td>1986</td>
<td>Eyring</td>
<td>pb</td>
</tr>
<tr>
<td>1961</td>
<td>Castaing &amp; Meunier*</td>
<td>pb</td>
<td>1988</td>
<td>Williams</td>
<td>ext. dig. brevis</td>
</tr>
<tr>
<td>1969</td>
<td>Chrisman &amp; Snook</td>
<td>pb</td>
<td>1989</td>
<td>Boszotta</td>
<td>pb</td>
</tr>
<tr>
<td>1969</td>
<td>Pouzet***</td>
<td>plantaris longus</td>
<td>1989</td>
<td>Dockery</td>
<td>pb</td>
</tr>
<tr>
<td>1974</td>
<td>Viernstein#</td>
<td>pb</td>
<td>1989</td>
<td>Zwipp</td>
<td>pb</td>
</tr>
<tr>
<td>1976</td>
<td>Gianella</td>
<td>pb</td>
<td>1989</td>
<td>Zwipp</td>
<td>pb</td>
</tr>
<tr>
<td>1978</td>
<td>Ottosson##</td>
<td>pb</td>
<td>1990</td>
<td>Larsen</td>
<td>pb, dynamic</td>
</tr>
<tr>
<td>1979</td>
<td>Sefton</td>
<td>plantaris longus</td>
<td>1990</td>
<td>Larsen</td>
<td>pb, static</td>
</tr>
<tr>
<td>1980</td>
<td>Solheim</td>
<td>achilles</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ligament reconstructions

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Procedure</th>
<th>Year</th>
<th>Author</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>Haig*</td>
<td>Periost</td>
<td>1958</td>
<td>Geschwend*</td>
<td></td>
</tr>
<tr>
<td>1954</td>
<td>Anderson</td>
<td>1989 Periost</td>
<td>1961</td>
<td>Francillon*</td>
<td></td>
</tr>
<tr>
<td>1961</td>
<td>Ruth</td>
<td>1970 Jäger*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1966</td>
<td>Broström</td>
<td>1977 Wirth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1977</td>
<td>Wirth</td>
<td>Fascia</td>
<td>1980</td>
<td>Jenkins</td>
<td></td>
</tr>
<tr>
<td>1981</td>
<td>Althoff/Peterson</td>
<td>Fascia</td>
<td>1985</td>
<td>Burri</td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>Ahlgren</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>Zwipp</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bovine graft

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>Dockery</td>
<td>1990 Bär</td>
</tr>
</tbody>
</table>

The influence of reconstructive procedures on the evverting strength in patients operated for CLI has been evaluated by St. Pierre et al., 179 They compared 10 Evans and 10 Chrisman and Snook procedures using the Cybex II isokinetic dynamometer. Eversion was in their study defined as "elevation of the lateral border of the foot", which corresponds to abduction as opposed to adduction used in this study. Neither of the operations resulted in significant loss of eversion strength.
Dynamic instead of static peroneus brevis tendon transfer has been used by some authors. In a randomized study Larsen compared static and dynamic repair using the whole or the split peroneus longus tendon. The result was in favor of the static procedure regarding both subjective and objective parameters.

Younes et al. retrospectively compared the Evans and the Watson-Jones procedures and found the later more effective in reducing the antero-posterior instability, whereas the Evans technique was superior to reduce the talar tilt.

To avoid interference with the muscular function of the pronators, other tendons such as the plantaris tendon and part of the Achilles tendon have been used. Morscher et al. used a combination of a calcaneus osteotomy according to Dwyer and a ligament reconstruction using the tendon of the plantaris longus muscle. A few cases were treated without recurrence of the instability.

Periost, fascia lata, corium, carbon fiber, xenograft bioprosthesis, allogenic tendon grafts and PDS (polydioxanon band), (Table 3) have also been used to reconstruct the lateral ankle ligaments, but none of these methods has gained popularity partly because of inferior results. Bär et al. reported discouraging results using PDS and deliberately warned against its use.

Some authors argue that the use of the pronator tendons negatively interferes with the normal anatomy and muscular function whereas others disagree. To restore the anatomy it would seem more appropriate to use the torn or elongated ligaments. However, ruptured ends of ligaments were previously believed to become successively shortened and finally absorbed. Later Stener observed that the torn end of the ulnar collateral ligaments of the thumb were preserved in patients with chronic disability.

Broström reported 60 reconstructions using sutures of the lateral ligaments. Later Peterson et al. and Karlsson et al. described a technique of reconstructing the ATF and/or the CF with transection, imbrication and suturing to the distal fibula and reported satisfactory results in 86% (132/152) six years after the surgery. Minor surgical complications were reported in six cases. Excellent or good result in 27 of 28 ankles with no complications were reported by Hamilton et al. in a five-year follow-up study of the Gould modification of the Broström procedure.

Thus during the last years the anatomic reconstructive procedures seem to be the predominant operative treatment for CLI and have been
recommended as the first choice (instructional course, AAOS meeting, 1994(AAOS94)).

The reconstructive technique studied in this Thesis was described by Ahlgren and Larsson who in a primary report noted excellent or good results in 78/82 ankles after two years.

**Postoperative treatment**

In most studies an immobilization time for six weeks is used postoperatively followed by physiotherapy, however, without comments the duration of immobilization. In a randomized study Zwipp et al. found that early mobilization after suture of the recently torn lateral ligaments gave superior results compared to immobilization. There is no corresponding study regarding immobilization after reconstruction for CLI.
Aims of the study

The purpose of the present study was to evaluate chronic lateral instability of the ankle (in this Thesis defined as chronic, when symptoms of lateral instability was present for more than six months) regarding the natural course, the proprioception, the skeletal motions and stability, the stabilizing capability of an ankle brace and finally to prospectively evaluate the reconstruction of the lateral ankle ligaments concerning patient satisfaction and ankle stability.

Roentgen stereophotogrammetric analysis
- To develop a method for measuring and documentation of ankle stability with roentgen stereophotogrammetric analysis.

Natural course
- To investigate the clinical course and frequency of degenerative arthritis in non operated patients with chronic lateral instability of the ankle. (I)

Pathophysiology
- To determine the reaction time of the peroneus longus and the tibialis posterior muscles in patients with chronic lateral instability of the ankle and control persons subjected to a sudden adduction of the ankle (II).
- To measure the three-dimensional motions of the fibula, the talus and the calcaneus in patients with chronic lateral instability of the ankle during standardized testing procedures using roentgen stereophotogrammetric analysis . (III-VII).

Treatment
- To assess the stabilizing effect of an ankle brace.
- To assess the clinical and functional outcome two and five years after a ligament reconstruction for chronic lateral instability of the ankle.
- To measure the effect on talar motions and stability with roentgen stereophotogrammetric analysis two and five years after a ligament reconstruction for chronic lateral instability of the ankle.
Patients and methods

Patients and controls. (Table 4)

Patients

Thesis includes 127 ankles in 78 patients (30 women, 48 men) with a mean age of 39 years at the examination (range 16 to 73 years). All had sought medical attention because of chronic lateral instability of the ankle at the department of Orthopaedics, Umeå University Hospital between 1969 and 1990.

Thirty-six patients (25 men/10 women, mean age 31 years) scheduled for reconstructive surgery because of residual symptoms of CLI despite of physiotherapy participated in a prospective study using RSA (III,IV,V,VI,VII). The duration of symptoms was eight years (0.5-25 years) at the initial visit. No other selection of patients regarding sports, occupation, leisure activity etc., was done.

Lateral ligament reconstruction was planned in all the 36 patients who entered the RSA studies starting 1984 and was performed in all but three. One patient moved before operation, one decided not to go through surgery (decision made close to scheduled operation time) and the third patient became non ambulant after an intercurrent cerebrovascular lesion.

Fifteen ankles in 13 patients were studied using EMG to measure the reaction time of the anterior tibial and peroneal longus musculature (II).

Thirty-seven non operated patients were followed up 20 years after their first contact with the orthopaedic department because of CLI (I). The mean age of these patients at the follow-up was 47 years (range 31 to 77 years).

---

Table 4.
Number of patients in the different studies. Some patients participated in more than one study.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Patients (n)</th>
<th>Gender M / F</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>37</td>
<td>21 / #</td>
<td>47</td>
</tr>
<tr>
<td>II</td>
<td>13</td>
<td>4 / 9</td>
<td>37</td>
</tr>
<tr>
<td>III</td>
<td>29</td>
<td>21 / 8</td>
<td>30</td>
</tr>
<tr>
<td>IV</td>
<td>29</td>
<td>21 / 8</td>
<td>30</td>
</tr>
<tr>
<td>V</td>
<td>14</td>
<td>10 / 4</td>
<td>35</td>
</tr>
<tr>
<td>VI</td>
<td>13</td>
<td>9 / 4</td>
<td>36</td>
</tr>
<tr>
<td>VII</td>
<td>27</td>
<td>21 / 6</td>
<td>30</td>
</tr>
</tbody>
</table>
Control persons.

Sixty-three persons with no previous injury to the ankles participated as controls (I, II, V). In the first two studies they matched the patient-group by sex and gender. In study V four normal subjects, who previously had tantalum markers inserted into the distal tibia and the foot, were included.

Symptoms.

