ACTA ORTHOPAEDICA et TRAUMATOLOGICA TURCICA

Acta Orthop Traumatol Turc 2010;44(5):365-377
doi:10.3944/AOTT.2010.2248

Evaluation of the lateral instability of the ankle by inversion simulation device and assessment of the rehabilitation program

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Objectives: To assess the correctibility of the muscle atrophy, proprioceptive loss, and slowing of the reflex arc around the ankle after ankle sprain with rehabilitation.

Methods: The study group consisted of 20 cases with chronic instability who had at least two episodes of ankle sprains (mean 20.6 years, range 16-32 years); control group consisted of 20 patients with same demographic characteristics but without instability. Isokinetic muscle strength measurements and proprioceptive evaluations were made using the Cybex device before and 1.5-month after rehabilitation period. Additionally, the inversion simulation device, which was developed together with the mechanical engineering department of our university, was correlated with the EMG device, and response periods of muscles to stimulation were measured.

Results: The proprioceptive loss present in all cases with ankle instability before treatment significantly improved after effective rehabilitation (p=0.001). It was detected that lengthened peroneal latent periods shortened with effective rehabilitation (p=0.001). Cross-interaction of rehabilitation was shown with the preservation of the difference between the pathologic and normal sides regarding proprioception and peroneal latent periods before and after treatment, without any difference between the control group and the pathologic sides.

Conclusion: After ankle sprains, especially in patients with chronic instability, strengthening of the muscles around the ankle with well-planned proprioceptive exercises helps the patients return to normal living and sports activities, and prevents unnecessary surgery, especially in cases with functional instability.

Key words: Ankle instability; functional instability; muscle power; proprioception; rehabilitation.

Currently, ankle injury is the most common sports injury and a very important problem affecting many people.[1-9] Despite the high incidence and the important morbidity potential, there is still no commonly agreed standard treatment for ankle injuries. While many patients can be treated with conservative treatment methods, ankle injury has been reported to cause late symptoms that can lead to various problems in 20% to 40% of patients.[10-13] Smith and Reichl[9] conducted a study in which this rate was found to reach 50% among basketball players; 15% of these athletes reported that this led to decreased performance.

Generally, the approach towards chronic ankle pain is not adequate; specific problems are not cor-

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Submitted: March 24, 2009 **Accepted:** September 8, 2009

rectly diagnosed, and appropriate diagnostic equipment is often not available.[14] Therefore, most patients with ankle problems are accustomed to their current condition and continue their lives by limiting their activities.

In order to prevent ankle sprains in patients with chronic ankle instability, we tried to answer the following questions: Which muscles contract first? What can be done to shorten the latent period of that muscle? Is there any cross-interaction after rehabilitation? Many previous studies in literature tried to answer these questions.[15-22] In the present study, we also studied these questions using inversion simulation device developed by us, and evaluated the cross-interaction during rehabilitation.

Patients and methods

Twenty patients referred to the Orthopedics Clinic by the Trainers Association between March 2005 and April 2006 were included in the study. Patients enrolled were those with a history of traumatic ankle injury followed by recurrent (2 or more times) ankle problems including pain and swelling (≥3-4 days) followed by a sense of ankle instability. All patients had injuries that occurred more than 3 months prior to the study. Informed consent was obtained from all patients.

Five patients were female, 15 were male. The age range was 16-32 years, and mean age was 20.6 years. Each patient had presented with the same set of complaints: pain, frequent sprains, and sense of instability. Complaint duration varied between 6 months and 4 years, with a mean complaint duration of 15 months. Each patient had experienced major inversion injury at least twice. Eight patients had a history of two serious injuries; eight had suffered three injuries; and four patients had experienced four or more serious injuries. Major ankle injury had occurred during sports in 14 patients (soccer), ballet in one patient, after an accident in one patient, and while running in four patients. Seven patients did not remember having treatment; eight had received elastic bandage; one had elastic bandage + nonsteroid anti-inflammatory drug (NSAID); two had splint and cold compression; one had İlomedin® + bandage; and one had an ankle band (Table 1). Our study comprised patients with unilateral chronic ankle instability who had no history of receiving rehabilitation for ankle instability. Cases with a history of ankle fracture, documented cartilage lesion, or hip or knee problem, were excluded from the study. The control group comprised cases that were consistent with the study group in terms of age, height, and gender. Patients with a history of ankle fracture, documented cartilage lesion, or hip or knee problem were excluded from the control group, as well. After the initial assessment, forms including the following parameters were filled out for patients who had been determined to have instability, to maintain a regular follow-up and standardization:

