

Static and Dynamic Roentgenographic Analysis of Ankle Stability in Braced and Nonbraced Stable and Functionally Unstable Ankles

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ABSTRACT

Patients suffering from functional ankle instability were selected based on a structured interview. Talar tilt was measured using supine ankle stress roentgenographs and standing talar tilt was measured using erect ankle stress roentgenographs. A digital roentgenocinematographic analysis of a 50° ankle sprain simulation was performed to measure dynamic talar tilt and inversion distance between two video images (inversion speed). A significant decrease in pathologic supine talar tilt in unstable ankles was found in the braced compared with the nonbraced situation (talar tilt = 13.1° versus 4.8° with brace). The talar tilt with the brace after activity was still significantly lower than the initial value without the brace. The standing talar tilt of unstable ankles was shown to be significantly lower with the orthosis than without (standing talar tilt = 16.6° versus 12.0° with brace). Roentgenocinematographic evaluation of ankle sprain simulation showed that the mean dynamic talar tilt during simulated sprain decreased significantly in the braced ankles compared with the nonbraced ankles (dynamic talar tilt = 9.8° versus 6.4° braced). A significant decrease in the digital measurement of inversion distance (from 110.6 pixels to 92.4 pixels) was observed in the total sample of 39 ankles during the initial high-speed phase of the simulated sprain. The brace significantly slows down the inversion speed.

Controversy still exists concerning the influence of external support on stable and unstable ankles. It remains unclear whether external support can decrease tension on passive and active tissues to prevent trauma during an ankle sprain. Evaluation of the effectiveness of external support should include functional and dynamic studies of inversion movements comparable with those occurring during a sprain.

Ankle joint instability is probably caused by a combination of factors: joint hypermobility, muscle weakness, proprioception deficits (slow active reflex response), insufficient passive slowdown of sprain, and variability in ankle ligament anatomy.^{9,18,20,42,47} *Functional instability* is defined as the disabling loss of reliable static and dynamic support of a joint. This condition should be differentiated from *mechanical hypermobility*, which is only one possible cause of the functional problem. The disability can be described in terms of loss of mobility, strength, position sense, stability standing on the impaired ankle, capacity for detecting passive movement of the ankle, and reflex speed, along with functional impairments. The effect of external support should be documented by evaluating the different tissues and functions involved. Designs of sprain simulation protocols that reproduce controlled settings comparable with the trauma situation could help us to understand what occurs during ankle trauma and could lead to more effective prevention.

Based on a review of the literature, there are six unresolved issues in the study of how bandaging and bracing affect ankle mobility and function.

1. *Limiting Range of Motion.* Restriction of ankle motion by an external support such as ankle taping or bracing has been investigated in a series of studies.^{10-12,15,26,31,35,36,41,45} Static isometric and dynamic (running) supination were

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No author or related institution has received any financial benefit from research in this study. See "Acknowledgements" for funding information.

found to be reduced by ankle bracing and taping.^{24,39} However, it remains unclear whether ankle bandages and braces can prevent trauma. Therefore, patients with hypermobility or pathologic mobility should be used to evaluate more precisely the possibilities of external support in limiting extreme range of motion that could cause tissue lesions. Using stress roentgenograms and measuring talar tilt offers a method to evaluate the efficacy of braces and taping in limiting pathologic mobility.^{21,44,49}

2. *Muscle Strength Versus Reaction Time.* Paris and Sullivan,³² in 1992, showed no difference in eversion and inversion isometric strength using a handheld dynamometer when comparing the nonsupported ankle with the taped ankle and four types of ankle braces. However, it remains uncertain as to whether external support has a beneficial influence on the strength of the eversion movement. Recent research has shown that peroneal reaction time was a more discriminating factor than peroneal strength after ankle sprain trauma.²²

3. *Measurement of Joint Proprioception.* The effect of ankle bandages and different orthoses on ankle proprioception has been investigated using 1) active reproduction of a specific ankle joint angle after passive positioning of the foot and ankle,^{5,14,18} 2) detection of passive motion of the ankle using isokinetic equipment,⁸ and 3) stabilometric measurements evaluating equilibrium control.^{4,7,13,18,42,43} It was shown that bandaging and orthotic devices increased proprioception. The error in matching reference positions while actively reproducing specific ankle joint angles was significantly less with the orthosis than without.⁵ Joint position sense was shown to improve significantly in taped and braced stable ankles.¹⁴ Several studies registered deficient posture control in patients with functional instability when standing on the impaired leg.^{18,20,23,25} Scores for single leg stance, single leg jump, and angle reproduction were found to improve in braced stable and unstable ankles.^{13,18} In contradiction to the beneficial results cited above, Bennell and Goldie¹ concluded that there was a detrimental effect of external support on equilibrium. Postural sway increased in subjects who had their ankles taped or braced.

