

# The Correlation between Ankle adaptations and Proximal Strategies during Shod Walking in Individuals with Functional Ankle Instability

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## ABSTRACT

*Trunk and hip joint stability and strength are important for proper gait mechanics and foot position during heel strike. The ankle joint requires very precise neuromuscular control during the transition from terminal swing to the early stance phase of the gait cycle. So, it is important to consider the patency of all the leg joints for stability during gait. The purpose of this study was to correlate between ankle joint adaptations and proximal (trunk and hip) strategies in cases of unilateral functional ankle instability during shod walking. 3-D motion analysis system used to record the gait kinematic and kinetics of trunk and hip joint of fifty subjects during shod walking (25 Functional ankle instability, and 25 age, gender, activity, and gait velocity matched controls). Kinematic and kinetics pattern differences were established at 90%, zero%, 10% and 30% of gait cycle in the sagittal and frontal planes. The functionally ankle instability subjects were significantly ( $P < 0.05$ ) more inverted in the frontal plane compared with controls in the entire studied parts of gait cycle. Also, subtalar joint motions appeared to be controlled by an invertors moment compared with an evertors moment in the controls. In addition to significant increase of ankle joint plantar flexion ( $P < 0.05$ ), proximal adaptations in form of significant increase in ipsilateral hip joint adduction and lateral trunk lean towards the affected side were found during walking. So, these proximal adaptations are significantly correlated to ankle adaptation in the same plane. These changes should be considered during establishment of rehabilitation programs for persons with functional ankle instability.*

*Key words: kinematics; kinetics; functional ankle instability; shod walking.*

## INTRODUCTION

The mechanics of the ankle and ankle injury have been studied frequently, and a relationship has been shown between the mechanics at the ankle and the mechanics of more proximal joints<sup>10</sup>. The

junction between the leg and foot presents a unique situation. At this anatomical area, vertical weight-bearing forces are transmitted to a horizontal system. Customarily, the ankle is considered to be the site of all leg-foot interaction. A more accurate interpretation includes also the subtalar joint<sup>26</sup>. The interdependence of the ankle joint complex with proximal joints of the lower extremities and the great weight-bearing stresses to which this area is subjected have resulted in a high frequency and a great diversity of difficulties in the joints of ankle complex. Specialists in orthopedics and sport medicine similarly find that problems attributable to ankle dysfunction make up a substantial percentage of their practice<sup>15</sup>.

Ankle injuries result in a significant amount of time loss from work and sport activity. The ankle is the most commonly injured joint in the body and 85% of those ankle injuries are inversion sprains<sup>9</sup>. The mechanism of a lateral ankle sprain is typically a violent inversion/hypersupination of the ankle complex<sup>11</sup>. Given the high prevalence of this injury, and the large proportion of sufferers who continue to experience related functional disability, it is important to identify impairments that contribute to functional ankle instability (FAI). The most common complications following ankle sprain are mechanical and functional instability<sup>36</sup>.

Mechanical ankle instability (MAI) is defined as ankle movement beyond the physiologic limit of the ankle's range of motion. The term "laxity" is often used synonymously with MAI. FAI is defined as the subjective feeling of ankle instability or recurrent, symptomatic ankle sprains (or both) due to proprioceptive and neuromuscular deficits. The subtalar joint is critical to the mechanics of ankle instability. It acts functionally as a mitered hinge, allowing the leg to rotate on the weight-bearing foot.

Biomechanically, the reaction force from the ground acts on the foot to create a moment acting on the subtalar joint<sup>33</sup>.

The joints of the human body are linked together in a form of chain (kinematic chain) so that the motion of one of the joints in this chain is accompanied by motion at an adjacent joint<sup>4</sup>. Based on this fact, unaddressed residual ankle instability may result in compensatory motions at other joints to keep the body physical activities at the functional level<sup>7</sup>. These compensatory motions are expected to be profound to cover up the multiple pathologic insufficiencies occurring as a result of recurrent ankle joint injuries<sup>29</sup>. The challenging question that needs an answer, at which part of the kinematic chain should these mechanical adaptations be expected. Leveangie and Norkin<sup>15</sup> mentioned that "the system of joints and links is constructed so that abnormal motion of one link to one joint will produce motions at all or some of the other joints in an unpredictable manner".

