Peroneus longus and tibialis anterior muscle activity in the stance phase

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

Jan Willem K Louwerens[1,2], Bert van Linge[1], Luuk W L de Klerk[1], Paul G H Mulder[3] and Chris J Snijders[2]

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

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

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

[1]Department of Orthopedics, University Hospital, Rotterdam, [2]Departments of Biomedical Physics and Technology and [3]Epidemiology and Biostatistics, Erasmus University, Rotterdam, The Netherlands
Correspondence: Dr. J.W.K. Louwerens, University Cluster of Orthopedics, Central Military Hospital, P.O. Box 90,000, 3509 AA Utrecht, The Netherlands. Tel +31 30-502000. Fax -502580
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The peroneal muscles are principally evertors (pronators) of the foot and are predominantly active during the stance phase of gait. They are also plantar flexors of the foot at the beginning of push-off (Sutherland 1966, Basmajian 1967, Jonsson and Rundgren 1971, Ambagtsheer 1978). However, the specific role of the peroneal muscles during gait is still unclear and has received little attention. Only once has it been described how these muscles take part in controlling the medial lateral balance in walking (Matsusaka 1986).

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

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

We investigated whether the peroneus longus muscle is active when the foot is at risk of sustaining an inversion injury and whether a change in muscle con-

Table 1. Some characteristics of the patient and control groups

Group	Number	Gender M	Gender F	Age[a]	Weight[a]	Height[a]
Bilateral symptomatic	18	6	12	35 (21–67) *14.1*	69 (54–90) *11*	172 (156–186) *9.6*
Unilateral symptomatic	7	1	6	28 (18–43) *7.8*	76 (58–101) *11*	174 (165–183) *5.1*
Controls	10	6	4	32 (19–41) *7.5*	69 (53–88) *10*	177 (164–201) *11.8*

[a] mean (range) *SD*

trol can be identified in patients with chronic lateral instability.

To answer these questions we examined electromyographically the activity of the peroneus longus and tibialis anterior muscles during the stance phase, (1) with and without external support, (2) at different walking speeds and (3) to find the changes in activity of these muscles in patients with chronic lateral instability.

Patients and methods

25 patients (18 women) with chronic lateral instability complaints were consecutively recruited from the orthopedic out-patient department (Table 1). All patients complained of frequent inversion injuries and "giving way" sensations of one or both feet. Symptoms like pain, swelling and reduced activity level were often present, but were minor complaints (for instance, only for a short period following a sprain). The patients with a possible osteochondral lesion were excluded. Patients were otherwise healthy, with no other musculoskeletal or neurological dysfunction, and could walk without limping. The control group consisted of ten subjects without symptoms and a history without previous inversion injuries.

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

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

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

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

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

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

Statistics

Statistical tests were performed using SPSS/PC+ (version 5.0.2) and BMDP (module 5V). For each test $p < 0.05$ was considered significant. Differences in age, weight, and height between groups were analyzed using the Student's t-test. To study whether the groups were comparable in gender, a chi-square test was used.

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

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

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

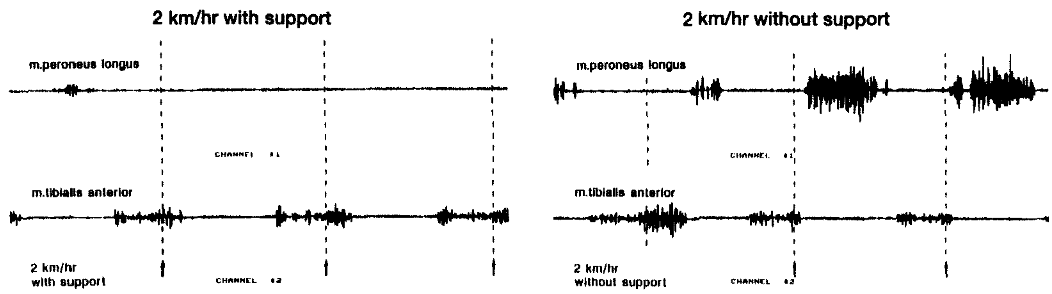
Results

To illustrate our findings, a case is presented in Figure 1. Walking at a speed of 2 km/hr while balance is secured with external support, the minimal activity of the peroneus longus is striking. The tibialis anterior shows regular activity, starting at the beginning of the sway-phase, followed by a dip in mid-swing and increasing around heel contact. As soon as the subject has no support and has to maintain balance in a natural way, there is strong activity of the peroneus longus in the stance-phase, with bursts up to 65%. However,

