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Active Ankle Circumduction to Identify Mobility Deficits in Sub-Acute Ankle Sprain Patients

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Abstract

Assessment of ankle mobility is complex and of clinical relevance after an ankle sprain. This study develops and tests a biomechanical model to assess active ankle circumduction and its reliability. The model was then applied to compare individuals' ankle mobility between injured and non-injured ankles after a sprain episode. Twenty patients with sub-acute unilateral ankle sprain were assessed at 4 and 10 weeks after the injury. They underwent a clinical exam and an ankle circumduction test during which the kinematics were recorded with an optoelectronic device. A biomechanical model was applied to explore ankle kinematics. Reliability of the ankle circumduction tests were good to excellent (ICC of 0.55-0.89). Comparison between non-injured and injured ankles showed a mobility deficit of the injured ankle (dorsiflexion = -27.4%, plantarflexion = -25.9%, eversion = -27.2% and inversion = -11.6%). The model allows a graphical representation of these deficits in four quadrants. Active ankle circumduction movement can be reliably assessed with this model. In addition, the graphical representation allows an easy understanding of the mobility deficits which were present in all four quadrants in our cohort of patients with sub-acute ankle sprain.

Keywords: biomechanical model, mobility deficit, circumduction.

Word count: 2753 words

Introduction

Ankle sprain is the most common type of acute sport trauma. It represents 80% of all ankle traumatism.[1] One inversion ankle injury occurs per 10’000 persons each day which mean that, in the United States, 23’000 new cases are reported per day.[2] In particular sports like basketball, soccer, volley and hiking have a high risk of injury due to frequent jumps and landings on one foot or sharp cutting maneuvers.[1,3]

One of the major concern in patients with ankle sprain is the risk of re-injuries.[4] A recognized risk factor for re-injury is a deficit in joint mobility or a so called decreased Range Of Motion (ROM). A limited ankle dorsiflexion can increase re-injuries.[5] Recurrent ankle sprains can lead to chronic ankle instability or degenerative bone disorder.[6,7] Therefore, a precise clinical evaluation of ROM and a tailored rehabilitation program are necessary to prevent recurrent ankle sprains.[8,9]

Quantification of ankle kinematics is an important area for clinicians and researchers. In a clinical setting the ROM is mostly measured with a classical goniometer, which allows the assessment of the joint mobility in one single plane. The circumduction movement is complex and the center of the ankle movement evolves in different planes during motion.[10] Therefore, an evaluation of the functional circumduction movement using an optoelectronic device is of interest and has the advantage that the ankle mobility can be measured in multiple planes.

For the ankle joint, previous studies used biomechanical models to evaluate active and passive movements.[11,12] However, circumduction movement of the ankle has never been studied. From a clinical point of view, identifying deficits in the sagittal and frontal planes during a circumduction movement should provide new insights which might help assess the influence of different rehabilitation protocols on ankle ROM and consequently to optimize rehabilitation programs.

The hypothesis was that a biomechanical model can reliably assess active ankle circumduction and identify the mobility deficits in the different plans after an acute ankle sprain. Therefore, the aims of this study were A) testing the reliability of the model and B) comparing individuals' ankle mobility between injured and non-injured ankles after a sprain episode.

Methods

Twenty patients suffering from a grade I or II lateral ankle sprain were recruited four weeks after the initial injury. Patients were excluded if they had neurologic or an orthopedic disorder influencing joint mobility, or if they had a previous ankle sprain within the last 12 months. The present study has been approved by the local ethical committee (protocol reference number 09-116). All participants received oral and written information and signed an informed consent before testing.

All lateral ankle sprain patients visited the emergency department of Geneva University Hospital (Switzerland). They received standard instructions about rest, ice, compression and elevation (RICE) protocol. In addition, patients received a semi-rigid Aircast ankle brace (DJO Global©, Vista CA, USA) during the first month. Patients who signed the informed consent underwent a clinical examination by an experienced physical therapist four weeks after the injury (evaluation 1). At this first visit, patient's anthropometrics data were collected (age, gender, height and weight). Pain during rest and walking was evaluated with a 10 centimeter Visual Analog Scale (VAS). Swelling of the ankle was measured with a tape measurer, perimeter at malleoli level was recorded. Then patients were equipped with reflective markers and an ankle circumduction test was performed as described below (aim "B"). In order to test the reliability of our biomechanical model (aim "A"), a second evaluation was made ten weeks after the injury (evaluation 2) only for the non-injured side.