Stability of the hip is important for proper gait mechanics and foot position during heel strike. Because of the intricate nature of lower extremity kinematics, it is important to consider the patency of all the leg joints for stability during gait<sup>10</sup>. Individuals with chronic ankle instability demonstrated increased inversion position immediately before, at, and immediately after initial contact compared to control subjects who had never sprained their ankles<sup>5,21</sup>. Foot placement at heel strike may be altered with change in the hip abductor or adductor moments generated during the swing phase of gait<sup>18</sup>. Moreover subjects with lateral ankle sprains had weaker hip abduction strength<sup>10</sup>. Therefore, the purpose of this study was to investigate whether ankle adaptations are correlated with trunk and hip adaptations in unilateral functional ankle instability in comparison with normal subjects during walking with regular shoes.

## MATERIALS AND METHODS

### Subjects

The study was conducted on fifty non athletic subjects (forty men and ten women). They were equally divided into two groups.

The study group suffered from (FAI), their age ranged from 20 to 30 years, height from 175 to 190 cm and weight from 73 to 92 kg. They were referred from orthopedic specialists with a diagnosis of unilateral right FAI. The subjects participated in this study were randomly selected according to the following inclusion criteria; At least one significant right lateral ankle sprain in which the subject was unable to walk independently without the aid of crutches. Repeated episodes of lateral ankle injury or feeling of ankle instability or "giving way" (more than three times in a six month duration). No present participation in a rehabilitation program. The ability to bear full weight on the affected ankle joint without a limp<sup>6</sup>.

The exclusion criteria included followings: A history of trauma or surgery to the trunk or lower extremities. Neurological or vestibular impairments with residual deficits. Positive anterior ankle drawer or talar tilt tests. Regular participation (more than once a week) in physical activities that involve cutting maneuvers. The latter exclusion criterion was chosen to eliminate a presumed learned stability effect that might be gained from activities that theoretically may train the ankle muscles group<sup>31</sup>.

The control group consisted of twenty five normal subject matched with the study group according to number, age, height, weight, sex and physical activity level. The exclusion criteria included the following: A history of any previous medical condition that may affect on their gait, and formal participation in an exercise program at the time of the study. All selected subjects were right handed to avoid the effect of dominance on performance while all the FAI group individuals were with unilateral right ankle instability for unifying of comparison between both groups. Prior to participation in the study, participants received an explanation of the study procedures and they provided informed consent to the Faculty of Physical Therapy, Cairo University.

### Instrumentations

3-Dimensional motion analysis system with a force plate unit consists of:

**a. Motion Capture Unit:** It includes six high speed Pro Reflex Infrared cameras with a frame rate of 120 Hz (Fig.1). The cameras are supported on a tripod stand that can be easily adjusted for proper position before capture.



**Fig. (1):** The motion capture unit (high speed camera).

**b. Wand-kit:** Wand-kit model number 130440 was used for the calibration of the system. The wand kit consists of two parts L-shaped part and T-shaped parts.

**c. Force platform:** An AMTI (Advanced Mechanical Technology Inc., USA) force plate is embedded in the center of walkway which has a length of six meters. Its dimensions are 40 by 60 cm. The sampling rate of the plate is 120 Hz.

**d. Personal computer:** It was used for data processing and analysis with the following software: Q-track software was used to capture the data from the cameras. Q-view software was used to view the captured data after being processed. Q-gait software was used to analyze the exported data format (TSV).

**e. Reflective markers and double faced adhesive tape:** Twenty passive light-weight reflective markers were placed over twenty bony land marks as indicated by the user manual. They are silver in color and have a surface area of eight cm<sup>2</sup>.

## Procedures

### I. Pre-experimental protocol

Subjects were familiarized with equipments and test procedures before testing commenced. Twenty reflective markers were placed on twenty bony land marks. Two markers each one was placed on the tip of each acromion process. One marker was placed at

the 12th thoracic vertebra. One marker was placed on the sacrum. Two markers were placed on the two anterior superior iliac spines. Two markers, were placed on the two greater trochanters. Two markers, were placed on the superior surfaces of the two patellae. Two markers, were placed on the lateral surfaces of both knees along the lateral joint lines. Two markers, were placed over the tuberosities of both tibias. Two markers, were placed over the two lateral malleoli. Two markers, were placed over the dorsum of both feet between the bases of the 2<sup>nd</sup> and 3<sup>rd</sup> metatarsal bones. Two markers, were placed over both heels (posterior aspects of calcaneus) at the same horizontal plane level as the toe marker. All subjects wear their shoes during conduction of the study which is more functional. So that for shod walking, markers number are placed on the corresponding places on the shoe. Finally, calibrate both of camera and force plate (Fig. 2).



**Fig. (2):** Markers placement on the shoes.

### II. Experimental protocol

Trials to adjust walking path and force place hit: To make each subject familiarized with the measurement procedures. It was considered that each subject must start from a position away enough from the measurement volume to reach a natural continuous walking pattern once he approached the measurement volume. The subject must hit the force plate with one foot at a time.