1. Demographic data of patients (age, gender, height, weight, dominant extremity) (Table 1)
2. Medical history (injury type, presence of ecchymosis in the anterolateral aspect during the injury, treatment)
3. Sports activity scoring for determination of the activity level (Table 2). This score was 3 in 14 patients, 2 in four patients, and 1 in two patients.
4. Sprain frequency scoring (Table 2) Minor ankle sprains were included in the assessment, as well. Eight patients had a score of 3; five patients had a score of 2; and three patients had a score of 1.
5. Physical examination notes (edema, joint range of motion, anterior drawer and talar tilt tests, tenderness localization, and impingement test).
6. Score on functional scale defined by Povacz et al.[23] to identify the notion of functional instability (Table 3). At the end of the assessment, two patients were found well, whereas 18 were found poor in condition. The distribution of the scores was as follows: one patient 9 points, one patient 10 points, one patient 13 points, three patients 15 points, five patients 19 points, seven patients 20 points, and two patients 21 points.
7. In radiological assessment, reliable and standardized stress radiography was performed to differentiate mechanical and functional instability among patients following the routine ankle films. For this purpose, antero-posterior and lateral stress films were obtained by the Telos stress device.
8. Patient satisfaction scores were recorded (Score 3: excellent, 2: good, 1: same, and 0: poor satisfaction).

Table 1
Demographic and clinical data of patients

Patient no	Name	Age	Gender	Side	Dominant side	Treatment	Duration of symptoms	The number of sprain	Povacz scoring	Injury mechanism
1	AK	24	M	R	R	Bandage	1 year	3	9	Soccer
2	FB	30	F	L	R	Bandage+NSAID	3 years	5+	20	While running
3	MG	18	M	L	R	Splint	1 year	3	13	Soccer
4	GT	31	F	L	R	Bandage	4 years	5+	15	Ballet
5	OG	23	M	R	R	None	2 years	2	20	Soccer
6	HC	18	M	R	R	None	1 year	5+	15	Soccer
7	HT	27	M	R	R	None	1 year	2	20	Soccer
8	HÇ	18	M	R	R	None	1 year	2	20	Soccer
9	CK	28	M	R	R	Bandage	1.5 year	3	21	Soccer
10	RÇ	16	M	R	R	Bracelets	6 months	2	21	Soccer
11	MB	28	M	L	R	None	1 year	3	20	While running
12	SD	21	M	L	L	Bandage	8 months	2	19	Soccer
13	AK	29	F	L	R	None	2 years	4+	15	While running
14	OG	17	M	R	R	Splint	6 months	3	19	Soccer
15	FD	18	M	R	R	Bandage	1 year	3	10	Soccer
16	BP	32	F	R	R	Bandage	8 months	2	20	While running
17	HÖ	18	M	R	R	Bandage	1 year	2	19	Soccer
18	SZK	18	M	L	L	Bandage	6 months	2	19	Soccer
19	EŞ	21	F	L	R	Iliomedin+bandage	8 months	3	20	Accident
20	AE	21	M	L	R	None	1 year	3	19	Soccer

M: Male, F: Female, R: Right, L: Left, NSAID: Nonsteroid anti-inflammatory drug.

Proprioceptive assessment with Cybex

Prior to the treatment, by consulting Physical Medicine and Rehabilitation Department, each patient was evaluated with Cybex device for proprioceptive sense and inversion-eversion muscle strength based on the joint position sense protocol. Ankle proprioception was evaluated with isokinetic dynamometer (Cybex Norm). Patients assumed a supine position with the hip and knee at flexion (80-110°). Proprioception was measured with ankle eversion at 20°, 10°, neutral 0°, and inversion at 10° and 20°. The person performing the measurement positioned the ankle at the predetermined angle and held at that angle for 10 sec. Then the patient was asked to position the ankle at the same angle again. Two measurements were carried out at both angles, and the values mentioned by the patient were noted. During the measurement, the eyes of the patients were covered with a sleep mask.

Following the proprioception measurement of each patient, inversion and eversion strength of the ankle was assessed with isokinetic dynamometer. Isokinetic muscle strength was evaluated 5 times at 60°/sec and 10 times at 150°/sec. Proprioception and muscle strength measurements were performed by first examining the healthy side and then the affected side by the same person. Those values were repeated after a treatment of 1.5 months.

Stress radiography

The Telos stress device was used for performing standard ankle stress radiography (Fig. 1a-d). The following values were measured with stress radiography: talar tilt angle, medial clear space, and tibiofibular clear space.

