

# Dynamics Study of Ankle Joint during Quiet Standing Balance Control with Emphasis on Dominant and Non-dominant Lower Limb

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## ABSTRACT

**Purpose:** The present study aimed to evaluate the effect of dominant lower limb on the correlation between some of the dynamic variables of ankle joint and center of mass during quiet standing balance control.

**Methods:** Twelve healthy females with no known neurological or musculoskeletal disorders, with the mean age of  $26 \pm 3.5$  years, participated in this study. Motion analysis system, force platform and Visual3D software were utilized in order to measure and compute the research variables. The relationship between research variables was evaluated using Pearson's correlation coefficient. T test and One-way ANOVA were used to examine the effect of dominant leg on the correlations.

**Results:** Findings indicated the correlation between ankle joint moment and center of mass displacement ( $r=0.95$ ) was higher than the correlation between ankle angular displacement and center of mass displacement ( $r=0.84$ ). It seems that the leg factor (dominance and non-dominance) does not influence the correlation of angular displacement of ankle joint and center of mass displacement. However, it influenced the correlation between ankle joint moment and center of mass displacement.

**Conclusion:** Therefore according to the present study it can be said that the kinetic variables of ankle joints are more important than kinematic variables for the prediction of center of mass displacement. In addition, it is suggested that in order to evaluate the lower extremity dynamics, during balance control, dominant and non-dominant lower limbs of the subjects be noticed too.

## 1. Introduction

According to the definition generally proposed for the balance, quiet standing balance control is preserving and controlling center of mass at base of the support [4-6]. Therefore, while assessing and measuring the balance, the researchers pay attention to the movements of center of mass. Concentrating on

the mass center as a biomechanical variable for assessing balance should be taken into account for some reasons. Firstly, estimating center of mass is technically complicated, cumbersome, costly, and error prone. This had made researchers to use another variable termed center of pressure for balance assessment. Although, center of pressure variable does not evaluate balance and stability of posture, its movement (only in limited conditions) is a result of secondary movement of center of mass [7, 8].

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Therefore, a wide range of researches on body balance have dealt with this issue in order to specify correlation between the kinematic elements of center of mass and foot center of pressure so that to introduce it as a standard factor for balance assessment. However, this factor has not been fully specified and there is no general census on it [9].

Another factor which can challenge application of center of mass as a major variable for assessing and measuring balance is that the center of mass can be a hypothetical point, which is indirectly stabilized. Consequently, controlling other variables such as joints position in relation to their baseline position will lead to control and stabilization of center of mass [10].

Thus, it seems logical that researchers concentrate on joints kinetics and kinematics rather than directly focusing on the center of mass or foot center of pressure as a major variable. A part of researches on balance control have been centralized on determining movement strategies, joint participation, and sensory systems manipulation on movement strategies. Winter researches in this regard had led to propose inverted pendulum model [7].

This model is based on the principle that at quiet standing balance control, the whole body oscillates around horizontal axis, which passes through center of ankle joint. Many researches have been carried out in different areas related to body balance with emphasis on inverted pendulum model. Also, in recent century, several other researches have been done with the aim of studying the role of other joints at quiet standing balance control. The results revealed that in addition to ankle joint, other joints of lower extremities and even the body have movements at quiet standing balance control [11-13].

Although in all of the mentioned researches, the purpose is to determine the movement strategies and to make an effort to remove the existing ambiguities in mechanisms of controlling balance, studying the results revealed that ankle joint motor function is significant in quiet standing balance control.

Therefore, we can concentrate on ankle joint for balance assessment and posture control. However, it is important to study the correlation between movement variable of this joint and movement of mass center. To deal with this issue, we can propose the following question. Do two ankle joints play an equal role in controlling balance at standing position on both legs? Researchers believe that individuals control their balance on one leg better than the other. This belief originates from several

researches, which investigated the role of dominant lower limb in balance control [1,14]. One of the purposes of this part of research is to show why athletes' injuries during sport activities are more observable in one leg than the other one [1].