Each patient was equipped with fourteen reflective skin markers, placed on both lower legs, as described by the International Society of Biomechanics[13]: tibial tuberosity, middle of lateral tibia's part, medial malleolus, lateral malleolus, heel, base of first metatarsal and base of fifth metatarsal. Marker trajectories were recorded with a 12 optoelectronic cameras Vicon Mx3+ (ViconPeak©, Oxford, UK) system at 100 Hz.

During circumduction test, the patient was sitting on an adjustable stool in the field of the camera. He was instructed how to perform the multiple ankle circumduction movements at a speed of one circumduction movement per second. Then, a baseline position with knee and ankle bent at 90° was adopted and used as reference position of the ankle joint. At the beginning of the test both feet touched the floor. Two seconds after starting the recording, the patient was asked to lift his foot and to perform a continuous movement of circumductions during 30 seconds. Both ankles were tested. All the tests were performed by the same assessor who gave instructions and showed the patients a short demonstration of the test.

Marker trajectories were reconstructed, labeled and filtered using the predicted mean-squared error filter in the Nexus software (Version 1.8.5). Then, a three-dimensional biomechanical model was used to calculate three dimension angles at the ankle from marker trajectories. Based on the labeled markers, segment coordinate systems were defined (at each point time) for leg and foot segments in accordance with the International Society of Biomechanics recommendations.[13] From these segment coordinate systems, the rotation sequences (Z_{lg} – X_f – Y_{ft}) were used to describe the ankle joint kinematics during circumduction movement. The indices lg, ft and f represented respectively axes embedded on the leg segment coordinate systems, the foot segment coordinate systems and a floating axis. In the following definitions, angle values corresponded at the instantaneous rotation value about the Z_{lg} axis i.e. ankle dorsiflexion-plantarflexion, about the Y_{ft} axis i.e. ankle internal and external rotation and about the X_f axis i.e. ankle inversion-eversion. Data were analyzed and exported using Matlab software (Mathworks, Natick MA, USA) and open-source Biomechanical Tool Kit package for MATLAB.[14]

Therefore, at each step of the movement, three angle values were produced for the ankle joint, each corresponding to a rotation component as defined below. From these values, ROM of dorsiflexion-plantarflexion and inversion-eversion angles and only maximal values were retained. To facilitate visualization of the ankle circumduction movement, a presentation of the results in four quadrants has been established. Based on calculated angles, the quadrant presentation shows a combination of dorsiflexion-plantarflexion and inversion-eversion axes to describe the movements: Quadrant 1: dorsiflexion-eversion; Quadrant 2: plantarflexion-eversion; Quadrant 3: plantarflexion-inversion; Quadrant 4: dorsiflexion-inversion. A presentation in four quadrants should help to assess the amount and direction of mobility limitation and verify for outlier data (Figure 1A).

Statistical analyses were performed using SPSS (Statistical Package for the Social Sciences Inc., Chicago IL, USA). Descriptive statistics were used to present anthropometrical data. Maximal values of dorsiflexion, plantarflexion, inversion and eversion that each patient was able to reach were calculated, expressed in degrees and used for the further statistical analysis.

Reliability of the biomechanical model was tested using the maximal values of the non-injured leg for evaluation 1 and evaluation 2 using Intraclass Correlation Coefficient (ICC) and standard error of measurement estimates. ICC above 0.75 was considered as an excellent reliability, 0.6-0.74 as a good reliability, 0.40-0.59 as a fair reliability and <0.4 as a poor reliability.[15,16]

Ankle mobility deficits at evaluation 1 were calculated using the difference between the maximal angles (plantarflexion, dorsiflexion, inversion and eversion) of the injured and the non-injured ankle. Differences were expressed with the median and interquartile range. Given the healthy side as reference value, the amount of deficits in mobility was further expressed in percentage taking plantarflexion, dorsiflexion, inversion and eversion. A percentage has also been calculated for each quadrant (mean of two movements) and one for the global movement including the four movements together. Mann-Whitney tests were used to check if differences between injured and non-injured ankle circumduction movements were significant. *P* values <.05 were considered significant.