After radiological assessment, patients with instability were split into 2 groups according to the type of the instability: the mechanical instability group and the functional instability group. During the differentiation, talar tilt angle was used as a criterion. A unilateral talar tilt angle >10° or presence of a difference >3° in the comparative radiography, demonstration of an anterior translation >10 mm, and difference >3 mm in comparative radiography were considered significant in terms of mechanical instability. Of the 20 patients in the study, eight had mechanical instability and 12 had functional instability. In comparison of normal and affected sides on anteroposterior films of the cases demonstrating mechanical instability, 1° difference was found in one patient, 5° difference was found in three patients, 8° difference was found in one patient, and 9° difference was found in one patient. Lateral radiography of two patients showed 6 mm anterior translation in comparison with the affected side.

Table 2

Scoring sporting activities and frequency of sprain

Sports activity	Scores
Normal daily activities	0
2-3 times in a month	1
1-3 times in a week	2
3 or more in a week	3
Frequency of sprain	
During each sportive activity or 3 or more in a week	4
1-3 times in a week	3
3 times in a month	2
1-3 times in a month	1
Rarely in a year	0

Inversion simulation and EMG assessment

A device was designed for simulation of ankle inversion injury among patients subjected to stress radiography. During the design process, our aim was to be able to perform simultaneous EMG records by simulating inversion injury among patients with instability to find the first muscle to contract as a reflex at the time of inversion injury. We planned to investigate changes after treatment by comparison with basal peroneal reflex times prior to treatment. In order to achieve this, an ankle inversion simulator device was designed and built in collaboration with the Mechanical Engineering Department of Akdeniz University. The design included two platforms with adjustable straps for immobilization of the feet on which patients could rest their feet. Both platforms were designed to permit the entire range of motion of the feet on demand. Thus, simulation of ankle inversion could be achieved in all the desired angles. In the present study, we preferred 20° inversion and 20° plantar flexion angles as the position of ankle inversion simulation (Fig. 2a-b).

During the design phase of the device, in the simulator device for ankle inversion, a pneumatic design was chosen for the mechanical parts, and both platforms were equipped with valves controlling the speed. These valves allowed simulation of ankle inversion to have adjustable speed. We chose an inversion speed of 35-40 msec. The position of ankle and simulation speed were determined according to previous studies.[15-22] After completing the design of the ankle inversion device, it was rendered compatible with the EMG device in order to prevent data errors originating from a delay between the two devices.

The feet of the patients were immobilized on the device. Surface electrodes were then placed on the predetermined muscles to measure the latent periods during the inversion simulation (Fig. 3). By waiting for the relaxation of the patient and not knowing when the stimulation would occur, both EMG recording and simulation test were started simultaneously by a neurologist pressing a button at hand. Thus, the latent periods of predetermined muscles were measured during the inversion stimulation, along with basal values of the muscles prior to the treatment (Fig. 4).

By using inversion simulation device and EMG, latent periods of the tibialis anterior, peroneus longus, peroneus brevis, flexor hallucis longus, and gastrocnemius muscles were measured during inversion simulation.

Rehabilitation program

The patients were included in the rehabilitation program after acquiring their initial values. All the patients were taught to perform Achilles-peroneal

Table 3
Povacz functional scale[23]

			Score
Stability (objective)	Stable		5
	Unstable		0
Stability (subjective)	Stable, no difference from the uninjured side		5
	Occational feeling of instability when walking, no giving-way		2
	Mild feeling of instability and slight, spontaneous giving-way		1
	Occasional sprains with pain and swelling		0
	Frequent sprains, even in the presence of mild pressure		0
	Constant giving-way, even in the presence of mild pressure		0
Fear of sprain	Yes		-2
	No		2
Frequency of sprain	Never		1
	Once in a day, week, or a month		0
Pain	Never		2
	Mild, rare episodes		1
	Severe, frequent episodes		0
Swelling	Yes		0
	No		1
Ability to walk on the lateral edge of the foot	No difficulty		2
	Poor ability		0
	Unable		0
Extent of movement	Same		5
	Loss ≤10°		2
	Loss >10°		0
Sensitivity	Normal		0
	Reduced		-1
Capacity of sports	I am now as proficient in sports as I was before the injury	True	2
		Un decided	1
		Not true	0
	My foot is no problem in sports	True	2
		Un decided	1
		Not true	0
Subsequent treatment	Yes		0
	No		1
Would you be willing to have the same treatment again?	Yes		2
	No		0

Total score of 25-30 indicates excellent result, 20-24 indicates good result, and 20 or less indicates poor result.

