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Lateral ankle sprain alters postural control in bipedal stance: Part 2 sensorial and mechanical effects induced by wearing an ankle orthosis

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To investigate the effects induced by wearing an orthosis during the rehabilitation process, 23 ankle sprain patients (degrees I and II) were evaluated in three conditions (reference, with an elastic compression stocking and with an orthosis), 14 h, 10 and 30 days on average after their injury and compared with those of 30 age-matched healthy individuals. The patients were tested with separate measurements of the reaction forces under each limb to highlight the possible compensatory mechanisms between the sound and the injured legs. Their postural stability was enhanced during unilateral orthosis wear, explained by a bilateral effect involving both feet. Wearing a compression stocking induced comparably mild intermediate effects compared with the effects observed with the orthosis. These effects were constant throughout the next month. Following lateral ankle sprain, wearing an orthosis allows patients to improve postural function a few hours after the injury to 1 month later. Only cutaneous pressure intervening without mechanical maintenance induced mild effects, indicating that orthosis effects on postural control could partly result from its sensorial stimulation. It, therefore, seems relevant to prescribe orthosis wear for at least 1 month.

Three therapeutic actions are classically associated with the functional treatment of lateral ankle sprain: pharmacological treatment (analgesic, anti-inflammatory, etc.), functional rehabilitation and contention with a joint orthosis. The latter generally produces two effects: (1) mechanical immobilization, which reduces the mechanical instability of the multiple ankle joints in both frontal and sagittal planes (Kerkhoffs et al., 2001; Eils et al., 2002; Thoumie et al., 2004), with both magnitude and velocity of ankle inversion movements reduced in this case (Nishikawa et al., 2000) and (2) a sensorial stimulation of cutaneous receptors, enhancing the proprioceptive inputs. Thus, during a fast inversion movement, wearing an orthosis facilitates the fibular reflex, reducing the delay and increasing the magnitude (Cordova & Ingersoll, 2003; Thoumie et al., 2004).

The literature reports rather contradictory effects of orthosis on postural control. Most of these studies have highlighted improved postural stability in patients immediately after injury (Friden et al., 1989), in patients with chronic ankle instability (Jerosch et al., 1995; Guskiewicz & Perrin, 1996; Baier & Hopf, 1998) or in healthy subjects (Calmels et al., 1991; Rougier et al., 2004). In these studies, the major gains arise in the frontal plane compared with the sagittal plane. However, it should be emphasized that one study was unable to show any change (Barkoukis et al., 2002), whereas a negative effect was found by Bennell and Goldie (1994). All these studies, however, suggest at least some interaction between postural control and orthosis wear. These discrepancies in results could stem from the variability of the postural evaluation protocol (i.e. one-legged vs two-legged stance) or from the behavioral variability of the tested subjects (healthy subjects vs patients with chronic ankle instability).

To our knowledge, no study has been undertaken to assess the postural effects of orthosis wear on recent ankle sprain patients using two-legged posture protocols. Because of inflammation as well as mechanical and proprioceptive loss in these patients, the postural effects could be different from those in healthy subjects or in patients with chronic instability. This lack of knowledge on recently injured patients is unfortunate because orthoses are classically prescribed to be worn as soon as possible after injury. Moreover, in the above-mentioned studies, no

Fig. 1. Illustration of the experimental conditions: (1) reference, barefoot (left), (2) with a compression stocking (City Confort Coton®, Thuasne, France) worn on the injured foot (middle) and (3) with an orthosis (Ligastrap Immo®, Thuasne, France) worn on the injured foot (right).

information was given on the scientific and clinical validity of such orthosis prescription close to the injury.

Along these lines, the objective of this study was to assess the effects of unilateral ankle orthosis wear on the postural control of recent lateral ankle sprain patients. This objective can be divided into two questions: (1) What is the specific contribution of the mechanical and sensorial stimulation of the orthosis to postural changes? (2) Do these effects remain constant from injury to 1 month later? It could be hypothesized that wearing an orthosis should enhance the postural stability of recent ankle sprain patients because of both its cutaneous stimulation and the mechanical maintenance provided. Improved sensory information from proprioceptive and tactile cues is recognized to improve healthy subjects' and patients' ability to control their upright stance. These effects are therefore expected to be constant during the first month following injury.

Materials and methods

The methods have been described in detail in the companion article and therefore only the main points are mentioned here.