All patients examined in this Thesis had functional instability (FI). This entity was defined as frequent sprains, recurrent giving way when walking and running and was sometimes associated with swollen ankles and pain. The patients had to look carefully, where they placed the foot to avoid sprains, even when walking indoors. Small objects on the floor could initiate a twist or cause the patients to fall. Some patients described this as "stepping through" corresponding to a "giving-way" situation. They had had the symptoms for at least six months.

Initial treatment.

At the first visit all patients were instructed by a physiotherapist with the purpose to strengthen the peroneal muscles and to improve the coordination (Figure 5). Peroneal strengthening was performed by abduction and adduction and using an elastic band. This was accomplished with the band attached to wall in one end and the other to the either the lateral or the medial side of the foot. The patient had an option to sit or stand. The patients were also instructed to do toe-ups preferably on one leg at the time.

The patients were also offered an ankle brace (Strong, Pi Medical AB, Sweden) described in paper VI. Although many patients tolerated the orthosis, some complained that it was uncomfortable and difficult to use in regular shoes. As an alternative other external supports such as the 3D® (DeRoyal, USA) ankle brace or the Air-Stirrup® model (Aircast Inc. USA) and others are now offered to the patients.
Operative treatment. (Figure 6, 7)

If physiotherapy did not sufficiently improve the symptoms (frequent sprains and recurrent giving way) for at least three months, surgical reconstruction of the ligaments\(^3\) was offered during the period for the prospective studies.

In the majority of cases the operation was performed in regional (epidural or spinal) anesthesia with a thigh tourniquet and the patient in "half-side or side" position on the operation table.

A curved skin-incision was made over the posterior part of the lateral malleolus, extending to the area distal to the tip (Figure 6).

A soft tissue flap was prepared using the periost, the fibrous tissue corresponding to the insertion of the anterior talo-fibular and calcaneo-fibular ligament and capsular tissue (Figure 7). The proximal margin of the flap should be approximately 2 cm proximal to the distal tip of the fibula according to Ahlgren and Larsson.\(^3\) The entire ligaments were not explored. The adjacent articular surfaces of the talus and the fibula were inspected and loose bodies and synovitis were removed.

Fig 6. The Skin incision is curved and five to six cm long, starting at the dorsal aspect of the distal fibula.

Figure 7. Operative method. Description, see text!
The fibula was then decorticated corresponding to the periosteal part of the flap. Three or four bore canals were prepared from the distal tip of the fibula into the decorticated area. Sutures (resorbable or non-resorbable) were threaded through the base of the periosteal-capsular-ligamentous flap, through one of the bore canals and back through another and finally through the base of the flap. The sutures were tightened with the foot in the pronated position.

The patients stayed in the hospital for four (1-8) days. The average time of operation was 56 (45-80) minutes. Postoperatively a below knee walking cast was used for six weeks. Full weight-bearing was allowed for the last four weeks, after which physiotherapy was initiated. Full activity without any restriction was allowed three months after the operation. In physically demanding situations, the patients were advised to use external support during the first year.

**RSA (roentgen stereophotogrammetric analysis)**

Roentgen stereophotogrammetry was introduced 1973 by Göran Selvik\(^{170}\) to obtain reliable measurements from radiographs. The method includes computations of three-dimensional motions based on rigid-body kinematics. During the period for this Thesis the software was continuously developed to enable processing on personal computers. The time for the evaluation procedure has then been shortened\(^{144,185}\). Detailed description of the software (UMRSA, UNIKUM, University of Umeå, Sweden,) and its clinical application have been accounted for previously.\(^{91,112,141,151,174}\) The RSA method includes implantation of bone markers, radiographic examination of the patient and calibration cages,

![Figure 8. Tantalum balls in the tibia, fibula, talus and calcaneus.](image)

*indicates calculated fictive point. The axes of the laboratory coordinate axes are indicated.
marking and measurements of radiographs and mathematical computations.

**Implantation of tantalum markers.**

Tantalum markers were implanted in the tibia, the talus, the fibula (36 patients) and the calcaneus (14 patients) bilaterally three weeks before the roentgen examination. Local or regional anesthesia (epidural or spinal anesthesia) was used.

The tantalum markers (diameter of 0.5 or 0.8 mm) were placed in a needle (2R2™, Switzerland) and kept in place by a small piece of bone wax. The needle was inserted in each bone and the tantalum markers were pushed out by a trocar. Three to six markers were placed in each bone (Figure 8).

**Stress tests and radiographic examination.**

With the patient in the supine position the ankle was placed in a Plexiglas® calibration cage mounted on a cassette-holder designed for biplanar examinations. The calibration cage defined the laboratory coordinate system (Figure 9). Before the examination the ankle was anesthetized by injection of 3 ml Citanest® (Astra, Sweden) into the joint. Exposures were done simultaneously in the AP and lateral views with the roentgen tubes at a distance of 1 meter from the roentgen films.
The ankles were examined in five to eight positions in the different studies (Table 5.). The neutral (reference) position was defined by placing the foot perpendicular to the longitudinal axis of the tibia. This was obtained by using an adjustable plastic splint. At this position the tibia and the ankle joint were aligned with the laboratory coordinate system in a standardized way. The longitudinal (Y) axis was parallel to the longitudinal axis of the tibia, the transverse axis (X) perpendicular to the Y axis in the frontal plane (defined by the longitudinal axis of the tibia and an inter-malleolar line), the sagittal axis (Z) was perpendicular to the X and Y axes (Figure 8).

Maximum dorsal flexion was obtained by adjustment of the splint. Maximum plantar flexion and manual adduction was performed by the examiner using lead gloves. At the manual adduction test the foot and ankle were allowed to obtain the position that gave the least resistance.

To standardize the procedure, the adduction test was also performed with a predetermined torque (5 Nm) (III). In the latter part of the study (V, VI, VII) the ankles were placed in a splint during this test with the intention to keep the ankle joint in the neutral position but allowing varus and valgus rotations (rotations around the z-axis).

At the drawer tests the foot was placed in 10 degrees of plantar flexion with the knee slightly flexed. A horizontal bar was attached to the lower leg 15 cm proximal to the medial malleolus. The bar was mounted on a frame allowing anterior-posterior displacement of the lower leg. Weights were attached to the horizontal bar corresponding to posteriorly directed forces of 40 N and 160 N for two and four minutes, respectively, before the radiographs were exposed. The ankle was also radiographed before the weights were attached to obtain an unloaded starting position for the subsequent calculation of the talar and the fibular motions between the unloaded and loaded positions.

| Table 5. Position of the ankles during the exposures. |
|-----------------------------------------------|----------------|----------------|----------------|
| 2. Passive plantarflexion                   | IV,VII         | 7. Adduction 5 Nm (orthosis)    | VI |
| 5. Adduction 5 Nm                           | III,V-VII      | 10. Drawer test 160 N          | III,IV,VII |

32
Marking and reconstruction of a fictive point in the talus.

The images of the tantalum markers in the patient and the calibration cage were numbered on the radiographs in a standardized way. The following procedure was performed to enable standardized measurements of talar translations. At the initial examination (reference position, 90 degrees) one so-called fictive point was plotted centrally on the talar cartilage. The medial-lateral and anterior-posterior position of this point corresponded to the midpoint of the talus at the most proximal part of the talar dome. The three-dimensional coordinates of the point were computed (see below). To reach the center of the talar trochlea the Y-coordinates were changed in each ankle on the reference position, corresponding to a distal displacement of 21 mm (Figure 8). This value was obtained by estimating the proximal-distal position of the talar center on the AP and lateral view, with the aid of circular guides. Repeated measurements in ten ankles to obtain the most optimum pairing between the two plotted points in XRAY90 revealed a constant distance of 21 mm (20-22 mm) between the vertex of the talar dome and its center of the talar trochlea. Thus, this procedure resulted in determination of the three-dimensional coordinates of the center of the talar body when the ankle was examined in the neutral reference position. The procedure was only done one time in each ankle. Determination of the same position in the subsequent examinations was done using the known position of the talar bone markers (see below).
Digitizing of the film markers - mathematical computations.

The two-dimensional film coordinates of the tantalum markers and the fictive point were digitized on a measuring Table (Wild Autograph A7 Z, Heerbrugg, Switzerland). The measured film coordinates were used to reconstruct the laboratory coordinate system and the coordinates for each roentgen foci enabling the computation of the three-dimensional coordinates for each bone marker. The three-dimensional configuration of each segment corresponding to the markers within each bone was reconstructed to evaluate the marker stability and configuration. Correction of erroneous marker identification and exclusion of unstable markers is supported by the software.

Transformation of the fictive (plotted) point from the examination in the neutral position to the examinations used to evaluate talar translations at the drawer tests was done using the known positions of the bone markers in the talus of each ankle. Thus, the fictive point had almost exactly the same position throughout the examination in each ankle. Due to inexactness in the plotting procedure a small variability could be present when comparing different ankles. The error caused by variability of the plotting procedure was regarded to be negligible, because of the location of the fictive point, close to the center of talar rotation, and the small rotations occurring during the anterior drawer test.

Figure 10. Talar translations along the z and y-axes, and the total talar translation to the right. The small arrow shows the anterior talar translation in most other studies.7.3,9.6
The tibial markers were used as the fixed reference segment at the calculation of the relative talar and fibular motions (papers III-VII). At the calculation of the calcaneal rotations (paper V) the talus was additionally used as reference segment.