4. *Simulation of Ankle Sprain.* Over the last 10 years, different researchers have studied forced inversion of the foot and ankle in the functional position. With the subject standing on a platform, trapdoor mechanisms were used and muscular responses were measured during sprain simulations using different tilt angles. Most of the studies measured EMG response of the peroneal muscles during the simulation. Sprigings et al.³⁸ used trapdoor inversion of 30° to compare the ankle without external support with the wrapped ankle and taped ankle. They did not find any change in EMG activity of the peroneus longus muscle during the inversion. Konradsen and Ravn²² confirmed these findings. Assessment of ankle support quality in a test situation comparable with the high-speed and extreme range of motion during the actual traumatic ankle sprain has been performed over only relatively small tilt distances. Trapdoor mechanisms that were used did not exceed a 35° tilt angle.^{17,19,21,22,27,28}

5. *Use of Epidemiologic Studies.* An epidemiologic study comparing the effectiveness of taping and bracing in decreasing the number of ankle sprains during an American football season showed that the combination associated with the fewest injuries was low-top shoes and laced ankle braces.³⁴ A significant decrease in ankle injuries among braced ankles compared with nonbraced ankles was recently confirmed for ankle sprains in basketball players by Sitler et al.,³⁷ and in soccer players by Surve et al.⁴⁰ After an epidemiologic study of the frequency of ankle sprains during a soccer season ($N = 450$), Tropp⁴² stated that coordination training on an ankle disk improved functional stability and postural control. An orthosis provided mechanical support. Both techniques reduced the frequency of ankle sprains.

6. *Influence of External Support on Athletic Performance.* Performance may decrease when ankles are taped or braced,²⁹ and it has been shown that ankle taping decreases athletic performance more than ankle bracing.² However, Pienkowski et al.,³³ Macpherson et al.,³⁰ and Wiley and Nigg⁴⁸ found that athletic performance was not significantly inhibited by ankle bracing.

Our purpose was to improve understanding of the influence of ankle bracing on pathologic mobility during static stress tests and forced dynamic inversion of the foot and ankle. Furthermore, dynamic inversion in the standing position was used to analyze changes in the control of movement in nonbraced and braced ankles. This procedure will be referred to as sprain simulation.

MATERIALS AND METHODS

Using a structured interview (Fig. 1), we selected patients who had functional ankle instability. A functionally unstable ankle was defined as having at least one traumatic ankle sprain that needed immobilization followed by at least two recurring ankle sprains with complaints of pain and swelling for a minimum of 5 days or a feeling of instability after each ankle sprain (noncompensated instability). Exclusion criteria were a history of ankle fracture or documented cartilage lesions of the joints of the ankle, or knee or hip joint abnormalities. The sample was drawn from patients of the Orthopaedic and Traumatology departments of the Academic Hospital at the Vrije Universiteit Brussel. Control subjects, who were matched for age and sex, were selected from a group who had no history of complaints of any kind in the lower leg, nor any knee or hip problems that could influence the procedure. All participants signed an informed consent document. All patients indicated that they had no recent history of serious ankle sprain for at least 3 months before the testing was conducted.

Static Approach

Supine Talar Tilt. The pathologic mobility of the ankle, or talar tilt, was documented with standard EMG-monitored inversion-varus stress roentgenographs using an apparatus⁴⁴ that is an adaptation of the original design by

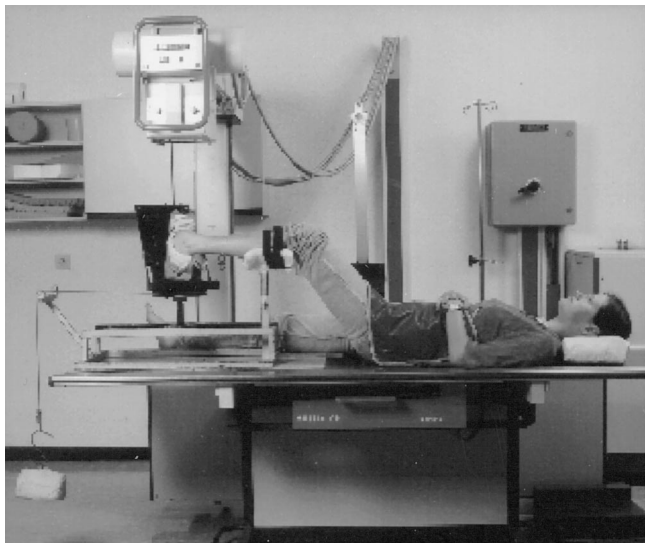


Figure 2. The Inman apparatus used to measure supine talar tilt.

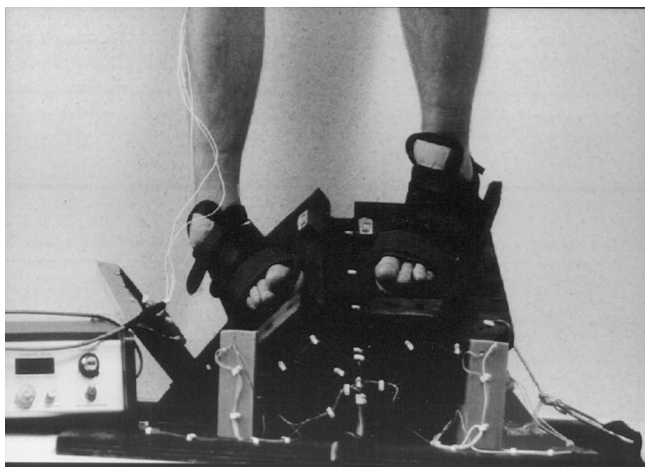


Figure 3. Sprain simulation platform used for the tests in the standing position. The ankle is in 40° of plantar flexion and the foot in 50° of inversion.

tients with ankle instability. The foot was placed in a sport shoe fixed on an inversion stress platform designed by the research group (see "Acknowledgments"). Inversion-varus AP stress roentgenographs were taken while EMG activity was monitored.