Subject recruitment

Twenty-three patients who had sustained a light or a moderate lateral ankle sprain (degree I or II) and 30 age-matched healthy subjects took part in the experiment. Adults under 60 with an ankle sprain occurring during the last 48 h were included in this study. The following criteria were required: (1) adult under 60 years of age, (2) first lateral ankle sprain or first repetition more than 1 year after the last sprain, (3) talofibular isolated or combined with calcanofibular ligament injury, (4) sprain occurring during the last 48 h, (5) degree I or II lateral ankle sprain (Renstrom & Konradsen, 1997), (6) ability to stand up for 40 s in bipedal stance and (7) ability to understand instructions. The following exclusion criteria were also applied: (1) bilateral ankle sprain, (2) internal ligament ankle sprain, (3) degree III lateral ankle sprain, (4) orthopedic disease, (5) prior analgesic treatment taken during the last 6 h and (6) pregnancy. Perimalleolus edema, ability to stand on one leg and pain (in discharge and in upright stance) were quantified.

Experimental procedure

The patients and the control group were evaluated, eyes masked, in two-legged stance (4 × 32 s trials, seat rest = 64 s), with each foot placed on one of two rectangular force platforms (PF02, Equi+, Aix les Bains, France) installed side by side. The subjects were asked to stand still, barefoot, the eyes masked, with each foot placed on one of the two platforms. Three randomized sequences were recorded: (1) barefoot (reference condition), (2) with a compression stocking (City Confort Coton®, Thuasne, France) worn on the sprained ankle foot (Fig. 1) and (3) with an orthosis (Ligastrap Immo®, Thuasne, France) worn on the sprained ankle foot. The compression stocking condition was used to assess the effect of a cutaneous pressure effect occurring without mechanical maintenance. According to the manufacturer, the size of the compression stocking is thought to infer a 15–20-mmHg pressure on the ankle. In the orthosis condition, both pressure and mechanical maintenance were applied to the ankle. This ankle orthosis was made up of an internal elastic taping covered by two lateral rigid shells maintained with two rigid straps (Fig. 1) and has been validated for its mechanical stabilising effect. A 5-min seated rest period was allowed between each condition.

This procedure was performed again for three sequences defined on the basis of the lateral ankle sprain recovery stages: (1) 14.7 (± 14.0) h following injury (D0), (2) 10.9 (± 2.2) days following injury (D10) and (3) 30.5 (± 2.9) days following injury (D30) (mean ± SD).

Signal processing

The signals from the eight load cells were amplified and converted from the analogue to the digital form using a 14-bit acquisition card and then recorded with a 64-Hz frequency (with no filtering). Plantar center of pressure (CoP) trajectories from both feet were computed from vertical ground reaction forces measured under the left and right feet. These two plantar CoP trajectories (namely, CoP_{ul} and CoP_{lf} trajectories for unloaded and loaded feet, respectively) result from muscular contractions developed by the supports for controlling upright stance (Okada & Fujiwara, 1983; Gatev et al., 1999; Kim et al., 2003) and were used to assess the contribution of the two legs in this test. The resultant center of pressure (CoP_{Res}) displacements were calculated along each mediolateral (ML) and anteroposterior (AP) axes from the left and right CoP displacements using the following formula (Winter, 1995):

$$CoP_{Res} = CoP_{lf} \times \frac{R_{lf}}{R_{lf} + R_{rf}} + CoP_{rf} \times \frac{R_{rf}}{R_{lf} + R_{rf}}$$

where CoP_{lf}, CoP_{rf}, R_{lf}, R_{rf}, are the CoP coordinates and the vertical reaction forces under the left and right feet, respectively.

These CoP_{Res} movements were used to highlight the consequences of plantar changes and body weight distribution over the two legs at a more global level.

Extracted parameters

The left and right plantar CoP trajectories were characterized on a planar basis in order to describe the reaction forces occurring under each leg independently of the ML–AP referential framework. Four parameters were calculated: (1) the mean body weight distribution applied on the legs, (2) the *RMS* (Root Mean Square) calculated on a frequency basis (0–3 Hz), representing the mean magnitude of plantar CoP trajectories, (3) the mean power frequency (*MPF*) of plantar CoP trajectories and (4) the lengthening ratio (*LR*), which expresses the shape of the trajectories measured under the legs. To be more precise, plantar CoP trajectories were decomposed along the longitudinal and lateral feet axes and characterized through their respective *RMS*. The *LR* was then computed as follows:

$$LR = \frac{RMS_{\text{longitudinal}} - RMS_{\text{lateral}}}{RMS_{\text{longitudinal}} + RMS_{\text{lateral}}}$$

By definition, this *LR* ratio ranges from -1 to 1. A value of 0 expresses similar CoP magnitudes along both longitudinal and lateral foot axes, whereas values close to 1 or -1 indicate that the displacements occur predominantly along the longitudinal or lateral axis of the foot, respectively.