Actual walking trials: Each subject was asked to walk wearing his regular shoe across the walkway at their comfortable normal walking speed (Fig.3). Each subject was instructed to look at a distant mark on the wall to avoid looking down and targeting on the force plate.

Three correct walking trials were recorded for each subject and saved for future analysis.

**Data processing and analysis:** After capturing the correct walking trials using Q-trace software, the 3-D data for each marker were sorted for each trial, only one complete gait cycle was selected for the later analysis. The complete gait cycle starts from the moment when the subject hits the ground (initial contact) to the following hitting of the same foot plus 25% of a step length. Q-gait software: By using Q-gait software, the imported data files from the Q-trace software were analyzed to get the required kinematic and kinetic gait parameters of all joints of the body as trunk angles, hip and ankle joints angles in the sagittal and frontal planes. Hip, and ankle joints moments in the sagittal and frontal planes.



**Fig. (3):** Subject wears his regular shoes during walking.

### Data Analysis

Data was analyzed using the Statistical Package for Social Sciences (SPSS version 16). Analysis of variance (ANOVA) was used to investigate the effect of unilateral chronic ankle instability on kinematics of the hip joint.

The level of significant was set at 0.05 for all statistical tests.

## RESULTS

Gait kinematics and kinetics differences between FAI and normal groups for trunk and lower extremities were established using a 3D motion analysis system and a force plate at 90%, zero%, 10% and 30% of gait cycle (GC).

### ***I. Comparison between Functional ankle instability and normal subjects***

#### ***a. Angular kinematics***

The results of this study showed that there were no significant differences ( $P > 0.05$ ) between the FAI and normal group for the mean values of joint angles of trunk and hip joint in the sagittal and frontal planes during shod walking, as shown in Table (1 and 2).

While there were significant differences ( $P < 0.05$ ) between the two groups in the following kinematic parameters; The mean values for trunk lateral tilt towards the affected side in the FAI group were significantly higher ( $P < 0.05$ ) than those obtained towards the unaffected side and towards both sides of the normal group, these statistical differences were calculated at zero% and 10% GC.

The mean values for the ankle joint plantar flexion angle of the affected side in the FAI group were significantly higher ( $P < 0.05$ ) than those of the right and left sides of the normal group, these statistical differences were calculated at zero% and 10% GC.

The mean values of the hip joint adduction angle of the affected side in the FAI group were significantly higher ( $P < 0.05$ ) than those of the unaffected side and both sides of the normal group, these statistical differences were calculated at 90%, zero% and 10% GC.

The mean values of the subtalar joint inversion angle for the affected side was significantly higher than those recorded from both sides of the normal group, these statistical differences were recorded at 90%, zero%, 10%, and 30% GC, as shown in Table (1 and 2).

**Table (1): The mean values of trunk, hip and ankle joints angles in the sagittal plane for FAI and normal groups during shod walking.**

Gait Cycle Percentage		90%		Zero%		10%		30%		
Body side		Rt	Lt	Rt	Lt	Rt	Lt	Rt	Lt	
Kinematic parameter	Trunk extension angle	FAI	2.31° ± 1.75		4.92° ± 2.14		7.34° ± 3.61		1.84° ± 1.12	
		Normal	2.45° ± 1.38		4.27° ± 1.99		6.92° ± 4.08		2.00° ± 0.92	
	Hip flexion angle	FAI	31.27° ± 7.13	32.49° ± 6.58	28.21° ± 8.93	26.97° ± 9.08	25.32° ± 2.78	25.61° ± 3.07	1.04° ± 0.63	1.48° ± 0.21
		Normal	32.31° ± 5.90	33.06° ± 4.47	27.64° ± 7.35	28.62° ± 6.61	23.14° ± 4.39	25.02° ± 3.84	1.33° ± 0.51	1.75° ± 0.29
	Ankle plantar flexion	FAI	*-0.98° ± 1.32	*-1.37° ± 0.44	6.94° ± 0.30	6.78° ± 0.24	11.96° ± 0.28	11.85° ± 0.23	*-11.37° ± 4.93	*-12.94° ± 3.72
		Normal	*-1.25° ± 0.51	*-1.48° ± 0.29	3.00° ± 0.05	2.91° ± 0.22	7.22° ± 0.29	7.32° ± 0.23	*-13.87° ± 2.99	*-13.11° ± 3.04

\* Negative sign indicates that motion occurs in the opposite direction.