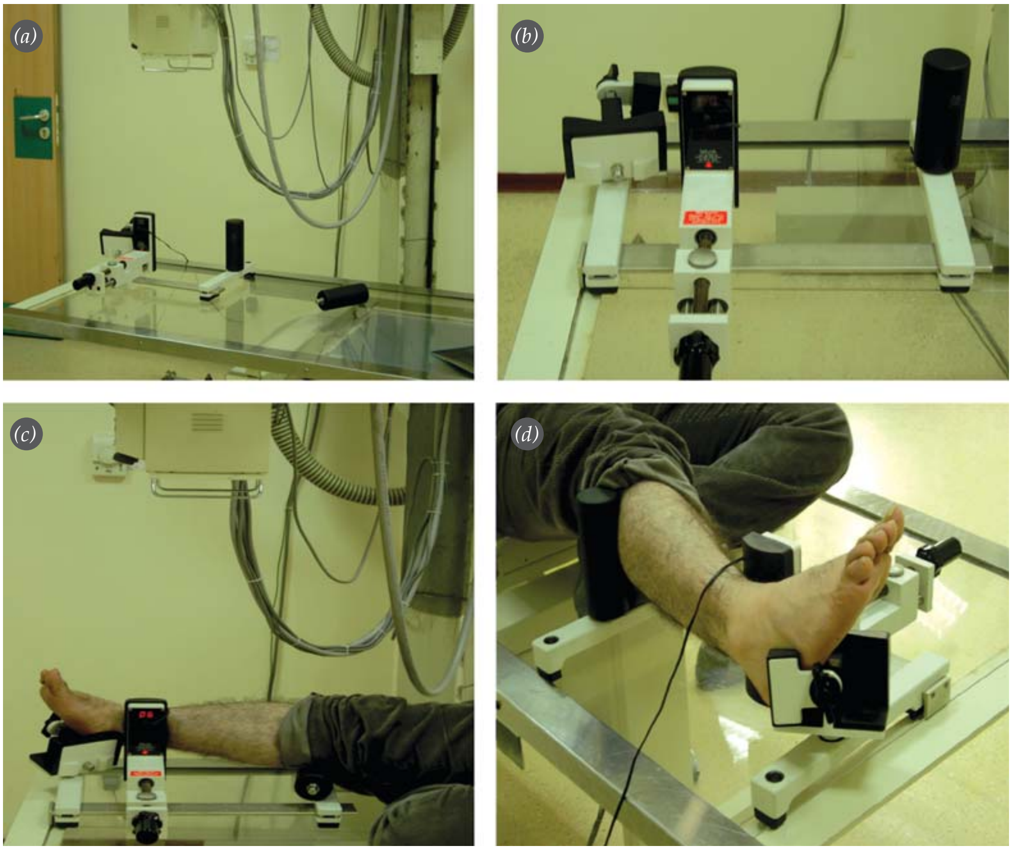

Fig. 1. **(a-d)** Telos device and stress radiography.

stretching and strengthening exercises with Esmarch bandage, and deep sense exercises with a balance board. Patients who started exercising were frequently called via telephone to check their compliance with the suggested exercise program.

Following a 1.5-month rehabilitation program, patients were invited to return for evaluation. Follow-up measurements were made using an inversion simulation device combined with EMG. Follow-up values of the latent period of muscles and proprioception were measured with a Cybex device.

Statistical analysis

Statistical analysis was carried out with SigmaStat 3.0 program (Systat Software, San Jose, CA, USA). Unpaired and paired t-test were used as appropriate; $p<0.05$ was recognized as statistically significant.

Fig. 2. **(a-b)** Simulation device of ankle inversion injury.

Results

Pretreatment findings

Isokinetic test results

Before treatment, mean peak torque values were lower in the affected side at all velocities and in all directions except 60° eversion, but the difference was not found to be statistically significant (Table 4).

Results of proprioceptive sense test with Cybex device

All patients had a statistically significant difference in proprioception between the normal and affected sides (p=0.001) (Table 4).

Results of inversion simulation device

Latent periods of five muscles were evaluated by using inversion stimulation and EMG during the inversion simulation (Table 5)

Tibialis anterior: Before rehabilitation, there was a statistically significant difference between the tibialis anterior latent periods of the affected and normal sides (p=0.041). Although there was a difference between the control group and the affected side, it was not statistically significant (p=0.194).

Peroneus longus: There was a statistically significant difference between the latent periods of the normal and affected sides prior to rehabilitation (p=0.002). A statistically significant difference was found between the latent periods of the controls and the affected sides (p=0.011).

Peroneus brevis: There was a statistically significant difference between the latent periods of the normal and affected sides prior to rehabilitation (p=0.004). There was also a statistically significant difference between the latent periods of the control group and the affected sides (p=0.005).

Flexor hallucis longus: Although there was a difference between the latent periods of the normal and affected sides prior to rehabilitation, it was not statistically significant (p=0.126). However, there was a statistically significant difference between the latent periods of the control group and the affected sides (p=0.013).

Gastrocnemius: Before rehabilitation, there was no statistically significant difference between latent periods of affected and normal sides (p=0.218). In terms of latent periods, there was a difference between the affected side and the control group, but it was not statistically significant (p=0.416).