The CoP_{Res} trajectories were separately analyzed along the ML and AP orthogonal axes. At a resultant level, the CoP trajectories were similarly described through the *RMS* and the *MPF* calculated along the ML and AP axes.

Statistical analysis

Parameters characterising plantar and resultant CoP trajectories were compared using three factors (group, foot or axis, experimental condition) analyses of variances (ANOVA). A Newman–Keuls comparison test was used as *post-hoc* analysis when necessary. The first level of significance for all tests was set at $P<0.05$. Because of the -1 to 1 range of the *LR* calculated for CP_{ul} and CP_{lf} trajectories, statistical tests were performed on z transforms to normalize the data.

Results

In this part, only the statistical results from the experimental condition factor (involving reference, compression stocking and orthosis) and their interactions with the other factors (group, foot and axis) are presented.

Clinical characteristics of ankle sprain patients

Twelve patients with degree I and 11 with degree II ankle sprains were included. Approximately 15 h after the injury, they were characterized by moderate edema and pain in discharge and in upright stance. Only three patients were able to maintain a one-legged stance on their injured leg without pain. These characteristics were substantially reduced 10 days later ($P<0.001$) and remained unchanged 30 days later ($P>0.05$). Please refer to the companion article for the patients' clinical characteristics.

Effects of orthosis wear on postural control

Plantar CoP trajectories

Weight-bearing asymmetry. No experimental condition effect was found [$F(2, 570) = 0.0$, $P<1$]. Thus, compression stocking or orthosis wear did not change the weight distribution of asymetric ankle sprain patients (Table 1).

Amplitude (RMS). An experimental condition effect [$F(2, 570) = 7.12$, $P<0.001$] with no interaction between condition and the foot factor [$F(2, 570) = 0.82$, $P<0.44$] was found (Fig. 2 and Table 1). Orthosis wear induced a decrease in the CoP magnitudes of both feet in comparison with the reference ($P<0.001$) and compression stocking wear conditions ($P<0.05$).

Table 1. Mean parameters (± SD) characterising the unloaded (injured, CoP_{uf}) and the loaded (sound, CoP_{lf}) CoP trajectories measured for the reference, compression stocking and orthosis conditions

	Reference	Compression stocking	Orthosis	ANOVA
% of body weight				
CoP_{uf}	46 (7)	47 (6)	47 (6)	$P=0.1$
CoP_{lf}	54 (7)	53 (6)	53 (6)	
Magnitude (*RMS*, mm)				
CoP_{uf}	0.65 (0.29)	0.59 (0.21)	0.53 (0.22)$^{\tau,\ \delta}$	$P<0.001$
CoP_{lf}	0.70 (0.23)	0.68 (0.22)	0.64 (0.19)$^{\tau,\ \delta}$	
Frequency (*MPF*, Hz)				
CoP_{uf}	0.60 (0.06)	0.60 (0.07)	0.61 (0.07)	$P=0.23$
CoP_{lf}	0.61 (0.08)	0.62 (0.08)	0.62 (0.08)	
Shape (LR)				
CoP_{uf}	0.81 (0.09)	0.82 (0.08)	0.78 (0.10)$^{\tau,\ \delta}$	$P<0.05$
CoP_{lf}	0.83 (0.06)	0.83 (0.06)	0.82 (0.07)$^{\tau,\ \delta}$	

From top to bottom: (1) weight bearing, (2) mean magnitude, (3) mean power frequency and (4) shape. The data represented are the mean values of the control groups and the patients evaluated on D0, D10 and D30. The statistical results are noted on the right: ANOVA (factor condition), τ and δ indicate a difference with the reference and the compression stocking conditions, respectively.

SD, standard deviation; CoP, center of pressure; ANOVA, analysis of variance; MPF, mean power frequency; LR, lengthening ratio; RMS, root mean square.