Rotations and translations were computed using the positions of the different segments in the reference position (neutral ankle position). This means that the program mathematically aligned the tibia in position 2-10 (Table 5.) to its initial position. This was done by using the inverse rotation matrix of the absolute tibial rotations between position one and the subsequent ones. The other segments (talar, fibular and calcaneal bone markers) were subjected to same rotations. This procedure is equivalent to a fixed position of the reference segment throughout the examination procedure.

To maintain the same alignment of the ankle in the preoperative and follow-up measurements in paper VII, the absolute tibial rotations between the neutral reference positions at each occasion were recorded. These motions were used to

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>diff. 1 sd</td>
<td>diff. 1 sd</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Rotations talus (degrees)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>plantarflexion</td>
<td>14</td>
<td>4.3</td>
</tr>
<tr>
<td>dorsiflexion</td>
<td>12</td>
<td>6.2</td>
</tr>
<tr>
<td>adduction manual</td>
<td>14</td>
<td>8.2</td>
</tr>
<tr>
<td>adduction (torque 5 Nm)</td>
<td>5</td>
<td>3.2</td>
</tr>
<tr>
<td>Rotations calcaneus-tibia (degrees)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>adduction manual</td>
<td>10</td>
<td>6.9</td>
</tr>
<tr>
<td>Rotations calcaneus-talus (degrees)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>adduction manual</td>
<td>9</td>
<td>1.0</td>
</tr>
<tr>
<td>Translations talus (mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 N</td>
<td>10</td>
<td>0.4</td>
</tr>
<tr>
<td>160 N</td>
<td>9</td>
<td>0.6</td>
</tr>
</tbody>
</table>
align the coordinate system to the same position at the follow-up examinations as on the preoperative examination.

Talar translation along the coordinate axes are presented in paper III. Because this detailed analysis did not provide additional information, the vectorial sum of these motions was used in the subsequent presentations (total translations in paper VII) (Figure 10).

The reproducibility of the various testing procedures was assessed in 17 ankles by repeating one or all the testing procedures (Table 6.)

**Conventional radiographic examination. (I)**

Conventional AP, lateral and oblique radiographic exposures were performed in 34 patients. The exposures were done non weight-bearing. All radiographs were evaluated by one examiner, who recorded signs and degree of osteoarthrosis according to Magnusson-Cedell\textsuperscript{30,132} (Table 7). The joint distance (mm) was measured at eight locations (Figure 12.).

**Clinical examination. (I)**

Range of motion was recorded in paper (I) with a protractor according to Lindsjö et al.\textsuperscript{125} with slight modification. The patient was standing with one foot on the floor and the other on a small box (30 cm high) in maximum plantarflexion and dorsiflexion. During this procedure the sole of the foot rested on the box. Hindfoot adduction and ADS were tested manually.
EMG-investigation (II).

EMG recordings were performed during sudden angular displacement of the ankle (Figure 11) resembling a sprain situation. Bipolar silver-silver chloride surface electrodes with a contact diameter of 6 mm were placed on the most prominent part of the belly of the peroneus longus and the tibialis anterior muscles bilaterally.

The EMG recordings were transmitted using a telemetric technique with the electrodes connected to a radio transmitter attached to a belt of the subjects. Small Medinik amplifiers (Örbyhus, Sweden) were used for linear amplifications of the EMG signals with a bandwidth of 5-500Hz. The signals were controlled for artefacts (hum and movement) and recorded on a jet ink writer (Siemens-Elema, Mingocard 7, Solna, Sweden) with a bandwidth of DC to 1 kHz. The paper speed was 100 mm/s.

The subjects were asked to stand with equal weight on the trapdoors. One of the them was released when the muscles were relaxed, i.e., when the EMG signals showed a basal activity. The subjects did not know which side was to be

Figure 11. A trap door mechanism was constructed with two movable platforms to simulate an ankle sprain situation. The adjacent sides of the platforms were each connected to a hinge that permitted the platforms to be tilted 30°. To keep the platforms in a horizontal position the opposite sides were supported by movable metal bars (white arrow to the right) which suddenly could be pulled away by an electrical powered motor. The subjects were placed on the trapdoor with the feet 10 cm apart. The straight arrows indicate the switches which indicate the start of the platform movement.
Summary of papers I - VII and results

I.

The outcome of non operated patients with chronic lateral instability of the ankle. A 20 - year follow-up study.

Patients and methods

Patients and controls.

The hospital records of 744 patients who during the period 1969 to 1973 were registered as distorsio pedis were reviewed. Thirty-seven patients with symptoms of CLI for more than six months were selected for follow-up.

Twenty-five patients were investigated clinically. Further twelve patients were interviewed by telephone (either because they lived at a long distance or because they were not willing to participate in the clinical examination). The time between the index visit and the follow-up was 20.3 years (18 years to 23 years).

Thirty-four patients (20 men and 14 women) participated in a radiographic examination. The mean age in this group was 45 years (31 to 73 years). Twelve of these patients had bilateral problems, giving a total of 46 ankles.

Standard ankle radiographs from patients who matched the follow-up group according to sex and age were used for comparison. These patients visited the emergency department during 1986. Their ankles had not previously been radiographically examined according to the hospital records. Indication for radiographic examination was trauma to the foot or ankle, but without any signs of fracture on the present examination.

Questionnaire and clinical examination.

Information regarding occupation, present leisure time, walking ability and support, stair climbing, occurrence of instability and pain, swollen ankles was obtained using a questionnaire. At the clinical examination the degree of ankle tilting, anterior drawer sign and range of motion was recorded. All patients (n=25) were investigated by the author.
**Radiographs.**

The radiographs (34 patients, 46 ankles) were examined by one investigator and classified according to Cedell and Magnusson\textsuperscript{30,132} (see Table 5) regarding the presence of osteoarthrosis.

**Results**

**Social situation and residual symptoms.**

Thirty patients were vocationally active. Twenty-six participated in regular physical activity (jogging, skiing etc.) and another seven took daily walks.

At follow up 22 patients (11 men and 11 women, 32 ankles) still suffered from instability of the ankle joint (Table 8). Ten patients (15 ankles) claimed that they could twist their ankles and occasionally fall while walking on even ground.

Pain occurred in 10 patients (14 ankles) and could in three cases be attributed to disorders other than residual instability. Five patients had swollen ankles. Four of these and the three patients with a limp (attributed to instability in two cases) had pain.

<table>
<thead>
<tr>
<th>symptoms of instability</th>
<th>patients</th>
<th>(ankles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>no</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>sloping surface</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>terrain</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>plane surface</td>
<td>10</td>
<td>15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>frequency of instability</th>
<th>patients</th>
<th>(ankles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>never</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>sporadic</td>
<td>17</td>
<td>24</td>
</tr>
<tr>
<td>1-2/month</td>
<td>5</td>
<td>8</td>
</tr>
</tbody>
</table>
Figure 12. In the patient group the average joint space (frontal A-E /dome B-D/lateral F-H) was significantly greater (p<0.001 Wilc. rank) in male ankles (3.6 / 3.2 / 3.3 mm) than in female ankles (2.8 / 2.6 / 2.8 mm).

Clinical examination.

At the examination, 17 of the 25 ankles with symptoms of instability also had increased tilting and 11 showed increased anterior drawer sign. Plantarflexion was greater in women and dorsiflexion greater in men (p=< 0.05, Wilc. rank.), but the total range of motion (73.7°/70.4°, Wilc. rank.) did not differ.

Radiographic examination

Radiographic osteoarthritic changes were found in six (13%) of the 46 ankles in the patient group and in four ankles (8.7%) in the control-group (NS., Chi-square test). The observed radiographic changes were minor (Magnusson/Cedell I) in both groups. Of 32 ankles with remaining instability there were three (9.4%) with minor signs of degenerative changes.

The patients with past or present symptoms of instability had the same average joint space on the AP (total, dome) and lateral view as the controls (Table 8). There was no correlation between age and joint space in either of the groups.

Because of this study one patient was referred for treatment of the instability (living at long distance) and another two have been operated with lateral ligament reconstruction (at our department).
Conclusions

In more than half the cases, symptoms of CLI did not resolve spontaneously, when present for more than six months. Minor degenerative changes was found after 20 years, but generally there was no significant reduction of the joint space. Only a few of our patients, left non operated for twenty years, regarded their residual problem a major hindrance in their present everyday life.

Table 9.

Average joint space in mm (SD). See also Figure 12.

<table>
<thead>
<tr>
<th>ankles</th>
<th>n</th>
<th>frontal (A - E)</th>
<th>dome (B - D)</th>
<th>lateral (F - H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>all</td>
<td>46</td>
<td>2.9 (0.5)</td>
<td>3.2 (0.6)</td>
<td>3.1 (0.5)</td>
</tr>
<tr>
<td>controls</td>
<td>46</td>
<td>3.1 (0.8)</td>
<td>3.3 (0.6)</td>
<td>3.0 (0.4)</td>
</tr>
<tr>
<td>still unstable</td>
<td>32</td>
<td>2.9 (0.5)</td>
<td>3.1 (0.6)</td>
<td>3.0 (0.5)</td>
</tr>
<tr>
<td>controls</td>
<td>32</td>
<td>3.0 (0.8)</td>
<td>3.1 (0.6)</td>
<td>2.9 (0.4)</td>
</tr>
</tbody>
</table>
Prolonged reaction time in patients with chronic lateral instability of the ankle.