Standing talar tilt was measured during functional static evaluation in the standing position and under full body weight axial joint loading. Surface EMG was used to measure muscle activity in the peroneus longus muscle during the stress procedure. Muscle activity of the peroneus longus is higher in the standing position than in the supine stress test position. To avoid false-negative results due to muscle activity, only stress tests with muscle activity of less than 95 μV were accepted. Values greater

than 120 μV were shown to decrease standing talar tilt. Evaluations were performed without external support and again immediately after application of the ankle brace.

Fifteen of the 25 patients had sufficient muscle relaxation for the test to be valid. Fifteen control subjects, matched for age and sex, also underwent the standing talar tilt test.

Dynamic Approach

Dynamic talar tilt and inversion distances over periods of 40 msec were measured on roentgenocinematographic imaging to evaluate the influence of external ankle support during simulated standing sprain under axial joint loading. Twenty-four ankles were randomly selected from the 41 mechanically hypermobile ankles showing talar tilt. These ankles were evaluated without external support and again immediately after application of the brace. Fifteen stable ankles were used as controls. Imaging was performed using digital roentgenocinematography at 25 images per second. The analysis was performed with a digital roentgen apparatus designed for examination of vascular blood flow (Hicor and Awos, Angiographic Work Station, Siemens, Erlangen, Germany).

Evaluating video images of ankle sprain during sports competitions showed us that the ankle was in plantar flexion and the lower leg and foot were internally rotated just before the actual sprain occurred.⁴⁶ For this reason, the ankles were positioned in 40° of plantar flexion and 15° of internal rotation.

For testing, the subject stood on a custom-designed apparatus (Fig. 3). Both feet were tightly fixed on independently moveable trapdoors. One ankle was loaded with full body weight. Next, a sudden, unilateral inversion was carried out by dropping one trapdoor toward a 50° inversion angle. The inversion was launched without warning. The patients had earphones on and were listening to loud music so they could not hear the preparation noises of the trapdoor release. Because ankle sprain occurs unexpectedly, in the test situation a sudden onset with maximally relaxed muscles offers an approach to study passive and active control. Therefore, surface EMG of the peroneus longus muscle was used to ensure maximal relaxation of the ankle evorter at inversion. The test procedure was preceded by several repetitions of the sprain simulation so that control subjects and patients were equally prepared (trained) and able to learn how to relax. The simulation of 50° of inversion was found to be completely harmless. Ultimately the subjects and patients learned to put their full body weight on the leg and ankle, relaxing the peroneal muscles with the knee fully extended just before the sprain simulation occurred. Every ankle was tested a minimum of six times. Only tests with maximally relaxed

|| Our experience shows that in a standing subject in neutral ankle position, an average of 50 μV of muscle activity is present in the peroneus longus muscle. Shifting the body weight to one leg and slowly applying the inversion stress increases muscle tone to a level of 100 μV . When concentrated on, the peroneus longus muscle can be relaxed further to reach a mean value lower than 95 μV .