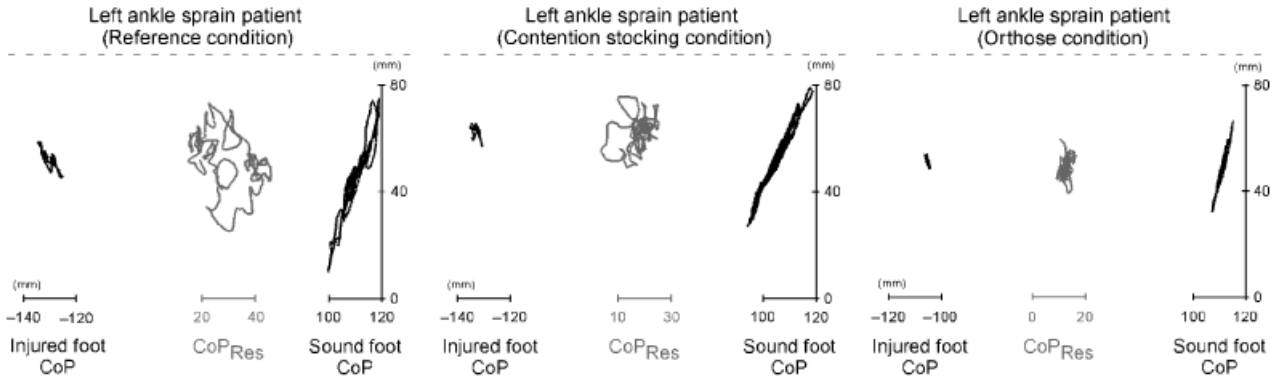

Fig. 2. Examples of center of pressure (CoP) trajectories (obtained at D0) under each foot (left and right) and CoP_{Res} (in grey) measured in one left ankle sprain patient during reference (left), compression stocking (middle) and orthosis (right) conditions.

No difference was reported between reference and compression stocking conditions ($P > 0.05$).

Frequency (MPF). Neither an experimental condition effect [$F(2, 570) = 1.45$, $P < 0.24$] nor an interaction between experimental condition and foot [$F(2, 570) = 0.15$, $P < 0.86$] was observed. Thus, compression stocking or orthosis wear did not change the plantar CoP trajectory MPF (Table 1).

Shape (LR). An experimental condition effect [$F(2, 570) = 3.40$, $P < 0.05$], but with no interaction between condition and foot [$F(2, 570) = 1.97$, $P < 0.14$], was found. The CoP LRs of both feet decreased with orthosis wear as compared with the reference ($P < 0.05$) and compression stocking conditions ($P < 0.05$). No difference was observed between the reference and the compression stocking conditions ($P > 0.05$). When the orthosis was worn, plantar CoP trajectories appeared less organized along the feet's longitudinal axis than in the reference and compression stocking conditions (Fig. 2 and Table 1).

CoP_{Res} trajectories

Amplitude (RMS). An experimental condition effect [$F(2, 570) = 8.43$, $P < 0.001$] with no interaction between condition and axis [$F(2, 570) = 0.10$, $P < 0.90$] was found. The mean CoP_{Res} amplitudes were reduced along both the ML and the AP axes during the orthosis wear condition in comparison with the reference ($P < 0.001$) and compression stocking conditions ($P < 0.05$). In addition, the mean CoP_{Res} amplitudes were reduced during compression stocking wear in comparison with the reference condition ($P < 0.05$, Fig. 2 and Table 2).

Frequency (MPF). An experimental condition effect [$F(2, 570) = 5.12$, $P < 0.001$], but with no interaction between the condition and the axis [$F(2, 570) = 0.89$, $P < 0.41$], was found. The mean CoP_{Res} frequencies increased with orthosis wear along both the ML and the AP axes in comparison with the reference ($P < 0.01$) and the compression stocking conditions ($P < 0.05$). No difference was reported between the reference and the compression stocking conditions ($P > 0.05$, Table 2).

Table 2. Mean parameters (± SD) characterising the CoP_{Res} trajectories (along ML and AP axes) measured for the reference, compression stocking and orthosis conditions

	Reference	Compression stocking	Orthosis	ANOVA
Magnitude (*RMS*, mm)				
ML axis	0.31 (0.20)	0.28 (0.13)$^{\tau}$	0.25 (0.12)$^{\tau,\ \delta}$	$P < 0.001$
AP axis	0.61 (0.22)	0.58 (0.17)$^{\tau}$	0.53 (0.16)$^{\tau,\ \delta}$	
Frequency (*MPF*, Hz)				
ML axis	0.62 (0.07)	0.63 (0.07)	0.65 (0.07)$^{\tau,\ \delta}$	$P < 0.001$
AP axis	0.60 (0.07)	0.61 (0.07)	0.62 (0.08)$^{\tau,\ \delta}$	

From top to bottom: (1) mean magnitude and (2) mean frequency. The data represented are the mean values of control groups and patients evaluated on D0, D10 and D30. Statistical results are noted on the right: ANOVA (factor condition), τ and δ indicate a difference with the reference and compression stocking conditions, respectively.
SD, standard deviation; CoP, center of pressure; ML, mediolateral axis; AP, anterposterior axis; RMS, root mean square; MPF, mean power frequency; ANOVA, analysis of variance.