Patients and controls

The reaction time of the peroneus longus and the anterior tibial muscles was measured when the ankle was subjected to sudden adduction. Thirteen patients (4 men/9 women) with CLI for at least 12 months were included. Two patients had bilateral symptoms. Thus, there were 15 ankles (6 left and 9 right).

The control group (medical personnel) matched the patient group to age, gender and side. They did not have a history of lower extremity trauma or ankle instability.

Results

The median IRT was significantly longer (PL 15.7 ms ; TA 16.4) in the patient group in both the recorded muscles when compared to the control group (p = 0.0001, Wilc.rank). However, no significant difference was observed when comparing the CRT in the patient group with the CRT in the control group (Table 9).

In the patients with unilateral symptoms the median IRT and CRT varied from 65.0 ms to 68.8 ms with no significant difference (Wilc. match) between the symptomatic and the non symptomatic side or between IRT and CRT.

The ipsilateral reaction times (IRTs) in the control group were 49 ms with no side-difference. The median contralateral reaction times (CRTs) were significantly longer in both muscles compared to the IRT.
Table 9.
Reaction times in ankles in control persons and ankles with symptoms. Wilcoxon matched signed rank test was used to compare the IRT and CRT the ankles with symptoms. Wilcoxon signed rank test was used to compare control group with the patient group.

### Controls

<table>
<thead>
<tr>
<th></th>
<th>M. Peroneus longus.</th>
<th>M. Tibialis anterior</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>Median</td>
<td>Range</td>
</tr>
<tr>
<td>IRT</td>
<td>15</td>
<td>49.2 (40.8 - 64.2)</td>
</tr>
<tr>
<td>CRT</td>
<td>15</td>
<td>64.2 (55.8 - 83.3)</td>
</tr>
<tr>
<td>P-value (IRT vs CRT)</td>
<td>0.001</td>
<td>0.0007</td>
</tr>
</tbody>
</table>

### Ankles with symptoms

<table>
<thead>
<tr>
<th></th>
<th>M. Peroneus longus.</th>
<th>M. Tibialis anterior</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>Median</td>
<td>Range</td>
</tr>
<tr>
<td>IRT</td>
<td>15</td>
<td>65.0 (52.5 - 89.2)</td>
</tr>
<tr>
<td>CRT</td>
<td>10</td>
<td>68.3 (51.0 - 83.3)</td>
</tr>
<tr>
<td>P-value (IRT vs CRT)</td>
<td>0.4148</td>
<td>0.1097</td>
</tr>
</tbody>
</table>

P-values comparing controls and ankles with symptoms

| P-value (IRT) | 0.0001 | 0.0001 |
| P-value (CRT) | 0.4208 | 0.2018 |

### Conclusions

1. Patients with CLI have prolonged ipsilateral reaction time (peroneus longus and tibialis anterior muscles) to sudden angular displacement of the ankle.

2. Impaired proprioception may be a contributing cause to chronic lateral instability of the ankle.
III

Chronic lateral instability of the ankle. Roentgen stereophotogrammetry of talar position.

Patients

The talar mobility was measured using RSA during adduction tests and drawer tests with posterior tibial loads of 40 and 160 N. Fifty-two ankles (Table 10) in 29 patients with uni- or bilateral symptoms of CLI for eight years were studied.

<table>
<thead>
<tr>
<th>Group</th>
<th>Symptoms</th>
<th>Side</th>
<th>Number of ankles</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Without</td>
<td>L or R</td>
<td>14</td>
</tr>
<tr>
<td>B</td>
<td>Unilateral</td>
<td>L or R</td>
<td>14</td>
</tr>
<tr>
<td>C</td>
<td>Bilateral</td>
<td>L</td>
<td>12</td>
</tr>
<tr>
<td>D</td>
<td>Bilateral</td>
<td>R</td>
<td>12</td>
</tr>
</tbody>
</table>

Results

During the testing procedure the degree of plantarflexion was not controlled. The ankles were allowed to obtain a position that provided the least resistance. This resulted in plantarflexion and internal rotation of the talus in all groups. Increased talar adduction was noted in ankles with symptoms compared to the non symptomatic ankles (p< 0.05, Wilc. rank.). The correlation coefficient between the manual test and the test with the predetermined torque was 0.8 (p<0.001, Spearman).

2Some errors concerning the grouping of patients (bilateral, unilateral, no symptoms in papers III and IV have been corrected in this summary, the correct classification and data are given in tables: 10 and 11-15,
Rotations.

The talus rotated slightly about the cardinal axes at posterior loading of the tibia. Both plantar and dorsal flexion was observed as well as internal and external rotation. The ankles with unilateral symptoms displayed varus-angulation, adduction, of the talus, which differed from the non symptomatic group (p<0.05 Wilc. rank.).

Translations.

At posterior tibial load of 40 N forward and distal translations of the talus were registered in all groups. Medial translation was recorded in the group B and C. The median talar translations were larger in all groups at 160 N compared with the posterior loading of the tibia at 40 N along the sagittal axis and the longitudinal axes (p<0.001). However, no significant differences in translations along the axes were found between the groups.

Table 11. Talar rotation (median, range) at manual adduction.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Plantarflexion +</th>
<th>Rotation, int. +, ext. -</th>
<th>Adduction +</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>13</td>
<td>23.6 (16.1 - 42.7)</td>
<td>2.4 (-10.7-14.5)</td>
<td>1.8 *# (-3.2-10.3)</td>
</tr>
<tr>
<td>B</td>
<td>13</td>
<td>25.5 (13.4 - 48.5)</td>
<td>2.3 (-14.4-14.6)</td>
<td>5.5 * (-1.2-16.6)</td>
</tr>
<tr>
<td>C</td>
<td>11</td>
<td>24.5 (9.6 - 38.9)</td>
<td>2.4 (-3.9-13.5)</td>
<td>11.1 * (-1.5-19.0)</td>
</tr>
<tr>
<td>D</td>
<td>11</td>
<td>32.2 (2.1 - 44.5)</td>
<td>2.6 (-4.7-12.6)</td>
<td>8.1 # (1.6-31.4)</td>
</tr>
</tbody>
</table>

Oneway anova (Kruskal- Wallis) ns ns 0.034

Significant difference * = A - B < 0.05 # = A - D < 0.05

(Wilc.rank.)

Table 12. Talar rotation (median, range) at drawer test 40 N.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Plantarflexion +</th>
<th>Rotation, int. +, ext. -</th>
<th>Adduction +</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>12</td>
<td>-0.2 (-10.7-8.9)</td>
<td>0.5 (-3.5-5.8)</td>
<td>-0.5 * (-1.8-0.7)</td>
</tr>
<tr>
<td>B</td>
<td>12</td>
<td>-0.5 (-4.7-5.2)</td>
<td>1.2 (-0.3-6.1)</td>
<td>0.2 * (-1.1-3.4)</td>
</tr>
<tr>
<td>C</td>
<td>9</td>
<td>-0.5 (-5.5-6.2)</td>
<td>-0.1 (-3.9-6.8)</td>
<td>-0.2 (-3.9-4.8)</td>
</tr>
<tr>
<td>D</td>
<td>10</td>
<td>0.1 (-1.5-12.4)</td>
<td>1.6 (-3.0-2.9)</td>
<td>-0.1 (-1.6-1.6)</td>
</tr>
</tbody>
</table>

Oneway anova (Kruskal-Wallis) ns ns ns

Significant difference * = A - B < 0.05 (Wilc.rank.)
Table 13. Talar translation (mm, median, range) at drawer test 40 N.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Medial +</th>
<th>Distal -</th>
<th>Anterior +</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>12</td>
<td>0.0 *a</td>
<td>-0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>B</td>
<td>12</td>
<td>0.3 *</td>
<td>-0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>C</td>
<td>9</td>
<td>0.3 ±</td>
<td>-0.4</td>
<td>1.5</td>
</tr>
<tr>
<td>D</td>
<td>10</td>
<td>0.0</td>
<td>-0.3</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Oneway anova
(Kruskall-Wallis)

Significant difference * = A - B < 0.05  a = A - C < 0.05 (Wilc.rank.)