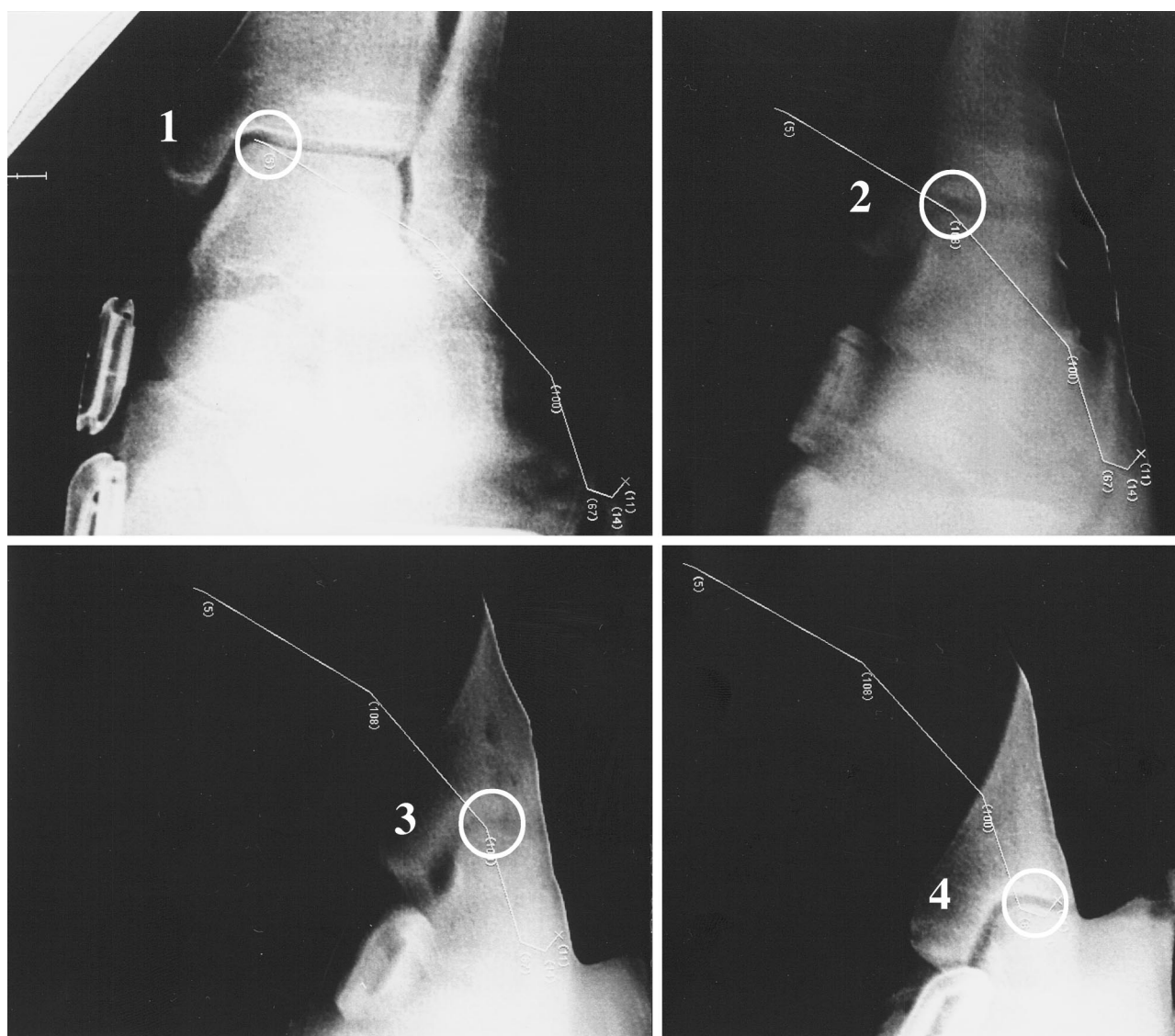
lower leg muscles were accepted. During sprain simulation several parameters were recorded.

Dynamic Talar Tilt. The dynamic talar tilt was measured in the functional standing position and during a 50° "free fall" sprain simulation (Fig. 3). This simulation dynamically evaluates the external ankle support. After training for the procedure, the first six repetitive simulations were performed without external support, followed by six simulations of the braced ankle, or vice versa (randomized order).

Inversion Distance. The inversion distances per 40 msec can be measured on the roentgenocinematographic film (Fig. 4). This is made possible by digitizing the video and measuring (in pixels), from one image to the next (at 40-msec intervals), the inversion distance of the shift from a reference point on the medial talar trochlea (Fig. 5).

Five inversion distances were measured (v1 to v5) during five consecutive video images at 40 msec intervals.^a These distances give information about the passive and active control and limitation of speed during the sprain simulation. Short distances indicate functional control of the inversion. Long distances indicate that the inversion is less controlled. The sprain simulation was used only if the inversion was unexpected and with sufficient relax-

^a It should be noted that distance v1 gives no reliable information because the instant of the departure of the inversion cannot be exactly synchronized with the film speed because of the high-speed movement. Video is not continuous; there is only one snapshot every 40 msec. It is impossible at present to reach full simultaneity between the exact start of the inversion and the electromechanically controlled video images. Therefore, synchronization between roentgenocinematography and sprain simulation can only be achieved if the film is running at the moment the inversion starts.



ation of the peroneal muscles (surface EMG signal less than $95 \mu\text{V}$). If the first image showed 40 pixels or more of inversion distance, the sprain simulation was excluded. This was arbitrarily chosen so that not more than 12% (40 of a total of 330 pixels) of the total inversion distance was lost for evaluation.

Before measuring the effects of external support using this procedure, the measurement method was validated by testing its reproducibility on a digitized roentgenograph and by evaluating the reproducibility of the sprain simulation. The measurement procedure on the digitized roentgenograph was tested for errors and shown to be reliable. The evaluation of the reproducibility of the measurements was performed by repeating measurements on the roentgenographs of 15 sprain simulations. Every inversion was measured twice. This procedure showed a high intraclass correlation coefficient ($r = 0.96$ to 0.98).

The ankle sprain simulation was also shown to be reproducible. The inversion distances (v2, v3, v4, and v5) of two consecutive sprains of the same ankle were not significantly different, with r ranging from 0.92 to 0.96. Reproducibility of the inversion distance measurement in a control sample ($N = 15$) during two consecutive sprain simulations of the same ankle was excellent (Table 1). Because of the high speed of the sprain simulation (>450 deg/sec) some of the ankles had already ended the inversion during the fourth image (v4) (this also explains the constant v5). Therefore the results of v4 and v5 are not reliable.

