Kinematics of the distal tibiofibular syndesmosis

Radiostereometry in 11 normal ankles

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ABSTRACT **In 11 healthy volunteers, the normal kinematics of the tibiofibular syndesmosis of the ankle during weight bearing and external rotation stress were compared to a nonweight-bearing neutral position by radiostereometry. We found very small rotations and displacements in this "normal" group, which indicated that the fibula is closely attached to the tibia, thereby preventing larger movements at the level of the ankle. We found no common kinematic pattern during weight bearing in the neutral position.**

Application of a 7.5 Nm external rotation moment on the foot caused external rotation of the fibula between 2 and 5 degrees, medial translation between 0 and 2.5 mm and posterior displacement between 1.0 and 3.1 mm. These data can be used as normal reference values for studies of patients with suspected syndesmotic injuries.

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not be positioned in a reproducible way to measure radiologically subtle changes in syndesmotic width (McDade 1975, own unpublished data).

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

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

Patients and methods

Of 21 patients operated on for unilateral chronic lateral ankle instability between 1985 and 1992 at

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

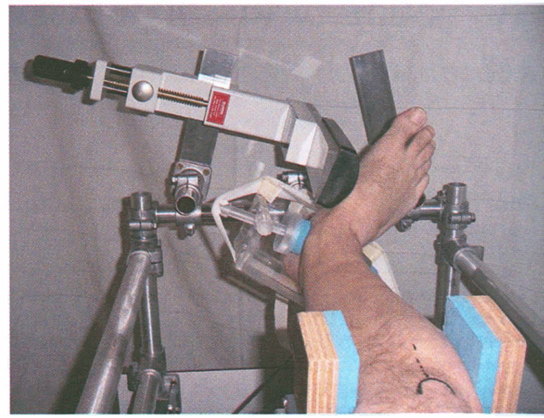

Figure 2. External rotation stress apparatus

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

We performed the RSA examinations in a standing position, using the uniplanar and biplanar technique (RSA Biomedical Innovation, Umeå, Sweden). In the standing position, 3 RSA examinations were done while the volunteers were placed on a pedestal that permitted simultaneous perpendicular exposures (Figure 1). First, with the ankle unloaded while slightly lifting the leg, which was still in contact with the floor ('neutral nonweight bearing'), then, with full body weight on the examined ankle that was kept in the neutral position ('neutral weight bearing'), and finally, with full body weight and maximal internal rotation of the leg, thereby creating an actively loaded external rotation exposure ('external rotation weight bearing'). With the volunteer in the supine position, the ankle was placed in a custom-made testing apparatus, in which external rotation stress could be applied with a common Telos device (Austin and Associates, Fallston, MD, USA), using Beumer et al.'s method (2003a). The ankle was exposed first in the neutral position ('neutral'), according to the zero starting position for the foot (American Association of Orthopaedic Surgeons 1965) and then with external rotation stress applied 5 cm distal to the center of rotation of the ankle (Lundberg et al. 1989), on the first

Table 1. Data of 11 volunteers with normal ankles

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

ROM range of motion (dorsiflexion/plantar flexion)

metatarsal bone, with a force of 150 N resulting in a moment of 7.5 Nm ('external rotation moment', Figure 2). All radiographs were processed and analyzed at Leiden University Medical Center, using RSA-CMS software (Medis, Leiden, The Netherlands). The error of calculation with this software has been assessed as about 0.11 mm and 0.24 degrees (Vrooman et al. 1998).

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

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

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

Statistics

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

Results

None of the syndesmotic stress tests was positive, nor did any volunteer complain of syndesmotic tenderness or irritation. In 3 volunteers, movement of the fibula during the fibula translation test was felt more than average. Since there was no pain or difference between the left and right ankles, this was considered to be normal. In 3 others, the anterior drawer test in the unoperated ankle was positive (Table 1).

Only 2 tali were excluded from analysis because of too high condition numbers—i.e., 148 and 246. The condition numbers for all other bony structures lay well within limits, so reliable translations and rotations could be calculated (Table 2).

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

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

Neutral weight bearing

We detected no recognizable patterns of fibular movement in relation to the tibia during neutral weight bearing, as compared to neutral nonweight bearing (Table 3). We found a correlation between the presence of hypermobility and posterior (r = 0.73, p = 0.01) as well as medial translation of the fibula (r = 0.78, p = 0.005) and external rotation of the talus (r = 0.92, p = < 0.001) during weight bearing. A positive anterior drawer test was shown to correlate with posterior displacement of the fibula (r = 0.62, p = 0.04).

All volunteers, except 1, loaded their ankle with the talus in internal rotation. There was a negative correlation (r = –0.934, p = < 0.001) between this internal rotation of the talus (max. 1.2 degree) and medial displacement of the fibula (max. 0.4 mm). None of the other clinical parameters, or foot positions recorded, affected the tibiofibular distance.

During neutral weight bearing, the rotation of the talus around the x-axis ranged from 11 degrees of plantar flexion to 1 degree of dorsiflexion. We found no correlation between this rotation of the talus and any of the fibular displacements during this test.

External rotation weight bearing

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

7.5 Nm external rotation moment

The external rotation moment around the longitudinal axis resulted, on average, in 3.9 degrees of external rotation of the fibula in relation to the tibia, as compared to neutral (Table 3). During this

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

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

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

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

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

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

Discussion

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

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

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

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

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

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

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

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

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

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

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