Table 14. Talar rotation (median, range) at drawer test 160 N.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Plantarflexion +</th>
<th>Rotation, int. +, ext. -</th>
<th>Adduction +</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>12</td>
<td>-0.2 (-16.3-7.6)</td>
<td>-0.3 (-4.4-5.2)</td>
<td>-0.8 (-2.0-1.6)</td>
</tr>
<tr>
<td>B</td>
<td>12</td>
<td>-1.6 (-13.7-7.3)</td>
<td>-1.2 (-7.8-3.4)</td>
<td>-0.3 (-4.8-0.9)</td>
</tr>
<tr>
<td>C</td>
<td>8</td>
<td>1.2 (-3.7-14.4)</td>
<td>-1.2 (-3.8-5.3)</td>
<td>0.5 (-4.2-7.9)</td>
</tr>
<tr>
<td>D</td>
<td>8</td>
<td>-0.1 (-6.3-17.2)</td>
<td>2.1 (-9.4-13.9)</td>
<td>-0.1 (-2.2-7.2)</td>
</tr>
</tbody>
</table>

Oneway anova
(Kruskall-Wallis)

Table 15. Talar translation (mm, median, range) at drawer test 160 N.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Medial +</th>
<th>Distal -</th>
<th>Anterior +</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>12</td>
<td>0.2 (-0.4-1.0)</td>
<td>-0.8 (-2.1-0.3)</td>
<td>2.4 (0.3-6.3)</td>
</tr>
<tr>
<td>B</td>
<td>12</td>
<td>0.6 (-1.9-4.2)</td>
<td>-1.2 (-2.0-0.1)</td>
<td>4.6 (0.6-6.7)</td>
</tr>
<tr>
<td>C</td>
<td>8</td>
<td>0.8 (-1.1-3.5)</td>
<td>-1.2 (-2.0-0.5)</td>
<td>4.1 (1.4-9.9)</td>
</tr>
<tr>
<td>D</td>
<td>8</td>
<td>-0.2 (-0.8-2.5)</td>
<td>-0.9 (-2.5-0.3)</td>
<td>3.6 (0.7-8.2)</td>
</tr>
</tbody>
</table>

Significant difference

Oneway anova
(Kruskall-Wallis)

Conclusion.

Patients with CLI displayed increased talar adduction. No significant increase of the anterior talar translations was recorded at the drawer tests with standardized loads.
IV

Fibular mobility in chronic lateral instability of the ankle.

Patients and methods

The fibular mobility was studied during passive plantar- and dorsiflexion, manual adduction and drawer tests with posterior tibial loads of 40 and 160 N using RSA.

Fifty-two ankles in 29 patients with uni- or bilateral symptoms of CLI for eight years were studied. The ankles were grouped according to paper III (Table 10).

Results

Translations

Medial(+)/lateral (-) translations (Figure 13).

The largest average fibular displacements occurred between neutral position and plantarflexion. In all groups, plantarflexion, anterior drawer and adduction tests resulted in an average medial displacement of the lateral malleolus (0.2 to 1.2 mm). Increasing the posterior tibial load during the drawer test resulted in a more medial position of the lateral malleolus in all groups (p<0.05, Wilc. match.) with no significant difference between them.

Proximal(+)/distal(-) translation (Figure 14).

Plantarflexion, dorsiflexion and posterior loading of the tibia were associated with no or minimum average proximal/distal fibular displacement in all groups.

3. Some errors concerning the grouping of patients (bilateral, unilateral, no symptoms in papers III and IV have been corrected in this summary, the correct classification and data are given in tables: 10 and 15-16.
At the adduction test the fibula was displaced more distally than in any of the other positions of the foot (p<0.001, Wilc. match.). The presence of symptoms did not significantly influence the distal displacements.

**Anterior(+) / Posterior(-) translation (Figure 15).**

Plantarflexion of the ankles induced average anterior (0.1 to 0.5 mm) and dorsiflexion induced posterior (-0.2 to -0.4 mm) fibular displacements. Small mean anterior/posterior fibular shifts (less than 0.6 mm) were also recorded at the adduction tests.

During the drawer tests the distal fibula displaced anteriorly. Increasing the posterior tibial load from 40 to 160 N resulted in a greater anterior fibular displacement in groups A, and D (p< 0.01, Wilc. match.).

**Total translation (Figure 16).**

The total lengths of the fibular displacements corresponded to the vectorial sum of the medial-lateral, proximal-distal and anterior-posterior movements. Plantarflexion of the foot resulted in average fibular movements of 1.2 to 1.5 mm and dorsiflexion 0.4 to 0.6 mm. At the adduction test increased fibular movements were recorded in one group of the bilaterally symptomatic ankles (Figure 16.). During posterior tibial loading at 40 N the average total translation (all groups) was 0.7 mm and increased to 1.1 mm at the load of 160 N (p < 0.001, Wilc.match.).

**Rotations (Table 15).**

During plantarflexion, dorsiflexion and at the adduction test small positive fibular rotations about the transverse axis (plantarflexions) were recorded whereas an average dorsiflexion was noted during posterior loading of the tibia. Fibular rotations about the longitudinal axis showed the greatest variability (range 4°external to internal 6.3°). During the anterior drawer tests the fibula rotated internally especially in the symptomatic ankles.
Figure 13. Medial - lateral fibular displacement in mm (mean, SD) during the different testing procedures. The talar position (degree of plantar or dorsiflexion) on the x-axis. ● = ankles without symptoms (group A), ■ = ankles with unilateral symptoms (group B), ▲ = ankles with bilateral symptoms left (group C) and ▼ = ankles with bilateral symptoms right (group D). δ and π = significant difference $p < 0.05$. B - C and A - C respectively (Wilc.rank.).

Figure 14. Proximal (+) and distal (-) displacement of the fibula in mm during the different testing procedures. Legends see Figure 13.
Figure 15. Anterior (+) and posterior (-) displacement of the fibula in mm during the different testing procedures. Legends see Figure 13. \( \pi \) = significant difference, where \( p < 0.05 \). B - C. (Wilk.rank.)

Figure 16. Total fibular displacement in mm during the different testing procedures. Legends see Figure 13. \( \pi \) = significant difference \( p < 0.05 \). B - C.
Table 16. Fibular rotations during the different testing procedures.

**Plantar (+) and dorsal (-) fibular rotation in degrees during different positions of the ankle.**

<table>
<thead>
<tr>
<th>Test</th>
<th>Plantarflexion</th>
<th>Dorsiflexion</th>
<th>Adduction</th>
<th>Drawer test (40 N)</th>
<th>Drawer test (160 N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>degrees</td>
<td>SD</td>
<td>n</td>
<td>degrees</td>
</tr>
<tr>
<td>A</td>
<td>14</td>
<td>0.2</td>
<td>0.6</td>
<td>13</td>
<td>0.0</td>
</tr>
<tr>
<td>B</td>
<td>14</td>
<td>0.1</td>
<td>0.5</td>
<td>12</td>
<td>0.1</td>
</tr>
<tr>
<td>C</td>
<td>12</td>
<td>0.3</td>
<td>0.7</td>
<td>11</td>
<td>0.3</td>
</tr>
<tr>
<td>D</td>
<td>12</td>
<td>0.5</td>
<td>0.5</td>
<td>10</td>
<td>0.2</td>
</tr>
</tbody>
</table>

* p < 0.05

**Internal (+) and external (-) fibular rotation in degrees during different positions of the ankle.**

<table>
<thead>
<tr>
<th>Test</th>
<th>Plantarflexion</th>
<th>Dorsiflexion</th>
<th>Adduction</th>
<th>Drawer test (40 N)</th>
<th>Drawer test (160 N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>degrees</td>
<td>SD</td>
<td>n</td>
<td>degrees</td>
</tr>
<tr>
<td>A</td>
<td>14</td>
<td>-0.1</td>
<td>1.8</td>
<td>13</td>
<td>0.0</td>
</tr>
<tr>
<td>B</td>
<td>14</td>
<td>0.2</td>
<td>1.8</td>
<td>12</td>
<td>-0.2</td>
</tr>
<tr>
<td>C</td>
<td>12</td>
<td>-0.3</td>
<td>1.1</td>
<td>11</td>
<td>0.0</td>
</tr>
<tr>
<td>D</td>
<td>12</td>
<td>0.6</td>
<td>1.8</td>
<td>10</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**Varus (+) and valgus (-) fibular rotation in degrees during different positions of the ankle.**

<table>
<thead>
<tr>
<th>Test</th>
<th>Plantarflexion</th>
<th>Dorsiflexion</th>
<th>Adduction</th>
<th>Drawer test (40 N)</th>
<th>Drawer test (160 N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>degrees</td>
<td>SD</td>
<td>n</td>
<td>degrees</td>
</tr>
<tr>
<td>A</td>
<td>14</td>
<td>0.5</td>
<td>0.4</td>
<td>13</td>
<td>0.0</td>
</tr>
<tr>
<td>B</td>
<td>14</td>
<td>0.3</td>
<td>0.4</td>
<td>12</td>
<td>0.0</td>
</tr>
<tr>
<td>C</td>
<td>12</td>
<td>0.3</td>
<td>0.6</td>
<td>11</td>
<td>-0.1</td>
</tr>
<tr>
<td>D</td>
<td>12</td>
<td>0.4</td>
<td>0.6</td>
<td>10</td>
<td>0.1</td>
</tr>
</tbody>
</table>

**Correlation between talar and fibular movements during the adduction and anterior drawer tests.**

Anterior talar translations at the drawer test (40N) were associated with internal fibular rotations in the groups with symptoms (group B=0.59 (P=0.04) C=0.80 (P=0.01) D=0.58 p=0.08 ;Spearman correlation coefficient) whereas no corresponding correlation was found in ankles without symptoms.
Conclusions

Increased fibular mobility may occur in patients with bilateral symptoms, perhaps reflecting generalized joint laxity.

Anterior displacements of the distal fibula during anterior drawer tests regardless of symptoms instability or not may indicate remaining function of the lateral ligaments.