**Table (2): The mean values of trunk, hip and subtalar joints angles in the frontal plane for FAI and normal groups during shod walking.**

Gait Cycle Percentage		90%		Zero%		10%		30%		
Body side		Rt	Lt	Rt	Lt	Rt	Lt	Rt	Lt	
Kinematic parameter	Trunk lateral tilt towards the affected side	FAI	3.12° ± 2.01	3.43° ± 1.93	6.07° ± 0.40	3.19° ± 0.32	7.98° ± 0.27	4.41° ± 0.44	8.10° ± 0.52	5.11° ± 0.63
		Normal	3.52° ± 2.12	2.92° ± 2.75	2.99° ± 0.30	2.92° ± 0.27	4.33° ± 0.40	4.09° ± 0.49	5.36° ± 0.53	5.75° ± 0.59
	Hip adduction angle	FAI	1.11° ± 0.23	*-3.00° ± 0.24	5.21° ± 0.17	2.43° ± 0.34	8.11° ± 0.23	4.98° ± 0.31	4.49° ± 1.89	3.95° ± 2.37
		Normal	*-3.06° ± 0.21	*-3.03° ± 0.23	2.36° ± 0.32	2.47° ± 0.37	4.81° ± 0.34	4.76° ± 0.31	3.83° ± 2.51	4.15° ± 1.79
	Subtalar inversion	FAI	6.25° ± 1.08	6.02° ± 0.09	5.92° ± 0.25	5.79° ± 0.29	4.09° ± 0.18	3.97° ± 0.20	1.01° ± 0.16	0.95° ± 0.13
		Normal	3.45° ± 0.21	3.37° ± 0.40	1.69° ± 0.05	1.56° ± 0.10	*-3.77° ± 0.25	*-3.87° ± 0.27	*-2.00° ± 0.11	*-1.98° ± 0.16

### b. Joint moments

The results of this study showed that there were no significant differences ( $P > 0.05$ ) between the FAI and normal groups for the mean values of the joint moments around hip joint in the sagittal and frontal planes, during shod walking, as shown in Table 3.

There were significant ( $P < 0.05$ ) differences between the two groups in the following kinetic parameters: The mean values of the ankle joint dorsiflexion eccentric moment around the affected side in the FAI group were significantly lower ( $P < 0.05$ ) than those of the right and left side of the normal

group, these statistical differences were calculated at zero% GC and 10% GC.

The mean values of hip joint adduction moment were significantly higher ( $P < 0.05$ ) around the affected side of FAI group than those around the unaffected side and both sides of the normal group, these statistical differences calculated at zero% and 10% GC.

The mean values of subtalar joint inversion moment were significantly higher ( $P < 0.05$ ) around the affected side of the FAI group compared with the right and left side of the normal group, these statistical differences were calculated at zero%, 10% and 30% GC.

**Table (3): The mean values of hip and ankle joints moments (N.m/kg) in the sagittal and frontal plane for FAI and normal groups during shod walking.**

Kinetic parameter			Gait Cycle Percentage		Zero%		10%		30%	
			Body side		Rt	Lt	Rt	Lt	Rt	Lt
Sagittal plane	Hip extension moment	FAI	0.43 ± 0.20	0.48 ± 0.19	0.42 ± 0.17	0.40 ± 0.18	*-0.71 ± 0.23	*-0.67 ± 0.21		
		Normal	0.50 ± 0.17	0.49 ± 0.17	0.41 ± 0.11	0.38 ± 0.21	*-0.70 ± 0.22	*-0.72 ± 0.24		
	Ankle dorsiflexion moment	FAI	0.05 ± 0.02	0.06 ± 0.03	0.15 ± 0.04	0.17 ± 0.04	1.31 ± 0.72	1.36 ± 0.62		
		Normal	0.13 ± 0.04	0.14 ± 0.05	0.32 ± 0.05	0.31 ± 0.04	1.29 ± 0.83	1.38 ± 0.97		
Frontal plane	Hip adduction moment	FAI	0.26 ± 0.04	*-0.28 ± 0.04	0.92 ± 0.11	0.46 ± 0.05	0.41 ± 0.18	0.37 ± 0.14		
		Normal	*-0.28 ± 0.08	*-0.31 ± 0.05	0.44 ± 0.06	0.42 ± 0.08	0.40 ± 0.13	0.38 ± 0.16		
	Subtalar inversion moment	FAI	0.29 ± 0.03	0.27 ± 0.04	0.32 ± 0.04	0.29 ± 0.04	0.21 ± 0.04	0.22 ± 0.04		
		Normal	*-0.29 ± 0.04	*-0.28 ± 0.06	*-0.61 ± 0.03	*-0.62 ± 0.02	*-0.35 ± 0.03	*-0.34 ± 0.04		