Table 2. Effects of speed and external support on activity of the peroneus longus and tibialis anterior muscles, measured in 18 patients with bilateral instability complaints and 10 controls. Values are mean, median, interquartal range (50% of all mean activity was within these limits). The figures refer to percentage activity. These seem to be low but one must realize that they are mean values of the intra-subject means (M), which were the average of the means (m) over 20 steps

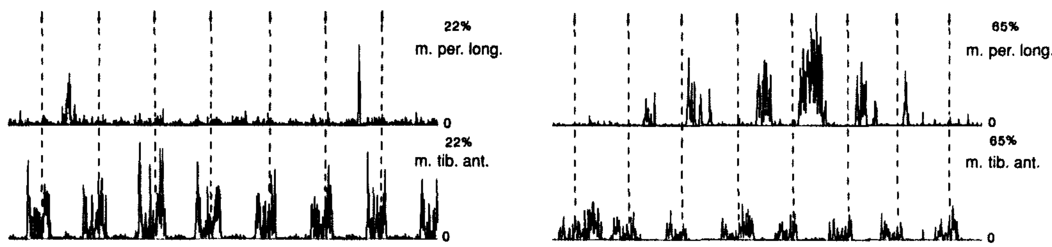
Quarter of stance		Peroneus longus						Tibialis anterior					
		Bilateral symptomatic			Controls			Bilateral symptomatic			Controls		
Speed													
2 km/hr	1	3.4	3.7	1.7–4.3	3.3	2.5	1.7–3.6	5.5	5.1	3.1–8.1	3.4	3.9	2.1–4.3
	2	4.4	3.7	2.7–6.1	4.7	3.7	1.9–6.4	1.8	1.5	0.9–2.6	1.4	1.3	0.7–1.9
	3	4.9	4.2	2.8–7.6	5.4	3.7	2.6–7.6	1.0	0.9	0.7–1.3	0.7	0.7	0.5–1.0
	4	4.6	4.4	2.9–5.2	3.6	2.9	2.0–5.1	0.8	0.7	0.7–1.0	0.5	0.5	0.4–0.6
4 km/hr	1	5.0	4.1	3.0–5.8	4.0	2.7	2.3–4.0	8.0	7.2	5.6–8.7	5.0	4.9	4.0–6.0
	2	5.0	3.6	2.6–6.3	4.6	3.5	2.6–4.8	1.5	1.5	0.9–2.0	1.1	1.0	0.7–1.4
	3	8.9	7.9	4.9–10.0	7.0	6.3	4.8–8.7	1.2	1.0	0.8–1.7	0.6	0.6	0.4–0.9
	4	7.2	5.6	4.3–8.8	4.9	3.8	2.8–6.9	1.2	1.0	0.6–1.6	0.6	0.5	0.4–0.7
Ext. support													
with	1	3.0	2.0	1.7–3.9	2.4	1.6	1.3–2.5	7.1	6.0	4.6–8.6	4.4	4.5	3.6–5.5
	2	1.9	1.4	1.2–2.0	2.0	1.5	0.7–2.3	1.3	1.2	0.6–1.7	1.0	0.8	0.5–1.5
	3	5.3	4.7	3.3–5.7	4.5	3.9	1.7–5.1	0.9	0.9	0.5–1.2	0.5	0.6	0.4–0.7
	4	5.5	4.4	3.4–6.7	3.5	3.2	1.7–4.5	0.8	0.7	0.5–1.1	0.5	0.5	0.3–0.6
without	1	5.4	4.9	3.5–6.4	4.9	3.6	2.7–5.5	6.3	5.9	4.2–8.0	4.0	4.2	2.7–5.1
	2	7.4	5.4	4.6–11.2	7.2	5.2	4.2–9.2	2.1	1.9	1.1–2.6	1.5	1.5	0.9–0.8
	3	8.4	6.7	5.1–12.4	8.0	6.0	5.4–10.7	1.3	1.1	0.8–1.7	0.8	0.8	0.5–1.1
	4	6.3	5.1	4.2–7.0	5.0	4.4	2.9–7.9	1.2	0.9	0.7–1.3	0.6	0.6	0.4–0.7

Figure 1. An example of a patient. The arrows and the dotted line indicate the time of heel contact.