Statistical Analysis

Within-group comparisons were made with a paired t -test between the sprain distances in braced versus nonbraced situations, both in the unstable ankles and in the control ankles. Reproducibility of the measurements was calculated with the intraclass correlation coefficient after a paired analysis of variance (ANOVA) between successive simulations of the nonbraced control ankles.

RESULTS

Static Approach

In the supine study of the 117 functionally unstable ankles (selected using the structured interview), 41 (35%) showed mechanical hypermobility with a minimum of 7° of talar tilt. Thus, subjects from this group of 41 ankles were used in several tests to evaluate the influence of external support. Talar tilt in the control sample of stable ankles ($N = 15$) was less than 3° , which is significantly different from the mean talar tilt of 13.1° seen in the group with hypermobility.

Supine Talar Tilt. The results of the supine roentgenographic ankle stress study of the 41 unstable ankles comparing braced and nonbraced ankles showed a significant ($P < 0.001$) decrease of talar tilt in the braced ankles (Table 2). The brace decreased pathologic talar tilt from 13.1° to 4.8° (example in Fig. 6). This is a significant ($P < 0.001$) decrease of 63.3% of the original hypermobility.

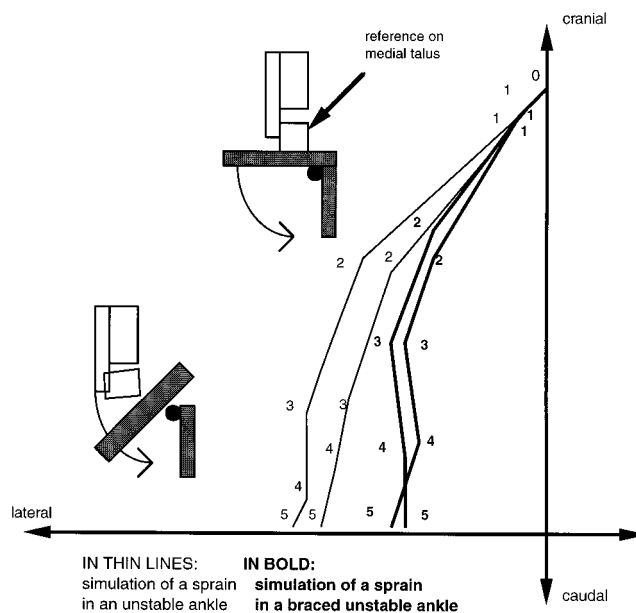


Figure 5. Examples of digital plotting of ankle sprain simulation in an unstable ankle without external support and an unstable braced ankle (bold lines). The curves were plotted using the reference point on the medial border of the trochlea tali (arrow). Zero is the starting point, point 1 follows 40 msec of inversion, and points 2 to 5 at 40-msec intervals. Note the large inversion distance, measured in pixels, from point 1 to point 2 (v2) in the nonbraced ankle (thin lines) compared with the braced ankle (bold lines).

Supine Talar Tilt After Activity. For the 25 patients with hypermobility who participated in the 30-minute activity program, after exercise the brace decreased pathologic talar tilt of 13.9° to 6.28° . This is a significant ($P < 0.001$) decrease of 62% of the original hypermobility and reduced the mean talar tilt to below 7° , which is the upper limit of talar tilt seen in a stable population.¹⁶ The comparison between the randomized subsample of 25 braced unstable ankles before and after the 30-minute activity program demonstrated that the significant correction was maintained after activity. The standard deviations were also lower in the braced samples. The application of the brace appears to reduce the interindividual range of mechanical ankle hypermobility. Although the talar tilt measured with the brace after exercise was larger than that with the brace before exercise, the difference was not significant ($P > 0.10$).

Standing Talar Tilt. Stress roentgenographs were also performed with the patient in the standing position. Fifteen patients with unstable ankles showed sufficient relaxation of the peroneal muscles during the procedures. Standing stress roentgenographs were also taken with the ankle braced. The control sample ($N = 15$) did not show an increase in talar tilt between the supine and the standing tests; it remained less than 3° . The patient mean standing talar tilt was 16.6° , compared with 13.1° talar tilt in the

TABLE 1
 Reproducibility of the Inversion Distance Measurement (Distance Unit is Pixels) in a Control Sample ($N = 15$) During Two Consecutive Sprain Simulations of the Same Ankle

Inversion distance	Simulation		Reproducibility		
	1 (mean \pm SD)	2 (mean \pm SD)	F	P	r
v2	118.0 \pm 22.7	118.8 \pm 23.5	0.070	0.795	0.96
v3	87.3 \pm 23.2	88.0 \pm 23.5	0.022	0.885	0.94
v4	46.9 \pm 10.2	52.1 \pm 10.2	5.473	0.058	0.92
v5	27.5 \pm 13.6	25.6 \pm 13.0	0.009	0.929	0.96

TABLE 2
 Comparison of Supine Talar Tilt in Unstable Ankles ($N = 41$) Between Braced and Nonbraced Conditions and in Unstable Ankles that Participated in the Activity Program