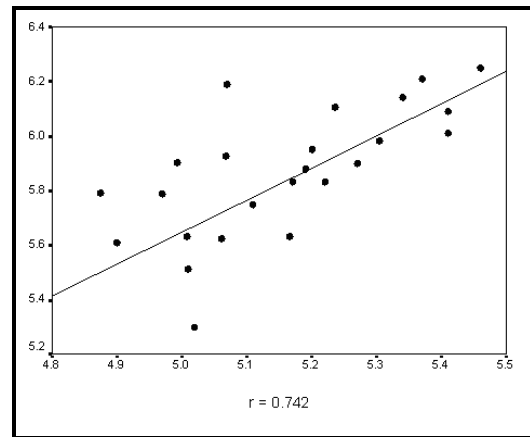
\* Negative sign indicates that motion produced by the moment of the opposite muscle group.

**II. Comparison between the affected and unaffected sides of FAI group**

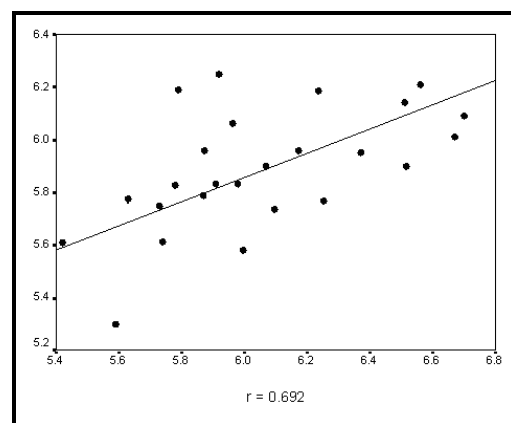
One way ANOVA showed that there were no significant differences ( $P > 0.05$ ) between the affected and unaffected sides for the mean values of the joint angles and moments at the ankle joints in the sagittal and frontal plane and trunk and hip joint in the sagittal plan at 90%, zero%, 10% and 30% GC. The mean values of the affected side were significantly higher ( $P < 0.05$ ) than those recorded from the unaffected side for the following kinematic and kinetic parameter: Hip joint adduction at 90%, zero%, 10% and 30% of GC. Hip abduction moment at zero% and 10% of GC, and trunk lateral tilt towards the affected side at zero% and 10% of GC.

**III. Correlations between frontal distal (subtalar) and proximal (trunk and hip) adaptations in FAI group**

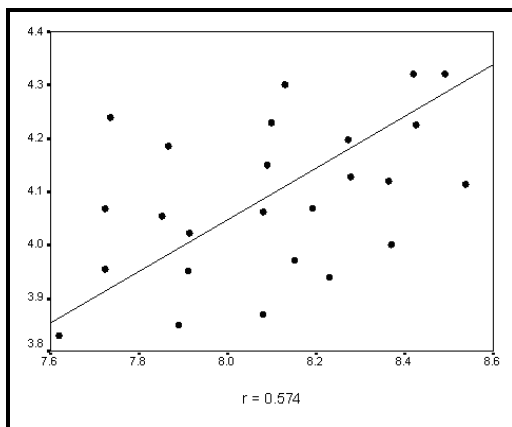
Pearson correlation tests showed the there was high positive correlation between subtalar joint inversion and hip joint adduction. The estimated coefficient of correlation at zero% GC,  $r = 0.742$  (Fig. 4) and at 10% GC,  $r = 0.692$  (Fig. 5). Moreover, there was positive correlation between subtalar joint inversion and lateral trunk tilt towards the affected side. The estimated coefficient of correlation at zero% GC,  $r = 0.574$  (Fig. 6) and at 10% GC,  $r = 0.608$  (Fig. 7).



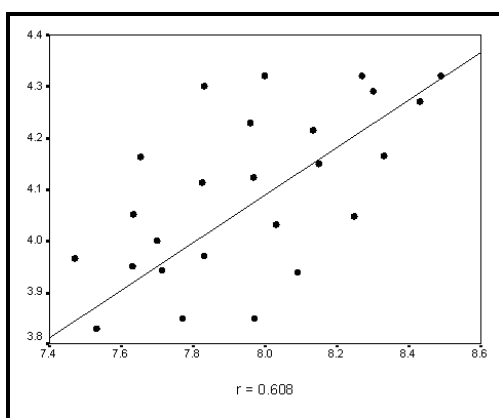
**Fig. (4): The correlation between subtalar joint inversion and hip joint adduction at zero% GC.**



**Fig. (5): The correlation between subtalar joint inversion and hip joint adduction at 10% GC.**



**Fig. (6):** The correlation between subtalar joint inversion and lateral trunk tilt towards the affected side at zero% GC.