Furthermore, specifying the amount of participation of each lower limb during balance control can be useful in offering rehabilitation programs or body building exercise for athletes. However, it is necessary to mention that the implementation method in said researches is as follows: having specified the dominant lower limb, the subjects perform the balance test at single leg standing position and then the results of the study variables between dominant and non-dominant lower limb are compared. None of these researches studied the effect of dominant leg at quiet standing balance control.

Even in studies, which were carried out with the purpose of assessing movement mechanisms and manner of participation of lower extremities joints for balance control at quiet standing. Although the tests were performed at standing position, the investigations were done with random selection of one leg and without specifying the dominant lower limb [15,16,17]. This negligence of dominant lower limb of subjects can affect presentation and report of the results of relevant researches.

Thus, due to the importance of ankle joint for balance control at standing position and considering the possibility of difference in participation of this ankle for quiet standing balance control in dominant and non-dominant lower limbs, in the present study, we have attempted to study some of dynamic variables of ankle joint and center of mass. We were also determined to specify the effect of dominant lower limb in this regard.

## 2. Materials & Methods

### Subjects

The participants of the present study consisted of 12 healthy females, with the mean age of 24-34 years, mean height of  $168 \pm 4.4$  cm, and mean weight of  $61 \pm 6.0$  kg who were selected randomly.

The subjects had no neurological or musculoskeletal disorders. The variables were measured after giving information to subjects about the test performance and obtaining consent letter at Musculoskeletal Research Center, Rehabilitation Faculty of Isfahan University of Medical Sciences.

## Tools

The kinetic information included ground reaction force (in horizontal and vertical direction). Instantaneous position of foot center of pressure was determined using Kistler force plate. Ankle joint moments at sagittal plane were calculated with inverted dynamic method using Visual 3D software.

Three dimensional data collection for calculating kinematic variables, which were angular displacement of ankle joint and center of mass, was done by using Qualisys track manager system. These data were obtained by 7 cameras from markers, which were directly placed on skins of subjects. A total of 55 markers with 14 mm were placed on anatomical parts of body with the technique of Visual 3D marker placement. The visual 3D was used to calculate ankle joint angle and estimate center of mass at sagittal plane. Since the position of mass center was determined with kinematic method [18], it was necessary to mark all parts of the body, including foot, leg, thigh, pelvis, trunk, and upper limb. The angle between foot and leg was considered as ankle joint angle.

## Data processing

The sampling frequency for collecting kinetics and kinematics data was 200 Hz. This information were filtered using fourth-ordered Butterworth filter. Cut-off frequency for kinetics and kinematics data were 10 and 5, respectively [2,3,15].

## Tests

The tests were performed as follows: every subject stood on force plate at balanced and standing position for one minute. The arms were placed beside the body and the subject looked at the plate, which was 3 m away and at horizontal direction. The distances between the legs were not determined before the test and the subject chose it, which shouldn't be more the shoulder's width. The test-retest was performed 4 times and the rest between the tests was 3 min.

## Determining the dominant leg

The two tests of kicking with leg and stepping forward was used for specifying lead leg in subjects. The results revealed that there is a significant correlation between these two tests for specifying lead leg [19].

The results of several researches indicate that most individuals use the opposite leg of lead leg for posture stability [20,21]. Therefore, in the present study, the opposite

leg of lead leg is considered as supporting leg (dominant leg).

## Body weight distribution on lower limbs

The manner of body weight distribution on each lower limb was assessed during the test. For this purpose, during the test the percentage of time, which the center of pressure inclined laterally toward each foot was calculated and registered. Generally, the COP moved between two feet at standing position. When the body weight distribution is more on one lower limb, the COP inclines toward that foot [22].

These estimations were made based on the instantaneous position of markers placed on lateral ankle and instantaneous movement position of COP in lateral direction using Matlab software.