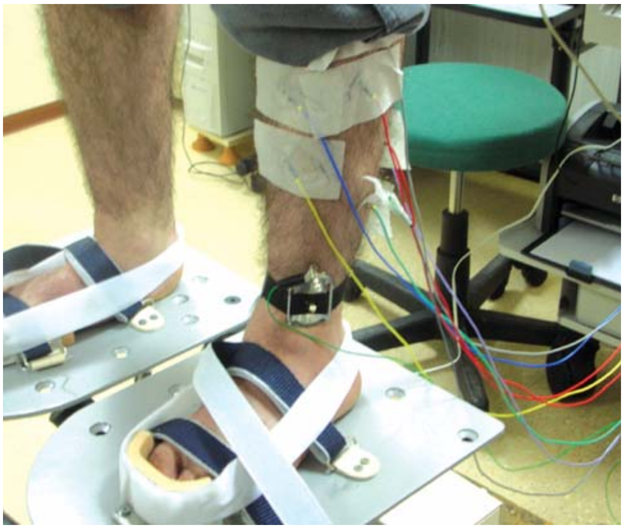

Fig. 3. Placement of EMG electrodes during inversion simulation.

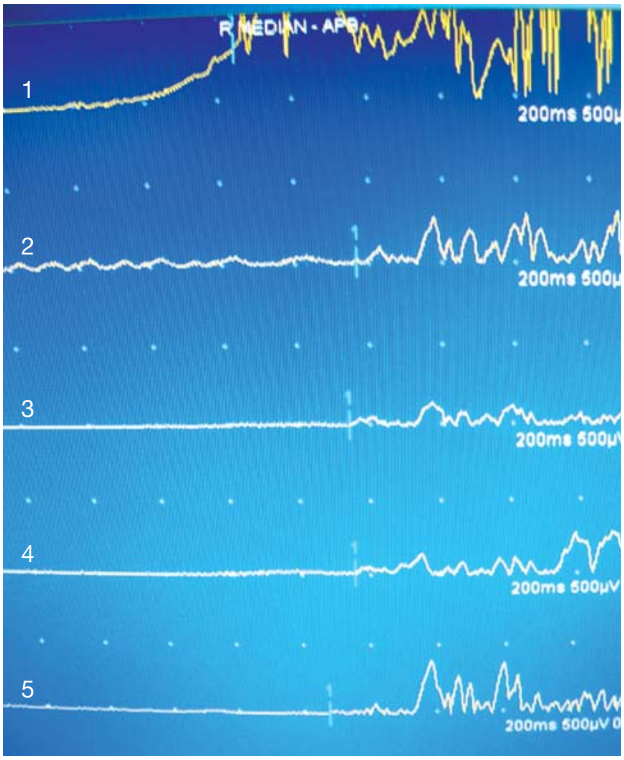

Fig. 4. EMG records during inversion simulation. 1: Peroneus longus, 2: Tibialis anterior, 3: Gastrocnemius, 4: Flexor hallucis longus, 5: Peroneus brevis.

None of the studied muscle groups of the patients demonstrated a statistically significant difference between the normal side and the control group (p>0.05) (Table 5).

Table 4
Isokinetic assessment and proprioceptive sense of the pathological side and normal side before and after the rehabilitation (mean±SD)

	Before the rehabilitation			After the rehabilitation			
	Pathological side	Normal side	p value*	Pathological side	Normal side	p value*	p value†
Isokinetic assessment (peak torque)							
Muscle groups							
60°/sc evertor	7.80±2.64	7.20±2.84	0.494	9.40±3.83	10.15±4.4	0.570	0.072
60°/sc invertor	8.35±3.28	8.45±3.41	0.925	10.09±3.86	11.00±3.40	0.901	0.001
150°/sc evertor	7.10±1.83	7.30±2.90	0.796	8.65±3.20	9.30±3.88	0.567	0.008
150°/sc invertor	7.70±2.55	8.35±3.66	0.818	10.35±4.72	10.15±3.49	0.880	0.003
Proprioceptive sense with Cybex device							
	4.64±1.09	3.38±1.24	0.001	3.13±1.14	2.43±0.99	0.030	0.001

*p value for pathological vs. normal side with Student t-test. †p value for before vs. after rehabilitation of pathological side with paired t-test.

Posttreatment findings

Isokinetic test results

The affected side was found to be strong at 60° and 150° inversion, whereas the normal side was found to be strong at 60° and 150° eversion; however, these values were not statistically significant (Table 4).

Results of the proprioception sense test performed with Cybex device

Both groups were found to show improvement according to the measurements with Cybex. The difference between groups was reduced after rehabilitation; however, the statistically significant difference between the normal and affected group was still present (p=0.030) (Table 4).