Absence of lateral displacement of the fibula during the adduction test implies that there is no major insufficiency of the distal tibio-fibular syndesmosis in patients with CLI.
Subtalar stability in chronic lateral instability of the ankle.

Patients and methods

Patients and controls.

The talar and calcaneal mobility was measured using RSA during adduction tests performed manually and with predetermined torque (5 Nm). Fourteen patients (10 men/4 women, 20 - 57 years, mean 34 years) with a duration of unilateral symptoms of CLI for 12.5 years were investigated. The control group comprised four healthy volunteers (medical personnel, 3 men/1 woman, 26-35 years, mean 33 years) without history of ankle trauma.

Methods.

The investigations of the control persons were performed at Karolinska Hospital, Stockholm. The patients were investigated at the University Hospital of Umeå. The same measuring equipment was used for both groups.

All the ankles were examined in the neutral position and at manual adduction. A splint was used to hold the sole of the foot perpendicular to the tibia at the adduction test with specified torque. Complete evaluation of both joints could in this study be done in all the controls, the tibio-talar joint in nine patients and the talo-calcaneal joint in six patients.
Results

Control group

At the manual adduction, plantarflexion was recorded in the tibio-talar joint and dorsiflexion in the talo-calcaneal joint. Internal rotation and varus angulation was noted in the hindfoot joint complex during the testing procedure; the most pronounced motions occurring in the talo-calcaneal joint. The varus angulation in the tibio-talar joint varied from 4.3° to 10.9° (mean 6.1°).

Similar but smaller rotations were observed using predetermined torque (except from a mean external rotation instead of an external in the tibio-talar joint.)

Patients

Manual adduction test - tibio-talar motions.

Mean talar plantarflexion (20°) and internal rotation (1.5°) was observed. The varus angulation in ankles with symptoms was 7.3°, (range -1.2°-14.3°) and in ankles without symptoms 3.4° (range -3.2°-10.3°) (p=0.002, paired t-test).

Manual adduction test - talo-calcaneal motions.

No significant difference was noted between ankles with and without symptoms.

Manual adduction test - tibio-calcaneal motions.

The plantarflexion and internal/external rotation did not differ between the two sides. The varus angulation was increased on the symptomatic side as an effect of increased talar motions.

Adduction test with torque (5Nm).

In general a reduction of the mean talar and calcaneal rotations was registered with the use of the predetermined torque. No significant differences between the ankles with and without symptoms of CLI were found.
Conclusions.

Patients with unilateral CLI displayed increased varus instability in the tibio-talar joint but not in the talo-calcaneal joint in this study.

Manual adduction tests were superior to a more constrained testing procedure using a torque of 5 Nm.

The ankles in the control group displayed mean tibio-calcaneal and talo-calcaneal varus angulation that was close to the ankles with symptoms.
VI

The influence of an ankle orthosis on the talar and calcaneal motions in chronic lateral instability of the ankle. A roentgen stereophotogrammetric analysis.

Patients and methods

Patients.

The stabilizing effect of an ankle brace (StrongR) (Figure 17) was studied in 14 ankles in 13 patients (9 men/4 women, 20-49 years, mean age 36 years) mean 12 years duration of CLI.

Figure 17. The "Strong® ankle brace", custom-made in a thermoplastic material, with an adjustable lateral strap.
Methods.

The three-dimensional mobility of the talus and calcaneus was studied using RSA with and without an ankle brace (Figure 17) according to Table 5. Evaluation of calcaneal motions with and without the brace could only be done in eight ankles with the specified torque due to difficulties to visualize the tantalum markers on the radiographs.

Results

Tibio-talar motions.

With the brace applied a significant decrease in the plantarflexion was observed (p <0.01, paired t-test) as well as a shift from internal to external rotation (p <0.01, paired t-test). The ankle brace reduced the average varus angulation in the talocrural joint from 6.2° to 0.9° at the manual adduction test (p = 0.001, paired t-test) and from 3.9° to 1.0° (p <0.05, paired t-test) using the predetermined torque.

Talo-calcaneal motions.

All the rotations in the talo-calcaneal joint were significantly reduced by the brace at the manual adduction and when the predetermined torque was used. The constrained testing procedure resulted in smaller calcaneal rotations of the unbraced ankle than at the manual testing procedure. Still a significant reduction of the three-planar rotations occurred with the brace.

The mean reduction of the varus-angulation induced by the ankle brace was 16.8° at the manual test and 15.2° at the test with the predetermined torque. The internal rotation was also significantly reduced at both tests but the plantarflexion only at the manual test. (p < 0.01 paired t-test)

Conclusions

The ankle brace tested in this study significantly reduced talar and calcaneal plantarflexion, internal rotation and varus angulation which supports its use in clinical practice.
Ligament reconstruction for chronic lateral instability.  
A 5-year RSA follow-up of 30 cases.

Patients and methods

Patients.

The mechanical ankle stability and the range of ankle motion were recorded using RSA in 27 patients (21 men/6 women, mean age 30 years) before surgical reconstruction of the lateral ligaments because of CLI and at two follow up occasions; 20 (12-35) months and 60 (42-83) months after surgery. The operations were done between December 1984 and November 1988. The mean duration of symptoms was eight years. Fourteen had unilateral and 13 bilateral problems. Thirty ankles were included.

Methods.

The patient satisfaction (pain, instability, working ability, sports) was recorded using a questionnaire filled out by the patient preoperatively and at the last follow-up. The RSA examinations were performed according to Table 5.

Results

Range of motion.

The talar rotation from maximum passive dorsal to plantarflexion was not impaired by the operation.
Manual adduction test. (Figure 19).

In patients with unilateral symptoms increased talar tilt was recorded preoperatively on the side with symptoms (5.5°; range: -1.2° - 16.6°) compared to the non symptomatic side (1.8°; range: -3.2°- 10.3; P = 0.009, Wilc match.). Twenty months after surgery the talar adduction was significantly reduced and remained the same at the second follow up at 60 months (Figure 19).

Adduction test with predetermined torque (5 Nm).

The correlation between the constrained (4.5°) and non constrained (5.7°) testing procedures regarding the talar rotation around the a-p axis was 0.75 (P < 0.001, Spearman). There was no significant difference in talar rotations around the a-p axis between the two testing procedures.

Anterior drawer test. (Figure 18).

Patients with unilateral symptoms displayed increased total talar translation at the preoperative examination (5.1 mm; 0.7 - 7.7 mm) compared to the opposite side (2.6 mm ; 0.3 - 6.4 mm) when tested at 160 N but not at 40 N (P < 0.03, n =11, Wilc.match.).

Before surgery the total talar translations were 1.4 mm ( 0.1 - 9.1 mm ) using 40 N and 5.3 mm (0.7 - 10 mm) at the greater load in the ankles with symptoms. The difference between the two loads was substantial not only at the initial examination (4.1 mm, P = 0.008, Wilc. match.) but also at the follow-up (Figure 18).

At the first follow-up the total talar translations decreased at both loads and still smaller laxity was recorded at the five-year follow- up using the 160 N load (Figure 17). No significant difference was noted in talar translation when comparing the ankles without symptoms (the initial examination) in patients with unilateral problems with their corresponding operated ankles at the five year follow-up.
Subjective results.

At the five year follow-up 16 patients (17 ankles) rated the overall result "excellent"; nine patients (11 ankles) were improved and two ankles were considered not improved.

The subjective feeling of instability had disappeared in 16 ankles and was reduced in 13. In one patient the symptom of instability remained unchanged. Twenty ankles were free of pain at follow-up and in five ankles the pain was reduced. In further five it was unaffected. Ankle kinematics in relation to subjective grading is shown in Table 17.

Conclusions.

Tensioning of the lateral ligaments in patients with CLI stabilized the ankle joints for at least five years without compromising the passive range of motion.
Table 17. Ankle joint laxity - stability in relation to the clinical results.

<table>
<thead>
<tr>
<th>Talar rotation around z axis in degrees</th>
<th>Preoperatively (A)</th>
<th>20 months (B)</th>
<th>60 months (C)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>Range</td>
<td>Median</td>
<td>Range</td>
</tr>
<tr>
<td>Excellent (n=14)</td>
<td>4.7</td>
<td>(-1.5 - 17)</td>
<td>2.7</td>
<td>(-2.8 - 15)</td>
</tr>
<tr>
<td>Improved (n=9)</td>
<td>8.1</td>
<td>(1.8 - 19)</td>
<td>6.2</td>
<td>(-1.7 - 13)</td>
</tr>
<tr>
<td>Unchanged (n=2)</td>
<td>11.6</td>
<td>5.9</td>
<td>14.3</td>
<td>11.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total talar translation in mm at 40 N.</th>
<th>Preoperatively (A)</th>
<th>20 months (B)</th>
<th>60 months (C)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>Range</td>
<td>Median</td>
<td>Range</td>
</tr>
<tr>
<td>Excellent (n=11)</td>
<td>1.5</td>
<td>(0.7 - 9.1)</td>
<td>0.5</td>
<td>(0.2 - 1.5)</td>
</tr>
<tr>
<td>Improved (n=9)</td>
<td>2.3</td>
<td>(0.4 - 5.7)</td>
<td>0.9</td>
<td>(0.2 - 3.5)</td>
</tr>
<tr>
<td>Unchanged (n=2)</td>
<td>0.1</td>
<td>0.5</td>
<td>0.1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total talar translation in mm at 160 N.</th>
<th>Preoperatively (A)</th>
<th>20 months (B)</th>
<th>60 months (C)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>Range</td>
<td>Median</td>
<td>Range</td>
</tr>
<tr>
<td>Excellent (n=11)</td>
<td>4.4</td>
<td>(2.3 - 10.1)</td>
<td>3.0</td>
<td>(0.2 - 6.9)</td>
</tr>
<tr>
<td>Improved (n=5)</td>
<td>2.3</td>
<td>(0.4 - 5.7)</td>
<td>0.9</td>
<td>(0.2 - 3.5)</td>
</tr>
<tr>
<td>Unchanged (n=2)</td>
<td>0.7</td>
<td>1.1</td>
<td>0.1</td>
<td></td>
</tr>
</tbody>
</table>

62
Figure 19. Talar rotation in degrees (N=25 mean, SEM.) during manual adduction preoperatively and at 20 and 60 months. The left y-axis denotes talar adduction and internal rotation and the right talar plantarflexion. The talar tilt or the adduction was significantly reduced D-E $P=0.002$, D-F $P=0.003$ (Wilc.match). The plantarflexion was also reduced at the follow-up examinations A-B $P=0.03$, A-C $P=0.015$. (Wilc.match).