**Fig. (7):** The correlation between subtalar joint inversion and lateral trunk tilt towards the affected side at 10% GC.

## DISCUSSION

This study was conducted to investigate whether ankle adaptations are correlated with trunk and hip adaptations in unilateral functional ankle instability in comparison with normal subjects during walking with regular shoes. There are important methodological considerations to be taken into account when interpreting the results of this investigation. In the present study, the controls were matched with those of FAI group for age due its influence on velocity and for gender mainly due to different mass distribution and different rations between body segment lengths<sup>17</sup>.

The walking pace chosen in this study represented their most comfortable and natural walking speed. This speed was chosen to reduce variability of gait trials as it has been demonstrated that variability increases when individuals walk faster or slower than their

free selected pace<sup>25</sup>. It is advised in the literature to use multiple trials for analysis to represent the individuals gait pattern due to natural gait variability<sup>17</sup>. So, the average of three trials was calculated for analysis and comparison between the FAI and the normal groups.

When designing this study with a unilateral affection, the choice had to be made between testing the unstable leg against opposite or against controls. Previous researches showed evidences of bilateral postural deficits in the FAI subjects even if the condition is unilateral<sup>1,13,35</sup>. Based on these findings it was decided to test against controls as testing against the opposite limb might not show any deficits. Analysis was delimited to the sagittal and frontal planes only as it was reported that most of gait adaptations happen in the planes at which joint motions are wide enough<sup>8</sup>.

The results showed increased inverted foot position throughout the studied part of GC. The increased magnitude of abnormal foot inversion could be attributed to the weight and breadth of the shoe. The latter causes an increase in the length of the inverting force lever arm. On the other hand, the reported weakness of unstable ankle evertors makes the foot more vulnerable to repeated bouts of hyperinversion resulting in micro-traumas to the lateral ankle ligaments<sup>33</sup>.

Another alteration in the kinematic pattern of the FAI subjects during shod walking is a significant increase in the values of ankle joint plantar flexion at zero % and 10% of GC. Nordin and Frankel<sup>22</sup> demonstrated that at heel strike the GRF vector passes posterior to the axis of the ankle joint causing a plantar flexion moment that tends to clap the forefoot down on the ground. The heel of the shoe causes the GRF vector to move more posteriorly in relation to the joint axis producing a lever arm that is considerably larger than that produced with a barefoot.

The shoes put the foot in a position of increased plantar flexion puts the ankle in a risky situation at the beginning of stance phase since this foot position is inherently less stable than foot dorsiflexion. The shape of the talus, which is wide anteriorly and narrow posteriorly, gives less stability while the ankle

is plantar flexed. It has been shown that examining the drawer sign of the ankle in a position of 15° plantar flexion gives the maximum forward displacement in individuals with FAI<sup>24</sup>.

The results of this present study also showed a significant decrease in the degree of hip abduction at 90% of GC while values obtained at zero% and 10% showed significant increases of hip joint adduction. The change in hip kinematics in the FAI individuals in comparison with normals suggested the need for hip strategy during shod condition. This additional proximal adaptations seems to happen when the ankle strategy is not sufficient to maintain balance during the oncoming unilateral stance.

These findings are consistent with the theoretical concept explained by Riemann<sup>28</sup> who stated that the ankle joint would have been likely the location for the adaptations necessary to remain in equilibrium. Assuming high degrees of ankle instability would give rise to compensatory adaptations at a proximal location. This location was identified to be the hip joint in cases of functional ankle instability.

This study showed also increased lateral deviation of the trunk towards the affected side in the FAI group as compared with the controls. Shifting the trunk towards the supporting limb in stance is a useful substitute to reduce the demands on hip abductors. This action reduces the adduction torque created by the trunk mass through moving the weight towards the center of the supporting hip. The amount of lateral lean varies with the demand and/or weakness of the hip musculature<sup>26</sup>.

A strong relationship is documented between hip joint, pelvic and lumbar spine motions in closed-chain situations. An important example of these relations can be seen during gait. When subjects walk, the pelvis elevates slightly around the supporting hip joint (hip joint adduction). If the head and trunk followed the pelvis, the body would lean away from the supporting extremity and the line of gravity would fall outside the supporting foot. Instead, the spine laterally flexes towards the side of supporting limb to keep in equilibrium. This example given by

Levangie and Norkin<sup>22</sup> would give reason for the significant increase in trunk lateral tilt towards the unstable side in the FAI group.