Results

Twenty patients were assessed. One patient was excluded from analysis due to a problem with the identification of marker trajectories. Thus, nine women and ten men were retained for the analysis. Median age was 32 (range, 22-40) years and median Body Mass

Index was 24.2 (range, 22.5-25.8) $kg.m^{-2}$. Thirteen persons had a right and six had a left sprained ankle (Table 1). A graphical representation of the result from a circumduction test was made (Figure 1B).

Reliability of active ankle circumduction in four quadrants was calculated based on 15 patients as four patients did not come to the second evaluation due to personal reasons. The biomechanical model used to determine ankle mobility showed a good to excellent ICC. The highest reliability was shown for plantarflexion (ICC = 0.89 [0.72-0.96], *P* < .001) whereas the lowest was found for inversion (ICC = 0.55 [0.54-0.83], *P* = .016) (Table 2). A graphical illustration of the mobility deficits during the circumduction test of one representative patient was made (Figure 2).

Comparison of individuals' ankle mobility showed that the injured side presented a decreased ankle mobility compared to the non-injured ankle in all movements, except for inversion that failed to be significant (dorsiflexion = -4.6 (-27.4%, *P* = .022), plantarflexion = -13.5 (-25.9%, *P* = .001), eversion = -4.6 (-27.2%, *P* = .010) and inversion = -2.8 (-11.6%, *P* = .193).

The largest mobility deficit has been identified in the first quadrant (Quadrant 1 = -27.3%; Quadrant 2 = -26.5%; Quadrant 3 = -18.7%; Quadrant 4 = -19.5%). The global mobility deficits of the injured ankle represent -23% when calculating all percentages movement together (Table 3).

Discussion

This study shows that evaluation of active ankle circumduction movement revealed good to excellent correlation coefficient and can be considered as a reliable measurement tool. In addition, results demonstrated that the mobility in dorsiflexion, plantarflexion and eversion were particularly affected in the injured side compared to the non-injured side.

Previous studies have studied foot kinematics and found that repeatability of the model was good.[17-19] Repeatability in this study was established in all movements except for inversion for which we found lower correlation coefficient (ICC = 0.55). Indeed, rotation around the floating axis X_f is, by calculation, less reliable than the two others axes.[18]

Mobility of sprained ankle established a deficit in all quadrants compared to the non-injured ankle at evaluation 1. This result concurs with previous studies which measured ankle mobility in dorsiflexion-plantarflexion.[20,21] In comparison, mobility deficit in inversion was lower than mobility deficit in the other quadrants (Table 3). A clinical explanation could be that the calcaneofibular ligament is particularly concerned by inversion however it is the cause of only 25% of lateral injuries. Secondly, this ligament is lax during stretching but not at the extremes degrees of inversion.[22] Another explanation might be that pain has caused these mobility deficits. Our patients reported a mild pain of 1.6 (range, 0.2-3.0) at rest and of 2.3 (range, 0.9-5.3) while walking on the VAS (0-10). However, it is unlikely that edema caused this mobility deficit as the ankle perimeter of the non-injured ankle (26.0 cm (range, 23.8-26.3)) was equal to the ankle perimeter of the injured ankle (26.0 cm (range, 24.8-27.5)).

The largest mobility deficits were identified in Quadrant 1 and Quadrant 2 with respectively -27.3% and -26.5% mobility diminution. It is likely that the articular capsule as well as the anterior talofibular and calcaneofibular ligaments which are mostly affected by ankle sprain,[2] were still presenting inflammatory process and caused these mobility deficits. In addition, it might be that a compression of the injured fibers induced pain and reduced the voluntary mobility in these directions.

To our knowledge, this is the first study presenting functional ankle mobility deficits in sub-acute ankle sprain patients. Graphical representation of mobility deficits in quadrants is rather innovative and can help clinicians and researchers to better understand which part of the movement is disturbed. Similar representations have only been used in studies for the wrist.[23,24]

The circumduction circles on the graphical presentation looked asymmetric with respect to the anatomical axes. ROM of the ankle may differ among people depending of individuals’ flexibility but stays similar between right and left sides.[25] Therefore by overlapping the mobility graphs of injured and non-injured legs the difference of mobility can easily be illustrated (Figure 2) and it provides an interesting tool to clinicians to assess and compare ankle mobility deficits in multiple planes.