Figure 18. Talar translation in degrees at drawer tests 160 and 40 N., preoperatively and at 20 and 60 months (40 N n=22 and 160 N n=18 mean, SEM). A-B $P=0.007$, A-C $P<0.001$, B-C $p=0.02$. D-E $p=0.011$, D-F $p=0.001$ (Wilc.match.).
Most authors agree that operative treatment for chronic lateral instability of the ankle is indicated, when nonoperative treatment fails, especially in patients suffering from the disability during everyday life. In the present study (Paper I) a majority (22/37) of the patients still had residual symptoms 20 years after their initiation. Some could sprain their ankles or fall even while walking on flat ground. On the other hand, fifteen persons (17 ankles) with at least six months duration of instability (Paper I) displayed no remaining symptoms 20 years later, suggesting a possibility of "spontaneous" recovery.

Karlsson et al. consider nonoperative treatment the first option in CLI. They treated 100 patients with peroneal strengthening, ROM- and proprioception exercises and reported good or excellent results in half the cases, but had no untreated control group. On the contrary, Harper reported only three ankles of 14 with satisfactory results after conservative treatment.

Many authors refer to Harrington when claiming that CLI will eventually lead to osteoarthrosis of the talocrural joint. In the present study minor degenerative changes were found both in the patient group and the control group questioning the importance of CLI as an etiological factor in the development of secondary arthritis (paper I). Most of the patients (28/36) in the study by Harrington sought medical attention not only because of CLI, but primarily because of progressive pain. His material encounters a selection of patients indicating that general conclusions regarding the outcome of CLI could not be drawn.

Although mentioned by Bonnin in 1948, Freeman et al. draw attention to the importance of impaired proprioception as a cause of CLI. Later studies as well as the present (paper II) support the presumption, that impaired proprioception is associated with functional ankle instability.

The ligaments of the human body have previously been regarded as passive stabilizing structures. In 1865 Rauber described sensitive corpuscles in articular ligaments. The importance of the ligaments in the proprioceptive process was further shown by De Avila et al., who described the existence of mechanoreceptor innervation of the fibular collateral ligament in the human knee joint. Beard et al. found increased reflex latency in patients with unilateral anterior cruciate ligament deficiency indicating that the ligaments have several
functions in supporting joint stability. The sensation of angular displacement seems not only to depend on muscle-, tendon-, ligament-, and capsular innervation. Karlsson et al. suggested that tactile skin stimulus, e.g., from the taping the ankle contributed to shorter reaction times during sudden angular displacements.

The finding of longer IRT and unaffected CRT in the patients with CLI supports the theory that the immediate reaction to a sudden angular displacement of the ankle is impaired in patients with CLI. This response is conducted by the stretch receptors in the muscle-spindles. They are active in the monosynaptic reflex to the alpha-motor neurons, responsible for the postural tone. Gamma-motor-neuron activation of the muscle spindles heightens their sensitivity to stretch, by that augmenting the monosynaptic response. Via influence on the gamma-muscle-spindle system the joint nerve receptors may contribute to the regulation of muscle tone in posture. The functional joint stability is according to Djupsjöbacka influenced by the ligaments via the gamma-muscle spindle system. The low-threshold mechanoreceptor joint afferents do not cause reflex effects "directly" on the alpha-motor neurons but through the influence on the gamma-spindle system. The shorter reaction times in the control persons in the present study could thus be explained by a higher postural tone, which subsequently would result in a more rapid answer to a stretch stimulus. Physiotherapy might increase the "pretension" in the muscle-spindles and by that the muscular tone. This might explain the beneficial effect muscular strengthening and coordination training. However, in longstanding CLI or when there is a substantial mechanical instability the conservative treatment is usually not sufficient.

Many technical devices have been used to document talar mobility and ankle joint laxity. The talar tilt (TT) provoked by forced adduction (TT) varies considerably between different investigations. Rubin & Witten stated that TT in normal persons varied from 0° to 23° using a force of eleven pounds. Brand et al. reported TT 10° or greater in 14% of 175 healthy men tested manually. The upper limit for TT was 16° in a series of 404 manually tested ankles by Cox & Hewes. Karlsson used the TELOS apparatus and recorded a mean TT in functionally stable ankles of 3.2° (0° to 8°) in males and 4.3° (0° to 8°) in females. The corresponding values for the functionally unstable ankles were 10° in males and 11° in females (range 2° to 27°). In this Thesis no such limit identifying mechanical instability could be established. (Figure 20.)
Figure 20. Scatter diagrams showing manual adduction in degrees on the y-axis and talar translation at 40 N above and 160 N below. Squares (□) = ankles without symptoms, filled squares (■) = ankles with symptoms.
A torque about one axis may induce rotations about all three cardinal axes. For that reason Daniel et al. advocated unconstrained testing procedures. Rotations about all of the coordinate axes were observed also when a more constrained testing procedure was used in this Thesis to reveal varus instability. At the manual adduction performed with a minimum of constraint the talus rotated into plantarflexion and internal rotation, corresponding to the position of the ankle immediately before a sprain.

The loads used for measuring the ATT in the present study corresponded to the loads used in some previous studies. To obtain a standardized evaluation of the TT a constrained testing procedure with predetermined torque was added at the later part of this study. The correlation was $r = 0.75$ ($P < 0.001$, Spearman) comparing the manual ($5.7^\circ$) and constrained ($4.5^\circ$) testing procedures, but the talar adduction tended to be greater at the manual test. This finding may support the use of an unconstrained testing procedure. However, standardized tests using the same amount of load, applied at the same anatomical location and in the same the position of the patient would make comparisons between different studies more reliable. It would have been interesting to compare RSA results from the testing procedure used in the present study with those obtained using a TELOS apparatus. In this Thesis the use of simultaneous perpendicular exposures (biplanar technique) restricted the choice of methods to test varus instability due to limited space inside the cage and difficulties to radiographically visualize the markers on the lateral view. Using uniplanar technique would enable other RSA-examinations of the ankle (e.g. TELOS apparatus). However, it would also imply reduced accuracy of the measurement of anterior-posterior talar translations.

In the present study the actual skeletal translation, i.e., the distance between the starting position before loading and the position obtained during the loading procedure was measured. In most previous studies only the loaded position was recorded. The ATT was usually measured as the shortest distance between the tangent of the talar trochlea and the inferior-posterior corner of the distal tibia corresponding to a combination of anterior and distal translation. With this method the joint cartilage is included in the recorded translation. In other studies the method for obtaining the TT and the ATT is not mentioned.

When comparing the talar translations in the present study with others the width of the joint cartilage has to be considered. It has an average width of 3.1 mm (+/-0.6 mm) in normal ankles as well as in ankles with longstanding instability.
(Paper I). By the gravitational forces the tibia might have displaced slightly posteriorly in our setup, because the patient was supine resulting in a slight relative anterior talar translation in the starting position. These factors and probably also the lack of correction for magnification in previous studies could explain that the talar translations in our study were smaller than previously reported. By using the pre- to postoperative reduction in talar translation, differences in the technique of measurement can partly be compensated for.

In the patients with unilateral symptoms the side with instability displaced increased total talar translation at the preoperative examination compared to the opposite side when tested at 160 N, but not at 40 N (Paper VII). According to Frank et al.60 ligamentous tissues allow some joint displacement at relatively small loads but provides increasing resistance as the deformation increases. Decreased peroneal strength on the affected side could also explain this finding.