Orthosis effects over time

For all parameters, no interaction was observed between the experimental condition factor (reference, compression stocking, orthosis) and the subject factor (control, patients evaluated at D0, D10 and D30) (Table 3). The effects of compression stocking and orthosis wear were the same for the control group and the ankle sprain patients. Similarly, these effects remained the same for the patients evaluated 14 h after the injury and 10 and 30 days later.

Table 3. ANOVA results: interactions between experimental conditions (reference, compression stocking and orthosis) and groups (control, D0, D10, D30)

Parameters	$F(6, 570)$	P
Plantar CoP trajectories		
% of body weight	0	1
Magnitude (*RMS*, mm)	0.85	0.53
Frequency (*MPF*, Hz)	0.32	0.93
Shape (*LR*)	0.14	0.99
Resultant CoP trajectory		
Magnitude (*RMS*, mm)	0.92	0.48
Frequency (*MPF*, Hz)	0.33	0.92

All the differences tested were statistically non-significant.
ANOVA, analysis of variance; CoP, center of pressure; *MPF*, mean power frequency; *LR*, lengthening ratio.

Discussion

To our knowledge, no recent study has attempted to analyze the effects of ankle orthosis wear on the postural control of ankle sprain patients evaluated using a two-legged stance protocol shortly after their injury. Four novel findings were shown in this study: (1) wearing an orthosis does not modify the weight-bearing asymmetry of ankle sprain patients, (2) by inducing an effect on the two legs, wearing an orthosis reduces the postural instability of ankle sprain patients, (3) cutaneous ankle stimulation, without additional mechanical maintenance, induces mild effects and (4) these effects were constant throughout the month after the injury.

Wearing an orthosis changes plantar organization

Following lateral ankle sprain, the postural control of patients is characterized by weight-bearing asymmetry, with more weight applied on their sound leg. Wearing an orthosis does not alter this feature.

Postural stabilization of ankle sprain patients is, however, significantly modified by the orthosis. Firstly, unilateral wear of an orthosis induces a bilateral reduction in the CoP trajectory magnitudes under the two feet. Because plantar CoP trajectories are the direct consequences of muscular activation developed by the legs for controlling postural motions, these results could reveal a reduction in the left and right muscular activations with the orthosis, i.e. along the AP axis, the body behaves like an inverted pendulum (Gage et al., 2004), involving principally the ankle joints and more precisely the soleus muscles (Okada, 1972). As a result, by its sensorial and/or mechanical effects, the orthosis may reduce the length variations of the soleus on the injured leg.

Wearing an orthosis induces a reduction in the left and right plantar CoP *LR*s. These parameters were computed to describe the shape of the left and right plantar CoP trajectories, which, in normal subjects, are principally organized along the foot's longitudinal axis. This pattern reflects the major role of the flexor/extensor ankle muscles on AP postural stabilization. Intervening on this parameter, likely through orthosis rigidity, could therefore alter this muscular recruitment. Even though this rigidity is most pronounced in the frontal plane, strapping (bedding the entire orthosis) could also limit AP mobility (Kerkhoffs et al., 2001; Eils et al., 2002; Thoumie et al., 2004).

It is interesting to note that these effects, for both subjects and patients, involves both legs. Although the orthosis was worn unilaterally, it induced bilateral behavioral adaptations, suggesting a biomechanical and/or a neurosensorial relation between the two legs in maintaining an upright stance. A perturbation of the postural regulation occurring under one leg seems to infer similar changes under the other leg. This point is interesting because a worsened postural stability along both ML and AP axes would have been observed with changes intervening solely on one leg. In other words, when one plantar CP movement is reduced, the only way to reduce CP_{Res} displacements is to modulate the ML displacements under both feet identically. Because CP_{uf} displacements are reduced by the orthosis effect, the CP_{lf} under the sound leg should behave accordingly.