Talar tilt conditions	N	Condition		Paired <i>t</i>	df	P
		1 (Mean \pm SD)	2 (Mean \pm SD)			
All nonbraced vs. braced	41	13.09° \pm 6.20°	4.78° \pm 3.27°	9.99	40	<0.001
Unstable nonbraced vs. braced	25	13.88° \pm 6.49°	5.26° \pm 2.80°	7.35	24	<0.001
Braced vs. postactivity braced	25	5.26° \pm 2.80°	6.28° \pm 3.55°	-1.70	24	0.103
Nonbraced vs. postactivity braced	25	13.88° \pm 6.49°	6.28° \pm 3.55°	7.12	24	<0.001

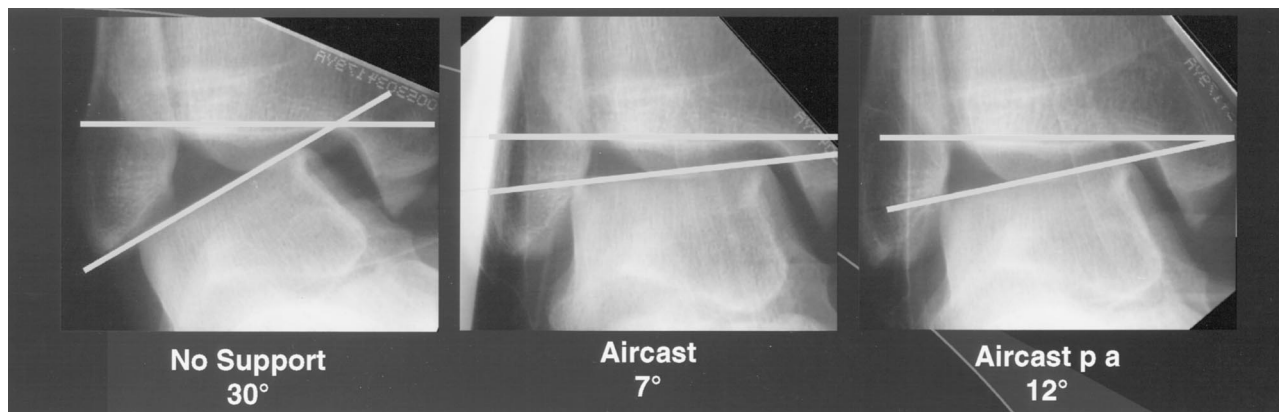


Figure 6. Influence of the ankle brace on a mechanically hypermobile ankle tested using supine inversion stress and AP roentgenographs on the Inman apparatus shown in Figure 1. The talar tilt was 30° without brace and 7° with brace. Postactivity (pa), the talar tilt was 12° (mean values in Table 1).

supine test. The ankle brace decreased pathologic standing talar tilt from 16.6° to 12° (Table 3), a significant ($P < 0.01$) decrease of 28%. Note that the influence of the same brace in the supine position showed a decrease of more than 60% of the talar tilt measured without external support (Table 2).

Dynamic Study

Dynamic Talar Tilt. In the dynamic test during sprain simulation, dynamic talar tilt was measured in a subsample of 24 mechanically hypermobile ankles with functional instability and compared with a control sample of 15 stable ankles. Stable ankles did not demonstrate dynamic talar tilt. Only 10 of 24 mechanically hypermobile ankles showed dynamic talar tilt (Table 3). The comparison between the dynamic talar tilt of the nonbraced and the braced hypermobile ankles revealed a significant de-

crease in dynamic talar tilt with the brace ($P < 0.01$). Dynamic talar tilt was reduced from 9.8° without the brace to 6.4° with the brace. The results of the talar tilt measurements in the supine test compared with the dy-

TABLE 3
 Standing Talar Tilt ($N = 15$) and Dynamic Talar Tilt ($N = 10$) in Unstable Ankles With and Without External Support^a

Talar tilt condition	Mean \pm SD	Paired <i>t</i>	df	P
Standing Nonbraced	16.60° \pm 8.35°	3.81	14	<0.01
Braced	11.97° \pm 4.85°			
Dynamic Nonbraced	9.75° \pm 2.87°	3.83	9	<0.01
Braced	6.40° \pm 1.45°			

^a Only tests with relaxed peroneal muscles were accepted.

dynamic test situation in these 10 patients, both with and without the brace, showed lower values for the dynamic talar tilt.

Inversion Distance. Every ankle was inverted six times without the brace and six times with the brace. For every ankle, four simulations were selected (two nonbraced and two braced) based on good relaxation of muscles just before the simulation and correct synchronization between the start of the simulation and the roentgenocinematographic registration. The distance inverted per 40 msec in the high-speed phase of the inversion was shorter in the braced ankles than in the nonbraced ankles in the control sample of 15 ankles (Table 4) and in the mechanically hypermobile sample of 24 ankles (Table 5).

In the control sample, during both first and second sprain simulation a significant decrease of the inversion distance v2 was observed in the braced ankles compared with the nonbraced ($P < 0.001$ and $P = 0.002$, respectively). The significant decrease in inversion distance with the brace for the third inversion distance found in the first simulation ($P = 0.02$) was not confirmed in the second simulation ($P = 0.157$).