The scatter diagrams on the total talar translations preoperatively corresponding TT is shown in Figure 20. The more uniform scattering at 40 N might reflect that some patients have insufficient muscular strength to withstand the posterior load of 160 Newtons for four minutes. The negative TT values are probably caused by the position of the talus at the initial neutral position or its mobility pattern in the mortise. Contrary to the majority of ankles which displayed adduction at plantarflexion and positive TT, negative TT was associated with talar abduction at maximum plantarflexion

Mullins and Sallis137 considered widening of the ankle mortise to be a common but overlooked cause of CLI and advocated operative treatment to avoid recurrent sprains. For that reason investigation of the distal fibular mobility was included (Paper IV). Movements of the distal end of the fibula have previously been investigated using wires,8 steel pins,36 callipers74, computed tomography86 and roentgen stereophotogrammetric analysis.113,184 From plantarflexion to dorsiflexion of the ankle the average widening in healthy persons has been estimated at 1 mm corresponding to the results of the present study regardless of symptoms of CLI or not (paper IV). Thus, increased laxity as a cause of CLI, could not be demonstrated in the present study.

Subtalar instability has been suggested one of the causes to CLI19,34,47,104,111,105,156,163 but this is controversial.178 In vitro sectioning of the lateral ankle ligaments or the ligaments in the sinus and canalis tarsi has resulted in increased talo-calcaneal motions.33,81,104,105,121,147 In the present study(paper V) considerable talo-calcaneal joint motions were found, but no side-difference in patients with unilateral symptoms of instability. The recorded rotations were of
the same magnitude as in the control group. The pronounced rotations occurring in the subtalar joint imply that its functional stability depends mainly on other factors such as the strength of the lower leg musculature and a sufficiently short reaction time.

The preventive mechanism of external support is not completely known. Ankle taping, although a widely used and accepted method in the prevention and treatment of ankle sprains\textsuperscript{57,68,76,117}, loses some of its mechanical support after exercise\textsuperscript{75,117} whereas the orthosis does not. According to Glick et al.\textsuperscript{72} the advantage of taping is attributed to the stimulating effect on the peroneus brevis muscle. Although the external support has been documented to mechanically stabilize the ankle joint (paper VI) the tactile skin stimulus of the external support might considerably contribute to the prevention of recurrent sprains.\textsuperscript{98} The comparatively good results in the prospective studies\textsuperscript{138} might suggest, that not only the mechanical component of the support itself but maybe also regular follow-up occasions are important.

The clinical outcome of the surgical treatment in paper VII is comparable to previous studies reporting good or "excellent" result in 80 - 90\% of the cases although there are only a few studies with five years follow-up or more.\textsuperscript{28,78,96,109,173} None of them were strictly prospective.

Thus, studies that compare the preoperative and postoperative mechanical stability on long term basis are rare.\textsuperscript{93,101} In a retrospective study Milachowski and Wirth\textsuperscript{135} compared three different operative procedures for CLI. The talar tilt was reduced from 15° to 6-8° but they did not mention how the instability was measured. The reduction of ATT varied between 0.1 and 3.5 mm. In 21 patients they used a "ligament advancement" resembling our operative procedure and obtained 9.1° reduction in talar tilt and 3.5 mm reduction in anterior subluxation. However, the residual tilting was 6.1° and the anterior subluxation 8 mm indicating other testing procedures and/or a selection of patients with more pronounced mechanical instability.

In paper VII the talar total translations decreased between the two and five year follow-up when tested at 160 N, but not at 40 N. The muscle strength could have increased due to a feeling of improved stability and increased physical activity. Another explanation might be a continuous stiffening of the ligaments and the lateral capsular tissue, which is more easy to demonstrate at the higher loads.

The operative procedure used in paper VII addresses both the ATF and the CF ligaments. This is also recommended by others\textsuperscript{93}. By using this method there is no need for detailed anatomical dissection of the separate ligaments and no in-
creased risk of interfering with the innervation of the capsular and ligamentous tissues. Beside the discouraging long-term results found by Karlsson et al. wound healing problems, numbness and the formation of neuroma are frequently encountered in the "tendon operative procedures", because of the relatively extensive operative preparation. In the present study there was no complication related to the operative procedure.

In this Thesis patients with CLI were found to have a delayed muscular response to sudden angular displacement and often a mechanical instability in terms of increased varus angulation and translations of the talar center when examined under standardized conditions. Surgical treatment using ligamentous-periosteal technique resulted in improved function and mechanical stabilization lasting for at least five years.

In the future, further studies of the proprioception and its role in acute ankle sprains could contribute to the understanding of the development of CLI. Since the proprioception is impaired in patients with CLI it would be interesting to study whether reconstructive procedures influence the neuromuscular reaction to angular displacement.

Based on the present and previous studies the following recommendations regarding the treatment of chronic lateral instability of the ankle:

- physiotherapy for at least three months (peroneal strengthening, ankle disk exercises)
- external support (ankle bracing or tape) during the same period
- reconstructive procedure could be offered, using an anatomical method, if conservative treatment fails.
General conclusions

In patients with lateral instability as defined in this thesis of the ankle the following conclusions can be made:

- Three-dimensional motions of the talus, the fibula and the calcaneus could be measured with high accuracy at the different testing procedures using roentgen stereophotogrammetric analysis.
- Symptoms of chronic lateral instability of the ankle does not resolve spontaneously in 60% of the cases.
- Minor degenerative changes may be found after 20 years to the same extent as in a control group, but generally there no significant reduction of the joint space.
- Prolonged reaction time to sudden angular displacement, because of impaired proprioception, may be one of the causes to chronic lateral instability of the ankle.
- Increased adduction but not anterior talar translation was recorded in patients with chronic lateral instability of the ankle. In a subset of patients with unilateral symptoms increased total translation was found preoperatively on the symptomatic side.
- Anterior displacements of the distal fibula occurred during the anterior drawer tests regardless of symptoms of instability or not and may suggest remaining function of the lateral ligaments.
- Absence of lateral displacement of the fibula during the adduction test implies that there is no major insufficiency of the distal tibio-fibular syndesmosis in patients with chronic lateral instability of the ankle.
- Increased varus angulation of the talo-calcaneal joint (subtalar instability) in patients with chronic lateral instability of the ankle could not be verified in this study.
- The tested ankle brace (Strong®) significantly reduced talar and calcaneal varus angulation which supports its use in clinical practice.
- Tensioning of the lateral ligaments with the presented surgical procedure stabilized the ankle joint for at least five years without compromising the passive range of motion. This stabiliztion was associated with good patient satisfaction in a majority of cases.
I would like to express my gratitude to all those, who made this Thesis possible, especially:

My friend and tutor, associate professor Johan Kärrholm, always positive and encouraging who with great patience have guided me into science.

Lars-Åke Broström, professor at the Department of Orthopaedics, for valuable comments and constructive criticism.

Sven Friberg, associate professor and head of the Department of Orthopaedics University Hospital of Northern Sweden, for valuable comments and for reviewing the manuscript.

Sven-Ola Hietala, professor and head of the Department of Diagnostic Radiology, making his department available for my research.

Olle Ahlgren, associate professor, and co-author, who introduced the operative procedure studied in this Thesis.

My other co-authors, Gunnevi Sundelin, Department of Occupational health, Björn Lund, Department of Diagnostic Radiology and Arne Lundberg, Department of Orthopaedics, Huddinge Hospital.

Barbro Appelblad and Torsten Sandström at the RSA-laboratory and Department of Sports Medicine, Umeå, for measuring thousands of small markers.

My colleagues at the Department of Orthopaedics, for fruitful discussions and encouragement.

The staff at the Department of Radiology, who have helped me enormously through the study.

All the patients who willingly participated in the study.

Ulla-Stina Frohm for valuable help and practical advice.

My Mother and Late Father for the opportunities presented to me.

My dear family Eva, Karin, Per and Britta for their patience and understanding.

Financial support making the Thesis possible has been obtained from: Riksförbundet mot rheumatism, Swedish Medical Research Foundation, Svenska Läkaresällskapet, Funds at the Medical Faculty, University of Umeå, Forskningsrådet LIC, Ingabrit och Arne Lundbergs Stiftelse.
References


8 Ashhurst APC, Bromer RS. Classification and mechanism of fractures of the leg bones involving the ankle. Arch Surg 1922; 4: 54-129.


15 Bonnin JG. Injuries to the ankle. 1970; . Hafner Publishing, Darien, Conn. USA.


97 Karlsson J. Lansinger O. Lateral instability of the ankle joint (1). Non-surgical treatment is the first choice—20 per cent may need ligament surgery."Lateral fotledsinstabilitet (1). Icke-operativ behandling i forsta hand—20 procent kan krava ledbandskirurgi". (Swedish) Läkartidningen 1991; 88: 1399-1402.
115 Langstaff RJ. Handley CH. Functional ankle instability in members of the armed forces, the results of the extensor digitorum brevis transfer operation. Injury 1991; 22: 105-107.


129 Lundberg A. Milachowski KA. Wirth CJ. The result of reconstruction of the lateral ligaments of the ankle. Int Orthop 1988; 12: 51-55.


Petersson/Althoff -81, Karlsson -88
Ligament suture, imbrication

Sammarco -88
Peroneus brevis

Larsen -88
Peroneus brevis static

Larsen -88
Peroneus brevis, dynamic

Ahgren and Larsson -89
Tensioning ligament- capsular flap

Boszotta -89
Peroneus brevis

Dockery -89, -90
Free p.b., xenograft

Zwipp-90
Periost

Horibe et al. -91
Allogenic graft

Korkala -91
Peroneus brevis

Colville-92
Peroneus brevis

Gould -90, Hamilton -93
Lig. suture + ext. retin.
Editor: the Dean of the Faculty of Medicine