Circumduction is an active movement. The benefit of active movements is that the experimenter doesn’t influence the test. However, it is a complex movement. The comprehension on how to realize the test and subject ability of coordination of movements could influence the results. Furthermore patients have to understand that their hip and knee joints should remain in the same position during the whole test duration in order to not alter ankle mobility through hip and knee movements.[26] Therefore, we tried to control patients’ lower leg position as carefully as possible during the tests. This is why only one assessor performed the tests in order to obtain a representative measurement of the circumduction of the ankle. His role was to instruct the patients, to correct the circumduction movement with a description and a short demonstration. Secondly patients had to test the movement before recording. Thirdly, they realized the circumduction movement during 30 seconds at a frequency close to one movement by second, so around 30 movements were performed and used in the analysis. Then, maximal ROM values of circumductions were retained. Thus, we attempted to minimize the difficulty to produce a correct movement. However, we cannot exclude that some participants encountered difficulties to realize this complex movement with a good coordination. We added this point in the limitation of the study. It also reduced the risks of errors due to positioning of markers (approximate position, edema, weight gain, cutaneous movement, etc.).[27] In addition, as edema wasn’t present at the first assessment helped to easily identify anatomical landmarks.

The study chose to consider the foot as a rigid segment, although the fact that rotation can occur between front and rear foot during circumduction. This choice was made for two reasons, first, International Society of Biomechanics standard was followed and secondly, ankle sprains concern only the rear foot.[13] Rotations occur in Chopart articulation during inversion and eversion but do not concern the ankle itself.[10] This allowed to limit the number of markers and reduce methodological errors[28]. Understanding of motion between front and rear foot with the model chosen is not possible. A specific model between front and rear foot should be developed.

The main limitation of our study is the six weeks period between the two evaluations to test the reliability which can induce a bias. For example, activity level might differ from one patient to another which might lower the reliability results. Bishop et al. suggests to test the reliability within 1 to 7 days.[29] Based on the reliability test of the non-injured leg, the time gap doesn’t seemed to have influenced the results. The results were certainly rather an underestimation than an overestimation for ICC as we cannot exclude that the unaffected ankle may change to accommodate for the injured side. Furthermore, testing the reliability of the injured leg would imply to do a second test in a short interval due to the different influencing factors (healing, pain, edema etc.). Thus, it was preferred to test the reliability of the circumduction movement of the non-injured leg first.

When this approach becomes an accepted and valid assessment tool of ankle circumduction future research should assess mobility deficits at a longer follow-up. Particular interest should be paid at 6 months after the injury knowing that chronic pain and ankle stiffness can occur.[9]

It would also be of interest to further develop this method in order to get an objective tool to define grade of ankle sprains which is nowadays only based on subjective criteria and to assess different types of treatment. In addition, circumduction test can easily be applied to other population or pathologies (e.g. elderly, diabetic persons). However, it should be noted that this assessment approach is time consuming and costly due to the material and the specialist manpower. In order to use such an approach in a clinical setting the use of inertial sensors might make it accessible for all clinicians.[30] The use of a biomechanical model to assess deficits of an active ankle circumduction movement in sub-acute patients with ankle sprain is possible and provides reliable data. A graphical presentation in quadrants allows an easy visualization of ankle mobility deficits. Patients with sub-acute ankle sprain demonstrated an 11.6-27.4% deficit in mobility while performing a circumduction movement.

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Tables

Table 1 Patients' anthropometric data at four weeks after ankle sprain.

Data N=19	Median	25th percentile	75th percentile
Age (years)	32.0	22.0	40.0
Body mass index (kg.m^{-2})	24.2	22.5	25.8
VAS of pain during rest (0-10)	1.6	0.2	3.0
VAS of pain during walking (0-10)	2.3	0.9	5.3
Perimeter: Non-injured ankle (cm)	26.0	23.8	26.3
Perimeter: Injured ankle (cm)	26.0	24.8	27.5

Table 2 Intraclass correlation coefficient and *P* value of ankles' movement of the non-injured ankle between the two circumduction tests (evaluations 1 and 2).

Movement	**Mean (°)**	**Min (°)**	**Max (°)**	**SEM (°)**	**ICC**	***P value***
Plantarflexion	50.4	19.1	76.2	4.7	.89**	<.001
Dorsiflexion	14.9	29.3	0.2	3.8	.80**	<.001
Inversion	23.5	6.1	32.8	4.3	.55*	.016
Eversion	17.3	25.9	6.8	2.8	.78**	<.001

Note. SEM: Standard Error of Measurement; * Significant ICC at $P < .05$ level; ** Significant ICC at $P < .01$ level.