In the unstable ankles, during both first and second sprain simulation a significant decrease of inversion distance v2, and thus a slowing down of the inversion speed, was measured in the braced ankles compared with the nonbraced unstable ankles ($P = 0.002$ and $P = 0.011$). This was not found for the inversion distance v3 during the first sprain simulation ($P = 0.209$). In repeating the sprain simulation, the inversion distance v3 was significantly decreased by the brace ($P = 0.016$).

Calculating the influence of the ankle brace for the total population of stable and unstable ankles ($N = 39$), the influence on inversion distance during v2 was significant. The decrease in the digital measurement of inversion distance (from 110.9 pixels in the nonbraced to 92.4 pixels in the braced) for all ankles was observed during the initial high-speed phase of the simulated sprain.

DISCUSSION

Although not the focus of this study, the criteria used to clinically define ankle instability should be understood. In

TABLE 4

Comparison of the Inversion Distance (in Pixels) in 40 msec Between the Control Ankles ($N = 15$) and the Braced Control Ankles ($N = 15$) During Sprain Simulation in the High-Speed Phase (Inversion Distances v2 and v3) and for Two Consecutive Sprain Simulations

Sprain distance	Control (mean ± SD)	Control braced (mean ± SD)	Paired <i>t</i>	<i>P</i>
Simulation 1				
v2	118.0 ± 22.7	95.4 ± 18.6	6.06	<0.001
v3	87.3 ± 23.2	74.8 ± 21.2	2.61	0.020 ^a
Simulation 2				
v2	118.8 ± 23.5	99.6 ± 20.5	3.98	0.002 ^b
v3	88.0 ± 23.5	80.7 ± 13.5	1.49	0.157

^a $P < 0.05$.

^b $P < 0.01$.

TABLE 5

Comparison of the Inversion Distance (in Pixels) in 40 msec Between Unstable Ankles ($N = 24$) and Braced Unstable Ankles ($N = 24$) During Sprain Simulation in the High-speed Phase (Inversion Distances v2 and v3) and for Two Consecutive Sprain Simulations

Sprain distance	Unstable (mean ± SD)	Unstable braced (mean ± SD)	Paired <i>t</i>	<i>P</i>
Simulation 1				
v2	106.0 ± 27.0	90.5 ± 18.4	3.60	0.002 ^a
v3	82.3 ± 17.2	77.0 ± 19.2	1.29	0.209
Simulation 2				
v2	109.0 ± 20.8	96.5 ± 20.4	2.76	0.011 ^b
v3	85.5 ± 18.8	78.4 ± 18.8	2.60	0.016 ^b

^a $P < 0.01$.

^b $P < 0.05$.

the samples selected for this study, the structured interview (Fig. 1) was used to identify functional instability. Mechanical hypermobility was found in only 41 of 117 selected unstable ankles. Furthermore, a differentiation between compensated unstable ankles and noncompensated unstable ankles is proposed in Figure 1. This selection is based on the traumatizing effect of repeated ankle sprains in functionally unstable ankles. Some unstable ankles frequently sprain without further complaints (compensated), while others show swelling and pain for several days after repetitive spraining (noncompensated). If all of these are studied together in one sample, differences between stable and unstable ankles tend to disappear. This is probably because of the functional correction that prevents minor injury in the compensated unstable ankles.

Concerning the influence of external support on *mobility* versus the influence on *pathologic mobility*, it should be emphasized that if the brace is designed to prevent injury, the quality of the external support should be tested using the traumatizing mobility, this is a tilting of the talus sufficient to rupture the lateral collateral ankle ligaments. Surface EMG is sufficient to verify muscle relaxation in the foot evertors to make sure the standard stress roentgenographs are valid and reproducible.⁴⁴

During static and dynamic stress tests the foot and ankle were placed in the plantar flexion position because the mechanism of ankle sprain injury is thought to be an inversion of the ankle in a plantar flexed position.³ Furthermore, plantar flexion offered a direct view in the talocrural joint space, showing parallel joint surfaces in the neutral (inversion/eversion) position in the frontal plane.

The pathologic rotation of the talus increases when measured while standing, so this is the more functional position. We used EMG measurement of peroneus longus muscle activity to quantify the influence of muscle activity during equilibrium control in the standing position, and the roentgenograph was taken at the moment of the lowest peroneal activity.

The results of the comparison between the traditional supine and the standing roentgenograph stress studies of

ankles tested with and without external support show more decrease of talar rotation when the braced ankles are tested in the supine position. Here muscle relaxation is better and the 15-kg load inverting the ankle is less important than the total body weight placed on the ankle in the standing position.

As Fielding et al.⁶ reported for ligaments of the cervical spine, one should be aware that joint stress at high speed, like during ankle sprain, has a completely different effect on the joint capsule and ligaments compared with the slow stress of the stress roentgenographic examination. It is therefore important to examine dynamic inversion movements to determine whether external support has a measurable influence during simulated sprain.

The new parameter in this study, dynamic talar tilt, presents information that probably comes closer to the real life situation than do supine and static studies. Dynamic talar tilt is inferior to standing and supine talar tilt, presumably because of the high resistance of the collagen tissue of joint capsule and ligaments during high-velocity dynamic stretch compared with the slow static elongation. This dynamic talar rotation shows a significant decrease when measured during sprain simulation with a brace. This offers proof of the immediate influence of the external support in the dynamic phase of the movement.