The altered inverted foot position found in the FAI group in this study was associated with invertors moment during the studied part of GC opposite to the evertors moment exerted by the normal group. The invertor moment produced increases the supination moment that caused the to counteract the ankle instability. During walking with wearing shoes, many difficulties face the evertors in their ankle sprain prevention mission. First, the increased functional demand on the evertors due to increased magnitude of the opposing inverting moment. In this situation the foot and shoe can be regarded as a single entity working through a longer lever arm than that produced in barefoot condition<sup>23</sup>. Second, the increased ankle plantar flexion which created a significant delay in the response of the peroneal muscle group. This was reported by Lynch et al.,<sup>16</sup> who found that increased plantar flexion causes a corresponding increase of evertors muscles electromyographic latency. They suggested that an increase in the planar flexion position caused a decreased distance from origin to insertion of peroneal muscles which create some changes in muscle tone or latency. Third, shoes impair the awareness of foot position during locomotion that is provided by plantar tactile sensitivity. It has been reported that this plantar sensation plays a very important role in postural control<sup>19</sup>. These factors would explain why the evertor muscle might frequently fail to counterbalance the developed inversion moment in subjects with FAI when shoes are worn.

The study showed diminished dorsiflexors moment during the early stance phase of gait as compared with the normal group. The decrease of this counterclockwise moment allowed greater values of ankle joint plantar flexion to happen at zero% and 10% of GC. Decreased control of ankle dorsiflexors on gradual descent of the foot into the ground was more obvious in shod walking because of the increased opposite moment due to the weight of the shoe and the longer lever arm caused by the heel of the shoe<sup>22</sup>. It was



claimed by Wright et al.,<sup>39</sup> that increased touchdown plantar flexion might be the mechanism which causes ankles with history of ankle sprains to have an increased susceptibility to subsequent sprains. Meanwhile, touchdown subtalar joint angle was not found to have a considerable influence on sprain occurrence.

Early hip abduction moment at initial contact appeared in the FAI persons instead of the regular adduction moment in the normal group. This hip strategy used by the FAI subject to control the increased adduction values at heel strike. Hip adduction was reported to be used during shod walking as an alternative to lateral shift of the COG during barefoot walking. Excessive COG lateral shift may cause the lateral border of the foot to act as a fulcrum that induces sudden inversion of the foot beneath the weight bearing leg<sup>38</sup>.

These results agree with the findings of Beckman and Buchanan<sup>2</sup> which revealed a decrease in gluteus medius latency in individuals with FAI in response to ankle/foot inversion perturbation. At the same time, they disagree with those of Bullock-Saxton<sup>3</sup> which showed bilateral delay of gluteus medius latency in subjects with severe unilateral ankle sprain. The difference in the severity of ankle sprains may clarify the reason for disagreement between the two studies. McVey et al.,<sup>20</sup> suggested that arthrogenic muscle inhibition is present in the musculature of patients exhibiting severe functional ankle instability. The weakness of hip abductors on the involved side reported by Friel et al.,<sup>10</sup> could be attributed to the use of leg dynamometer in the assessment of isometric muscle strength. The muscle behaviour could be different in a weight bearing functional situation such as walking which was used in the current study.

The increased demand on hip abductors in the FAI group during 10% of the GC appears in the form of significantly greater values of abductor moments than those found in the normal group. Shifting the trunk towards the supporting limb in stance is a useful substitute to reduce the demands on hip abductors. This action reduces the adduction torque created by the trunk mass through moving the weight towards the center of the

supporting hip. The amount of lateral lean varies with the demand and/or weakness of the hip musculature<sup>26</sup>.

No significant difference was found between the affected and unaffected sides on the distal (ankle and subtalar) level. Surprisingly, this was not the case on the proximal level (hip and trunk). A significant difference was found between both sides regarding hip adduction and trunk lateral tilt towards the affected side. There are two possibilities to explain these results. The first one is that bilateral proximal adaptations may lead to increased energy expenditure and increased wear and tear of spinal structures. So, proximal adaptations are kept at minimal to keep functional performance as close to normal as possible. The other one is that it takes longer time for proximal adaptations to be bilateral than distal adaptations. The mean age of the FAI group in the present study was too young to detect the bilateral alterations at the hip and trunk level especially in a non-athletic population.