Table 3 Range of Motion (ROM) comparison and Mann-Whitney test of ROM difference between healthy and injured ankles at four weeks after the ankle sprain.

		Median (°)	**25th percentile (°)**	**75th percentile (°)**	**Deficit (°)**	**Deficit (%)**	***P* value**
Plantarflexion	**Non-injured**	52.2	45.0	56.2	-13.5	-25.9	.001
	Injured	38.7	29.3	47.2			
Dorsiflexion	**Non-injured**	16.8	21.2	9.9	-4.6	-27.4	.022
	Injured	12.2	17.7	7.2			
Inversion	**Non-injured**	24.1	21.5	27.7	-2.8	-11.6	.193
	Injured	21.3	12.5	27.1			
Eversion	**Non-injured**	16.9	21.1	13.9	-4.6	-27.2	.010
	Injured	12.3	17.3	8.7			

Figure captions

Figure 1A – Quadrants are defined by dorsiflexion-plantarflexion axis (Z) and inversion-eversion axis (X). Quadrant 1 (Q1): dorsiflexion-eversion. Quadrant 2 (Q2): plantarflexion-eversion. Quadrant 3 (Q3): plantarflexion-inversion. Quadrant 4 (Q4): dorsiflexion-inversion.

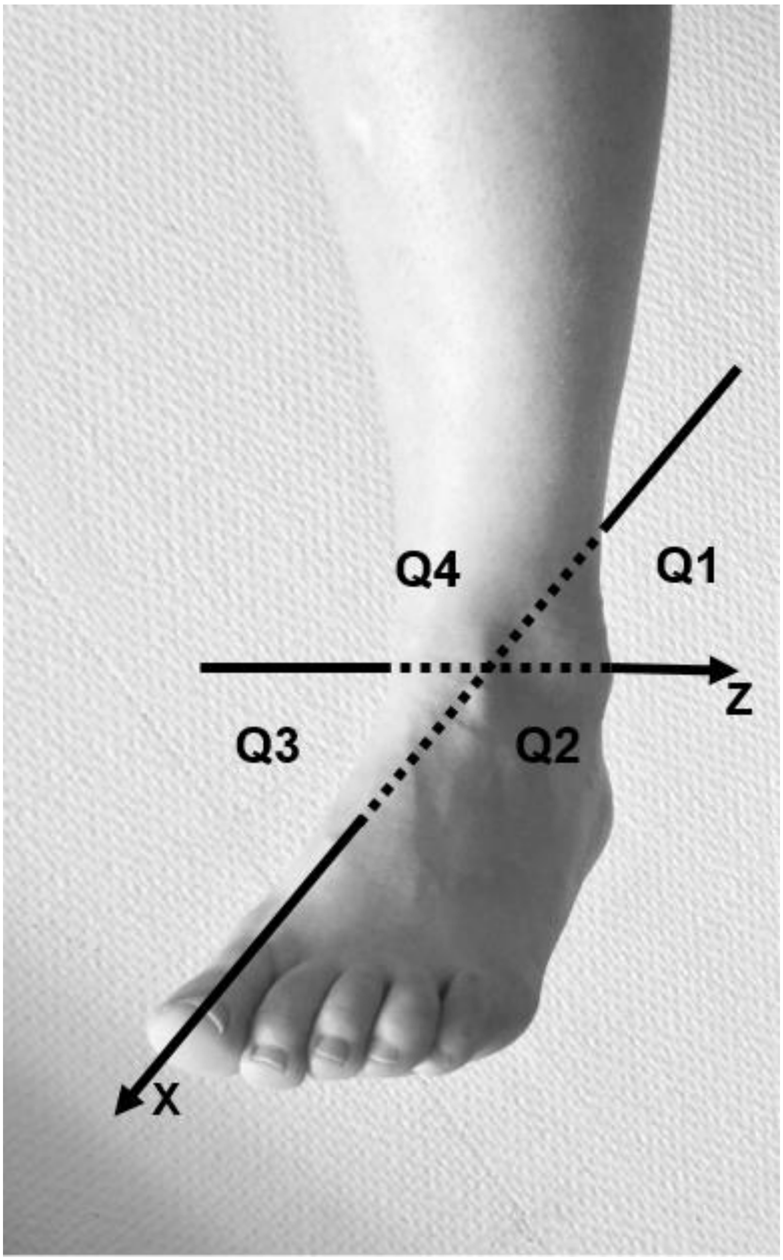


Figure 1B – Representative example of quadrant presentation for healthy non-injured ankle. Ankle circumductions are drawing curves passing successively from quadrant 1 to 4. Axes units are in degrees (°).