When measuring the influence of external support on mobility, one should be aware of the fact that 60% of functionally unstable ankles do not show pathologic talar tilt ($>7^\circ$ talar tilt left/right comparison, or $>15^\circ$ of talar tilt unilaterally).^{42,44} Other outcome measures should therefore be used to evaluate the influence of external support on proprioception deficits measured in unstable ankles. Using change in the speed of inversion as a criterion to study influence on sprain simulation of soft tissue (such as ligaments, fascia, and muscles) or bandages and braces, offers information on the physiologic course of (simulated) traumatic sprain and on effective solutions to prevent trauma.

Slowing down the speed of inversion by using ankle braces may create more time for muscle intervention. Muscles will have more time to effectively protect cartilage, joint capsule, and ligaments of the ankle. Research published by Isakov et al.¹⁷ and Johnson and Johnson,¹⁹ however, claims that muscle intervention is too slow to control ankle sprain. This statement is clearly countered by our findings of accelerometric and EMG analysis of simulated sprain.⁴⁶

Sprain simulation in stable ankles shows inversion distances from 40 to 80 msec that are significantly larger—this is during the initial, high-speed phase—than for the same ankle with the ankle brace. The brace significantly decreased the distance an ankle inverts over a 40-msec period during the initial high-speed phase (distance v2) of the ankle sprain simulation.

There was a measurable slowing down of the inversion in stable braced ankles compared with nonbraced ankles. Note that during the v2 inversion distance over a period of 40 msec, this is from 40 to 80 msec after the start of the inversion, about 40% of the complete distance of 50° is inverted. This v2 inversion distance offers information

about the passive or active control of the free fall during the sprain simulation.

In controlling the reliability of the procedure by analyzing a second sprain simulation, the third inversion distance, v3, was not always shown to be significantly decreased in the braced ankles. This may be due to the fact that in some of the ankles the foot has already landed at the end of the v3 distance, at about 120 msec after the start of inversion. This is confirmed by accelerometric measurements of sprain simulation on the same platform in another study of our group showing a mean of 109 msec as total inversion time in unstable ankles.⁴⁶ The significant decrease in inversion distance with the brace for the third inversion distance found in the first simulation was not confirmed in the second simulation ($P = 0.020$ and $P = 0.157$), possibly because of active muscle interference during the period from 80 to 120 msec after start of the inversion. The third inversion distance, v3, was shown to be less accurately measurable than the second inversion distance, v2. As was stated before, muscle reflex activity can be present during the 80 to 120 msec period after the start of inversion. This is from 30° to 50° of the sprain simulation. It may be the reason why the inversion distance v3 varies more than the second inversion distance. However, muscle activity related to changes in inversion distance per 40 msec during the sprain simulation was not examined in this study.

Finally, for future research, it is essential to determine if the support prevents early imbalance that puts the ankle in a potentially traumatic position before the impact of the body weight that could cause rupture of the ankle lateral and soft tissue supports.

Sprain simulation in unstable ankles revealed inversion distances from 40 to 80 msec that were significantly larger (this is during the initial, high-speed phase) compared with the same unstable ankles with the ankle braced. The brace decreased the distance an unstable ankle inverts during this 40-msec period. A possible slowing-down of the inversion in v3 by the application of the brace was confirmed in only one of the two simulation procedures. There was a measurable slowing-down of the inversion in braced unstable ankles compared with nonbraced unstable ankles. If the inversion speed can be decreased, the traumatic effect on passive soft tissue will be lessened and active intervention to prevent lesions can be facilitated.

CONCLUSION

Using the following parameters, talar tilt, standing talar tilt, and dynamic talar tilt, a static supine, static functional, and dynamic evaluation of the influence of an ankle brace can be performed. We have shown that valid, that is, reproducible and accurately measurable, analysis using roentgenographic procedures can offer objective proof of the influence of ankle braces on pathologic rotatory mobility of the talus in static, functional, and dynamic testing procedures. Evaluating the total sample for changes in sprain distance during the high-speed phase of the simu-

lated ankle sprain, a significant decrease in sprain distance, and thus in sprain speed, was measured in braced ankles, showing that the brace slowed down the simulated sprain. We demonstrated that it is necessary to study sprain simulation that surpasses 40° of sprain movement to measure muscle intervention during the final phase of extreme ankle inversion. There has recently been a clear evolution in research analyzing joint sprain and physiologic control of the inversion movements. This work offers information that may stimulate new designs of external support for joints and these supports may be more effective in preventing joint strain.

ACKNOWLEDGMENTS

The authors express their gratitude to Dr. Ph. De Wilde and M. Terrière of the Angiology Department and to Lieve Merckaert and Renaat Van den Broeck of the Medical Imaging and Radiology Department for their assistance in the acquisition of the medical imaging. We also thank Geert Van Rossen for the assistance in the construction of the sprain simulation platform and Dr. Alan Martin, University of British Columbia, Canada, for his critical advice and text corrections.

This research was funded by the Research Council of the Vrije Universiteit Brussel (OZR No. 20363) and supported by the Aircast company.

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