Inversion simulation device results

Following a rehabilitation program of 1.5 months, latent periods of five muscles in the normal and affected sides of the ankles were measured and compared with inversion simulation device and EMG. Those groups were compared with the control group (Table 5).

Tibialis anterior: While tibialis anterior latent period showed a reduction after the rehabilitation, the statistically significant difference between the affected and the normal sides was still present (p=0.028). However, there was no statistically significant difference between the affected ankles of the study group and the control group (p=0.692).

Peroneus longus: The latent period showed a decrease after the rehabilitation, but the statistically significant difference between the affected and the normal sides was still present (p=0.001). However, there was no statistically significant difference between the affected sides and the control group (p=0.528).

Peroneus brevis: Although there was a decrease in the latent period values after rehabilitation, the statistically significant difference remained because of parallel reduction in the healthy sides (p=0.002). The comparison of the latent periods of the affected sides with those of the control group revealed a statistically significant difference (p=0.029).

Flexor hallucis longus: Although there was a decrease in the latent period values after rehabilitation, the statistically significant difference remained because of parallel reduction in the healthy sides (p=0.012). No statistically significant difference was found between the affected ankles and the control group in terms of latent periods (p=0.166).

Gastrocnemius: There was no statistically significant difference between the latent periods of the affected sides and the healthy sides (p=0.449), nor was there a significant difference between the affected sides and the control group (p=0.823).

Comparison of pre-treatment and post-treatment findings

Isokinetic test results

There was a statistically significant difference between the pre- and post-treatment values of the affected ankles, with the exception of 60° eversion (p<0.05). There was a difference at 60° eversion, but it was not statistically significant (p=0.072). The differences of invertor muscles in pre- and post-treatment periods were more remarkable than those of evertor muscles (Table 4).

Results of the proprioceptive sense test performed with Cybex device

Statistically significant difference was determined between pre- and post-rehabilitation values of all patients (p=0.001) (Table 4).

Inversion simulation device results

In review of the simultaneously performed inversion simulation and EMG records, statistically significant differences were found between the pre- and post-rehabilitation values of all muscles except gastrocnemius. While there was a decrease in post-treatment latent period of gastrocnemius, it was not statistically significant (p=0.094) (Table 5). There was no difference between subjects with mechanical and functional instability in terms of response to rehabilitation.

Discussion

Ankle injury is the most common sports injury, and currently it is a very important problem affecting many people.[1-9] After ankle sprains, some patients continue to experience the following complaints: intermittent ankle pain, swelling, sense of instability, and recurring sprains. Those symptoms are estimated to be present in 20% to 40% of patients under conservative therapy for ankle injury.[10-13] The aforementioned symptoms have been shown to have no parallelism with the severity of the sprain.[11]

Broström[24] found anterior talofibular ligament (ATFL) or ATFL + calcaneofibular ligament rupture after inversion injuries in 85% of cases. As a result of the damage in the lateral ligaments, static stabilization of the ankle is impaired, and thus the frequency of recurring sprains is increased. The drawer and talar tilt tests are applied to assess the integrity of those ligaments. However, the evaluation of both of the

Table 5

Statistical analysis of the latent periods of ankle muscles before and after the rehabilitation determined by inversion simulation device and simultaneous EMG (mean±SD)

Muscles	Before the rehabilitation						After the rehabilitation					
	Pathological side	Normal side	Control group	p value*	p value†	p value‡	Pathological side	Normal side	Control group	p value*	p value†	p value$
Tibialis anterior	156.77±36.51	131.65±23.71	136.65±15.09	0.041	0.194	0.218	134.20±22.09	119.19±19.35	136.65±15.09	0.028	0.692	0.009
Peroneus longus	143.49±34.25	112.45±21.54	118.05±10.26	0.002	0.011	0.344	119.13±14.90	100.21±16.14	118.05±10.26	0.001	0.528	0.001
Peroneus brevis	145.50±33.01	120.46±15.94	121.50±6.81	0.004	0.005	0.848	123.85±16.22	106.51±16.58	121.50±6.81	0.002	0.029	0.001
Flexor hallucis longus	155.79±35.66	134.34±16.07	124.20±7.08	0.126	0.013	0.053	132.57±20.31	120.20±11.80	124.20±7.08	0.012	0.166	0.011
Gastrocnemius	161.84±35.46	143.72±17.92	142.95±19.84	0.218	0.416	0.832	147.02±20.32	142.32±22.79	142.95±19.84	0.049	0.823	0.094

* p value for pathological vs. normal side with Student t-test. † p value for pathological vs. control group with Mann-Whitney Rank Sum Test. ‡ p value for normal side vs. control group with Student t-test. $ p value for before vs. after rehabilitation of pathological side with paired t-test.

tests may vary depending on the clinician. Therefore, we preferred to use the telos device which is regarded by us as an easy-to-apply, available, and cost-effective instrument. By applying standardized stress radiographs, we separated the patients with mechanical instability from those with functional instability. Assessment of those radiographs revealed mechanical ankle instability in eight patients and functional ankle instability in 12 patients.