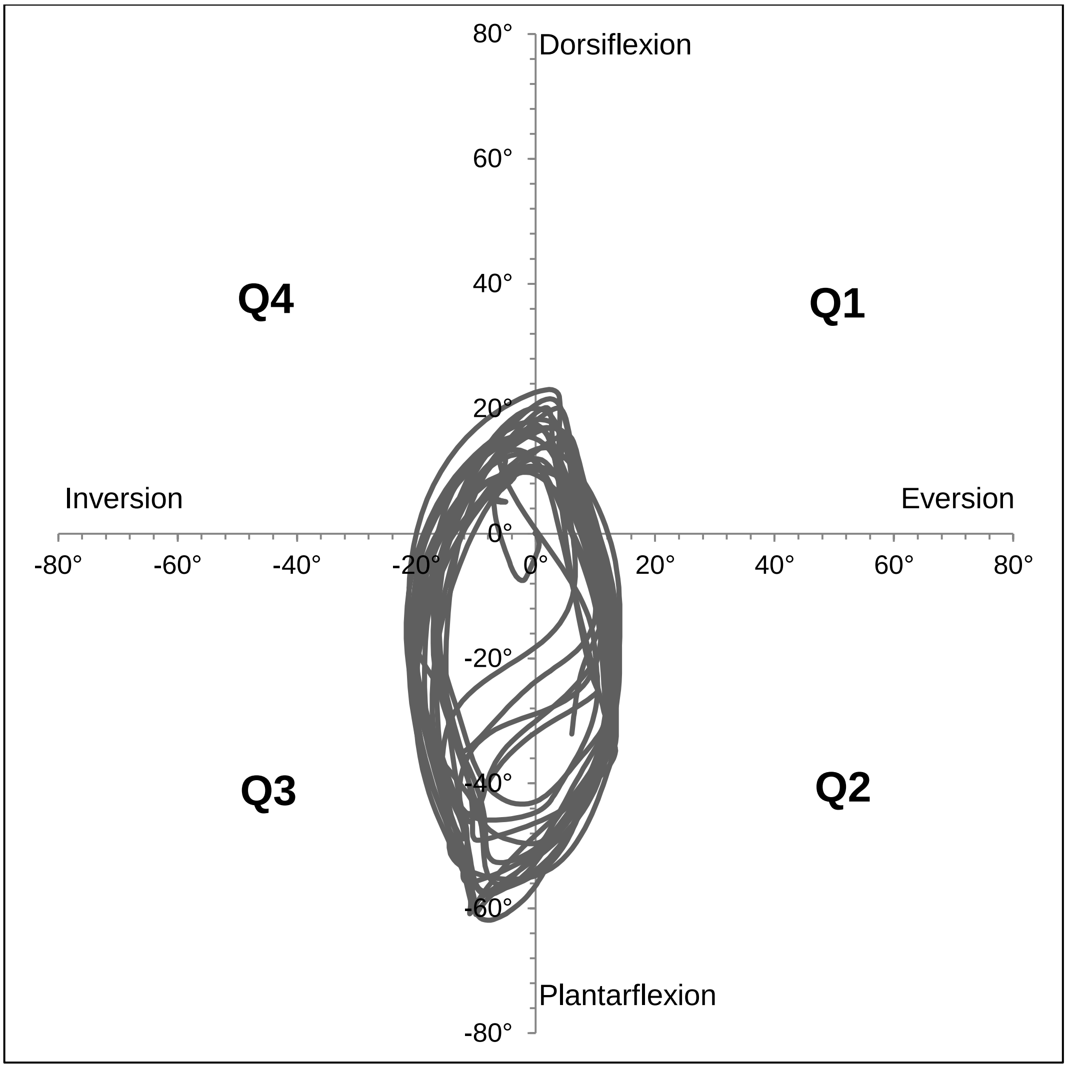
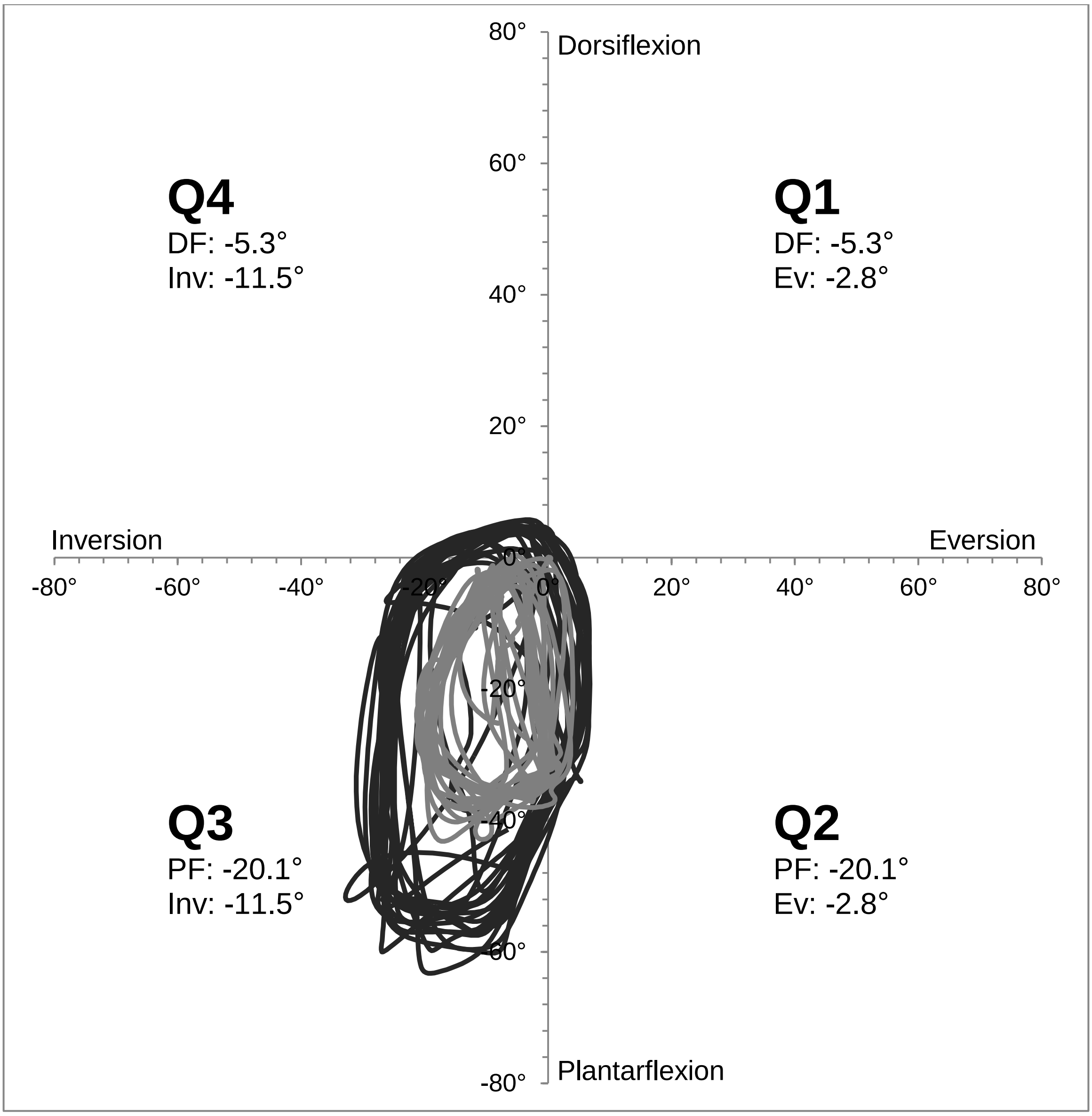


Figure 2 – Comparison of angular motion (in degrees) for the injured side (grey circles) and the non-injured side (black circles) of a representative patient’s trial presented in quadrants. Degrees of mobility deficits for each movement have been added in each quadrant.


80°
Dorsiflexion
60°
40°
20°
0°
-20°
-40°
-60°
-80°
Plantarflexion
Inversion
Eversion
-80°
-60°
-40°
-20°
0°
20°
40°
60°
80°
Q4
DF: -5.3°
Inv: -11.5°
Q1
DF: -5.3°
Ev: -2.8°
Q3
PF: -20.1°
Inv: -11.5°
Q2
PF: -20.1°
Ev: -2.8°