Wearing an orthosis increases postural stability

Our results show that CoP_{Res} displacements performed at higher frequencies are reduced with the orthosis. At this stage, it is necessary to recall that CoP_{Res} trajectories (or CoP obtained with a simple force platform) do not directly reflect postural performance, which ought to be quantified through the center of gravity (CoG) motions. Brenière (1996) proposed a frequency relationship between CoP_{Res} and CG trajectories from which it can be predicted that increasing the frequency bandwidth for given CoP_{Res} displacements should incur reduced CoG movements. Considering that the subjects were required in all conditions to reduce their body movements, it can be deduced that wearing an orthosis improves the postural stability of ankle sprain patients in the bipedal stance. This conclusion is in accordance with previous studies investigating patients with acute lateral ankle sprain (Friden et al., 1989), chronic ankle instability (Jerosch et al., 1995; Guskiewicz & Perrin, 1996; Baier & Hopf, 1998) and healthy subjects (Calmels et al., 1991; Rougier et al., 2004).

It is interesting to note that similar orthosis effects are reported along the ML and AP axes even though its principal aim is to maintain the ankle joint along the lateral axis. Considering that postural stability is principally controlled by ankle and hip strategies

along the AP and ML axes, respectively (Winter, 1995; Rougier, 2007), major effects are normally observed along the AP axis. Along this AP axis, the reduced CP_{ul} and CP_{lf} trajectories could directly explain this feature (Genthon & Rougier, 2003). Along the ML axis, postural stability is controlled by a charge/discharge strategy involving principally left and right hip adductors/abductors (Winter, 1995; Rougier, 2007) and very slightly the ankle invertors/evertors. For these reasons, the effects observed on lateral stability are rather surprising and suggest that the ankle contributes to the control of lateral stability.

Mechanical and sensorial effects of orthosis wear

Both mechanical and sensorial effects are classically associated with orthosis wear. Increasing the required strength in joint deformation (Thonnard et al., 1996) and reducing the joint mobility in the three dimensions are indeed expected (Robinson et al., 1986; Bruns et al., 1996; Kerkhoffs et al., 2001; Eils et al., 2002; Thoumie et al., 2004). In parallel, somesthetic cutaneous receptors are stimulated by the orthosis's cutaneous pressure, inducing a possible enhanced fibular reflex activity (Cordova & Ingersoll, 2003; Thoumie et al., 2004).

To dissociate the mechanical from the sensorial effects of the orthosis, the subjects were tested with a compression stocking in order to induce cutaneous pressure without mechanical maintenance. In comparison with the orthosis condition, it is relevant to note that mild effects were observed with a compression stocking, improving the postural stability along both ML and AP axes. A simple cutaneous pressure of 15–20 mmHg applied on the foot, ankle and shank would appear sufficient to improve postural stability. These postural changes could be explained by enhancing the proprioceptive cues stemming from cutaneous pressure stimulation of the joint (You et al., 2004).

In terms of design, it seems relevant to consider the sensorial role of the orthosis. Using specific material, reinforcing the orthosis sensorial stimulation without altering its weight could enhance its efficacy. Considering that functional gain is maximized when sensorial stimulation and mechanical maintenance are associated, the mechanical maintenance contributed by the orthosis should not be neglected. Because in the two conditions studied herein the sensorial stimulations were slightly different, these results should be relativized.

Interactions between subject characteristics and orthosis effects

Similar orthosis effects were reported in healthy subjects and patients evaluated 14 h, 10 and 30 days after their injury. This suggests that there is no interaction between the subjects' characteristics and the orthosis effects. Whereas pain, edema and mechanical instability vary considerably over time, the orthosis effects on postural control are constant. This suggests that the effects of the orthosis are not influenced by swelling and excessive local sensitivity. To enhance the postural stability of ankle sprain patients, it would seem relevant to prescribe the orthosis as soon as possible after the injury. Similarly, it seems relevant to keep the orthosis for 1 month (our patients spontaneously removed the orthosis roughly 10 days following their injury).

Perspectives

Wearing an orthosis improves postural stability immediately after ankle sprain injury and up to 1 month later. Therefore, an orthosis improves ankle function also when prescribed soon after injury. These changes could be explained by their sensorial and mechanical functions and are therefore good predictors of improved efficacy for more ecological motor tasks. Applying only cutaneous stimulation induces mild effects as compared with what is observed with sensorial reinforcement and mechanical maintenance. This information should be helpful in prescribing orthosis wear.

Key words: post urography, lateral ankle sprain, weight-bearing asymmetry, upright stance, postural control.

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