Previous biomechanical studies have shown a relationship between various muscle groups in lower extremity joints.[15-22] There is a coactivation between the agonist and antagonist muscles, which vary depending on the speed of the activity or the movement. During the functional activity, synergistic activity is generated among the three joints of the lower extremity, below the kinetic chain. Clinical studies have underscored the role of the contraction of agonist-antagonist muscles. The contraction varies based on the joint angle, force generated with the agonist muscle, movement speed, and patient performance.[25]

Among the causes of chronic pain and instability following ankle sprain, incomplete rehabilitation is the most prevalent.[26] None of the patients in our study group had received a proper program of physical therapy.

In assessment of muscle strength, isokinetic measurements are reported to be superior to isometric and isotonic measurements.[27] Isokinetic tests have been reported to be highly reliable and repeatable by many studies.[19,27,28] Most authors advocate that in presence of a difference more than 10% between the right and left extremities or agonist and antagonist muscles, muscle balance is impaired leading to an increase in susceptibility of the ankle to injury.[29]

Determination the rehabilitation program based on muscle weakness and imbalance evaluated by isokinetic methods following trauma is believed to reduce the incidence of injury.[16] Similarly, at the planning stage of our study, we thought that patients with an ankle instability would demonstrate delay in reaction times of some muscle groups in the ankle alongside weakness in the evertor muscle groups or agonist-antagonist muscle imbalance.

Evertor muscle weakness is one of the first findings of muscle strength evaluation performed after the ankle sprain.[17] Balduini and Tetzlaff[30] found peroneal dysfunction in 66% of patients complaining of instability after ankle injury. Many authors have mentioned the importance of strengthening evertor muscles in a rehabilitation program for ankle injuries.[30-32] Bosein et al.[32] determined weakness in evertor muscles after inversion injury that had been present more than 10 years. Kaminski[18] compared patients with a functional ankle instability and controls with no history of inversion injury, and found no remarkable weakness in the evertor muscles. In the present study, we evaluated the muscle strength of patients with ankle instability symptoms prior to rehabilitation and found reduced peak torque values at all speeds and positions except 60° eversion in the affected side, and found no statistically significant difference ($p>0.05$). However, comparison of the pre-treatment and post-treatment values of the affected side (except those of 60°), revealed a statistically significant difference ($p<0.05$). Despite the difference between the pre-treatment and post-treatment values at 60° eversion, it was not statistically significant ($p=0.072$). Peak torque values of the invertor muscles before and after the treatment were found to be more significantly increased compared with those of the evertor muscles.

In some studies, a positive correlation was determined between the muscle imbalance and the injury.[33,34] There are few studies on ankle agonist/antagonist muscle strength ratios and injury. Baumhauer et al.[35] found the eversion/inversion peak torque ratio at 30°/s angle speed to be 70% among patients with ankle inversion injury; and they suggested that increased evertor/invertor ratio aggravated the instability. In the current study, the pre-rehabilitation evertor/invertor peak torque ratio was decreased after the rehabilitation, indicating a correlation with the patients' symptoms.

Gam and Newton[19] conducted a study and found a significant loss in passive movement sensation in the sprained side compared with the healthy side. They also found an imbalance and loss of strength in two-thirds of their patients. At the end of their study, the investigators underscored the importance of assessing proprioceptive sense. Lentell and Katzman[20] did not detect any weakness in the evertor or invertor muscle groups among patients with chronic instability symptoms, but they found impaired unilateral postural balance. They concluded that proprioceptive deficit, independent of postural tonus, occurred in the unstable ankle. They also underscored the need for reliable scales for determination of functional deficits. In the current study, we assessed the proprioceptive senses of patients with a lateral ankle sprain by Cybex device, while using the functional scale employed by Povacz et al.[23] for identifying the degree of functional deficits.