While walking at a speed of 2 km/hr with external support, minimal activity of the peroneus longus is seen.

Without support, there is a marked increase in peroneus longus activity. This activity is variable and seems to alternate with activity of the anterior tibial muscle.



Normalized EMG signals with (left) and without support (right). Note the high bursts of peroneal muscle activity used to maintain balance. Division 22% or 65% of highest peak activity, respectively.

during some steps no activity of the peroneus longus is seen and during these steps the tibialis anterior is active in the stance-phase. This indicates that in this subject both muscles take part in controlling balance with alternating activity.

Comparing patients having bilateral complaints with the controls (Table 2)

No significant differences regarding age (p 0.6), weight (p 0.3), height (p 0.7) and gender (p 0.2) were found between the groups.

Peroneus longus. Higher walking speed and loss of external support resulted in a significant increase of peroneal activity (both $p < 0.0005$). Both factors also had a significant effect ($p < 0.0005$) on the distribution of activity over the 4 quarters of stance. The amount of activity was highest in the third quarter of stance and was lowest in the first quarter of stance. With increasing speed, the increase in activity was highest in the third and in the fourth quarters of stance. No major changes were found in the second quarter of stance. However, walking without support led to a major increase in peroneal activity in the second quarter of stance. Nevertheless, the overall activity remained highest in the third quarter.

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

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

Tibialis anterior. Most activity of the tibialis anterior under all circumstances was found in the first quarter of stance. At a higher speed, a significant increase in tibialis anterior activity was found ($p < 0.0005$). The influence of external support on the total amount of tibialis anterior activity was not sig-

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

	Patients with bilateral complaints (n 18) External support		Controls (n 10) External support	
Speed	With	Without	With	Without
2 km/hr	2.1	5.5	1.4	4.7
4 km/hr	5.0	5.5	3.7	5.1

nificant (p 0.3). However, external support significantly modified the distribution of activity per quarter of stance ($p < 0.0005$).

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

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

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

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

Discussion

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

Various investigators have reported that the peroneus longus is predominantly active during the parts of stance following foot-flat. EMG activity of the peroneus longus in gait has seldom been recorded and, when examined, the function of the peroneus longus is related to stabilization of the foot and to acceleration about the moment of push-off (Sutherland 1966, Ambagtsheer 1978, Winter and Yack 1987). Matsusaka (1986) tested gait from the viewpoint of ground reaction force, EMG activity and motion of pronation-supination in the foot. He demonstrated that the activity of the tibialis posterior and peroneus longus alternate in relation to the amplitude of the lateral component of the ground reaction force and take part in controlling balance. Ambagtsheer (1978) occasionally found the same alternation, but thought it improbable that this was to maintain balance.

We found a clear difference in all subjects between walking with and without secured balance. With secured balance, most peroneus activity took place in the third and fourth parts of stance. This activity emerges at each step and increases as walking speed increases. We suggest that this activity is related to acceleration. However, this function of the peroneus longus varied between individual subjects as was reported previously (van der Straaten et al. 1975, Pedotti 1977, Arsenault et al. 1986). Without secured balance, the subjects had to maintain balance of the body in a natural way and a clear increase in peroneus activity was seen in the period following foot-flat. Great bursts of activity were found that varied from step to step (Figure 1). This pattern of activity was present in all subjects and it is therefore suggested that balance control is the main and commonest task of the peroneus longus during normal walking. The interaction found between the factors of external support and speed can be explained as follows. Standing on one leg without support, all activity of the peroneus longus is used to maintain balance in the frontal plane. The slower the walking speed the more this muscle is used to maintain balance. However, with increase of speed, this function decreases and other activities concerning positioning of the foot, acceleration and what will later be described as active stabilization start to dominate. Medial lateral balance is probably increasingly secured by the lateral position of the foot with respect to the plane of progression; this is decided by the trajectory of the foot during swing, which is mainly controlled by the hip abductors and adductors (Winter 1994).

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

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

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

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

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

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