The positive correlation between subtalar joint inversion, hip joint adduction and trunk lateral tilt in individuals with FAI represent frontal plane integration for side to side control of posture. Riemann<sup>28</sup> clarified that dynamic conditions would require continuous reorganization of the body's center of mass over the moving base of support. To remain in equilibrium, necessary adaptations would take place in the ankle joint. The manner in which postural control is maintained appeared to be altered in patients with functional ankle instability (i.e., increased reliance on corrective actions at the hip joint).

These results are consistent with that of Tropp and Odenrick<sup>34</sup>, who examined the ankle and hip kinematics of single leg stance (eye open) in FAI and normal group. They concluded that subjects with instability displayed a higher reliance on the hip joint for postural corrections than healthy participants. It is possible that this altered strategies enable persons with FAI to demonstrate normal equilibrium as measured by force plate variables; especially centre of pressure, leading investigators to conclude that no difference in postural control exists between FAI and normal subjects<sup>14</sup>. The significant

increase in hip strategy was resolved completely after eight week ankle disk training program<sup>27</sup>. This explains the high correlation between subtalar and hip joints adaptations in the current study with the participants being non-athletic with no present participation in formal rehabilitation program.

The results of current study are supported by the findings of recent researchers<sup>5,30,32,37</sup> that identified altered spinal-level motor control mechanisms in persons with chronic ankle instability. Moreover, Hass et al.,<sup>12</sup> proved that chronic peripheral joint injury as lateral ankle sprains negatively alters supraspinal aspects of motor control to place a greater emphasis on reducing the postural demands on the involved limb, these supraspinal alterations should be considered either maladaptative or ineffective changes to the organization of movement.

### Conclusion

Gait changes were exhibited during shod walking on the distal level, increased ankle plantar flexion occurred at zero% and 10% of GC. This happened mostly due to inability of the ankle dorsiflexors to control the gradual descent of the forefoot on the ground during the early stance phase. On the proximal level, the FAI subjects started to use hip strategy in form of decreased hip abduction pre-heel strike and increased hip adduction at heel strike and loading response. These great values of hip adduction angles were controlled by an abductor moment which increased especially at 10% of GC. The use of hip adaptations was associated with lateral tilt of the trunk towards the affected side to decrease the load on the ipsilateral hip abductors. There was no difference at the distal (ankle and subtalar) joints level between the affected and unaffected sides of the FAI persons. However, similarity between both sides could not be applied on the exhibited proximal adaptations. Also, correlations were found between subtalar joint inversion, hip adduction, and lateral trunk tilt towards the affected side at 10% and 30% of the gait cycle.

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### الملخص العربي

#### التغيرات في حركات الجذع والخذ الميكانيكية المصاحبة لعدم إتزان الكاحل الوظيفي أثناء المشي

ثبات مفصل الفخذ والجذع وقوته مهم جداً حتى تكون ميكانيكية المشي دقيقة ويكون وضع القدم على الأرض سليم ، وبما أن مفصل الكعب يحتاج توافق عضلي عصبى أثناء مراحل دورة المشي المختلفة لذلك فإنه من الضروري توافق كل مفاصل الطرف السفلى لضماناً للثبات أثناء المشي . لذلك أجريت هذه الدراسة لتحديد تأثير عدم ثبات مفصل الكعب الوظيفي على حركات المشي الميكانيكية لفصل الفخذ والجذع. ولقد أجريت الدراسة على خمسين شخصاً ( 25 من المصابين بعدم إتزان الكاحل الوظيفي و 25 من الأصحاء المشابهين لهم في السن والجنس ومستوى النشاط البدني وسرعة المشي) . وقد تم تحديد الفروق الكيناميكية والكيناتيكية في طريقة المشي بين المجموعتين باستخدام جهاز تحليل الحركة ثلاثي الأبعاد وبلاطة قياس القوى عند صفر وعشرة وثلاثون وتسعون في المائة من دورة المشي ، علماً بأن جميع الأشخاص يرتدون حذائهم أثناء القياس . وقد أظهرت الدراسة أنه أثناء المشي يوجد زيادة واضحة في سقوط القدم وانقلابها للداخل وزيادة ملحوظة في زاوية ضم الفخذ للداخل وانحناء العمود الفقري في اتجاه الجانب المصاب . وقد وجد ارتباط وثيق بين هذه التغيرات وتلك التي تحدث على مستوى الكاحل في نفس السطح الحركي . ولهذا نوصي بمراعاة كل هذه التغيرات المرضية أثناء وضع برامج التأهيل للأشخاص المصابين بعدم الاتزان الكاحل الوظيفي .

الكلمات الدالة : كيناميكية وكيناتيكية ، عدم الاتزان الكاحل الوظيفي ، المشي بالحذاء .