The term "proprioceptive deficit" used by many clinicians indicates a disorder in nerve muscle response affecting the rapid muscle response against alteration in joint position. In the present study, assessment of the proprioceptive sense of patients prior to the treatment revealed findings supportive of the propositions of Lentell and Katzman.[20] Statistically significant differences were seen between the proprioceptive senses of the normal and affected sides prior to treatment (p=0.001). In all patients, improvement was achieved in proprioceptive senses of both the normal and the affected sides following 1.5 months of physical therapy treatment with balance exercises along with peroneal and Achilles strengthening. Since both normal and affected sides demonstrated similar levels of recovery, the statistically significant difference between the normal and the affected sides remained after rehabilitation (p=0.30). There was a parallelism between the significant recovery in the proprioceptive sense and improvement in the sense of instability. The continuing significant difference between affected and normal sides suggested that the notion of cross-interaction, which we thought of in the beginning of our study, might be true. Therefore, we thought that by working the contralateral normal extremity of the patients with a sprained ankle, the restoration of the proprioceptive sense of the affected extremity might be established earlier.

Ekstrand and Trop[36] calculated that the likelihood of a new sprain following lateral ankle injury was increased twice or thrice. Kleinrensink and Stoeckart[37] showed decrease in the superficial and deep peroneal nerve conduction velocities in recurring sprains (particularly 4 or more times) after inversion sprains. Following recurrent ankle sprains, traction damage in the peroneal nerve was thought to raise the peroneal reaction time. Among patients with a functional ankle instability, in face of "giving way," clinicians have considered it likely that there is slowing in peroneal muscle response.[37,38] During the subacute period, Nitz and Dobner[38] found no difference between the motor conduction velocities after EMG examination but found signs of denervation in both the peroneal and posterior tibial nerves. Therefore, they thought that impaired muscle nerve control might be associated with an afferent or efferent nerve lesion, or reflex inhibition of the neural impulses in the central nervous system. Bosien et al.[32] detected peroneal weakness in 22% of patients with functional ankle instability.

In the current study, there was a statistically significant difference between the peroneal latent periods of the normal and affected sides prior to rehabilitation ($p<0.05$). Moreover, a statistically significant difference was found between the affected and normal sides in the latent periods of peroneus longus and brevis muscles ($p<0.05$). After applying proprioceptive exercises along with peroneal and Achilles stretching exercises, we repeated the measurements. While the latent period of the peroneus longus decreased after rehabilitation, the statistically significant difference from the normal side was still present (p=0.01). However, no statistically significant difference was seen in the control group ($p>0.05$). After measurement, the comparison of the affected and normal sides of the tibialis anterior, peroneus longus, and peroneus brevis muscles relative to the pre-rehabilitation latent periods, revealed a prolongation; however, no statistically significant prolongation was detected in the latent periods of the affected sides of flexor hallucis longus and gastrocnemius muscles ($p>0.05$). This result suggested that prolonged reaction time may be observed mostly in the group of evertor muscles among patients with an ankle instability. The comparison of the latent period of the affected side of flexor hallucis longus with that of the control group prior to the treatment, revealed a statistically significant difference (p=0.013). This result suggested that latent period of the PHL muscle prolonged in the normal side, as well.

In terms of the latent periods following rehabilitation, the significant differences between the affected and the normal sides regarding tibialis anterior, peroneus longus, flexor hallucis longus muscles, were still present ($p<0.05$). No statistically significant difference was detected between the latent periods of the affected sides of those muscles with those of the control group in the post-treatment period. This result suggested that the normal side also benefited from the rehabilitation exercises. These data supported our original notion of cross-interaction. After rehabilitation, latent periods of the affected sides of all muscles except the gastrocnemius were reduced in a statistically significant fashion ($p<0.05$). Despite the presence of a decrease in the post-treatment latent period of gastrocnemius, it was not statistically significant ($p=0.094$). In light of these findings, we agree with the opinions of Bosien et al.[32] and Nitz and Dobner,[38] and believe that peroneal muscle presents with weakness and delayed reaction time in patients with ankle instability. However, we suggest that this weakness and delayed reaction time in the peroneal muscle can be treated with a properly arranged rehabilitation program.

While the ankle sprain was in left side in subjects with dominant left-side extremities, it was in the same side in 11 subjects and in the opposite side in seven subjects among 18 subjects with dominant right-side extremities. Since there was no injury, control group could not be evaluated in terms side of ankle sprain versus dominant extremity side, which is a limitation of the study.

Despite these positive findings, because of lack of time, we were unable to show that post-rehabilitation symptoms (sense of instability, recurring sprains) completely returned to normal in the long term among patients of the study group with chronic ankle instability symptoms. In the short term, those symptoms demonstrated a regression, while exhibiting an evident improvement in proprioceptive senses and significantly reduced peroneal latent periods.

As a conclusion, after ankle sprains, especially in patients with chronic instability, strengthening of the muscles around the ankle with well-planned proprioceptive exercises helps the patients to return to normal living and sports activities, and prevents unnecessary surgery, especially in cases with functional instability.

Acknowledgement

We would like to thank Assoc. Prof. Gabil Abdullayev, mechanical engineer, for his help and support on designing and realization of the ankle inversion simulation device.

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