## Data analysis

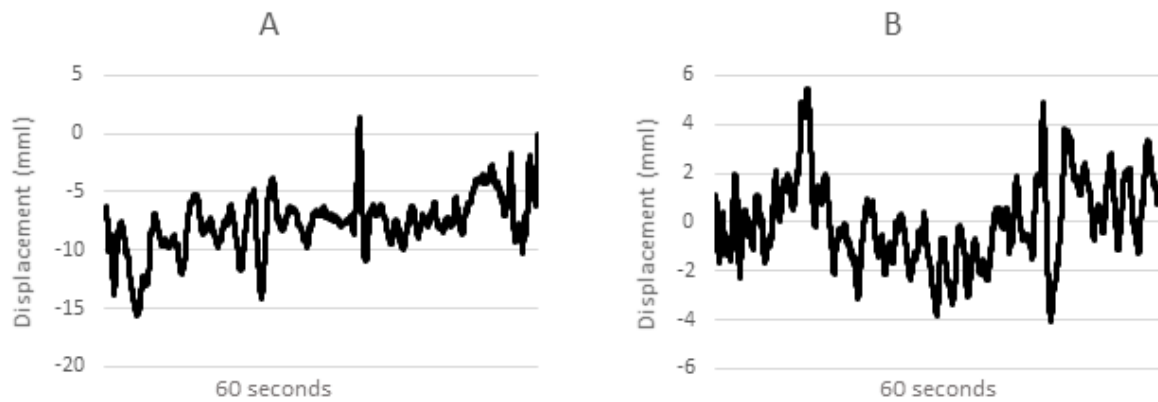
The correlation between two variables of joint angular displacement and joint movement of ankle with COM displacement was studied in 48 trials using Pearson regression. In order to compare values of the mentioned correlations (i.e., correlation of ankle joint displacement with center of mass displacement and correlation of ankle joint moment with center of mass displacement) paired sample t test was applied.

And finally, for evaluating the effect of dominant and non-dominant lower limb on correlation, one-way ANOVA was utilized.

## 3. Results

For data analysis, at first, the time percentage of COP inclination toward each foot during tests were studied. The results revealed that in 39 trials (out of 48 retests) the COP inclined toward dominant lower limb (in 85% of retests). In 9 trials, the COP inclination toward dominant and non-dominant lower limbs was approximately the same during the test (in 15% of trials). In figure 1, two patterns of COP displacement to lateral direction and its inclination toward dominant and non-dominant feet are presented. The negative displacement indicates COP inclination toward dominant foot and positive inclination indicates COP inclination toward non-dominant foot during the test.

Paired t test showed that the difference between weight distribution on dominant and non-dominant lower limb was statistically significant ( $P < 0.001$ ).



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**Figure 1.** COP displacement to lateral direction. (A): In 98% time of test, COP is inclined toward the dominant foot (displacement values in 98% of time test is negative). (B): In 54% of time of test, COP is inclined toward the dominant foot (displacement values in 54% of time test is negative).

The results of this section generally reveals that at standing position, the weight transfers from one lower limb to another, but in most cases (almost 85% cases) weight distribution is more on dominant lower limb.

The values related to correlation of center of mass displacement with the moment and angular displacement of ankle joint in dominant and non-dominant lower limb in all 48 trials are presented in Table 1. The results revealed that there was a strong correlation between angular displacement of ankle joint and center of mass displacement and this correlation was similar in dominant and non-dominant lower limb, which were  $0.84 \pm 0.12$  and  $0.80 \pm 0.2$ , respectively. However, the correlation between center of mass displacement and joint moment in joints of dominant and non-dominant lower limbs is not the same, so that the values for dominant and non-dominant lower limbs are  $0.95 \pm 0.05$  and  $0.43 \pm 0.2$ , respectively. As it is seen, the correlation was very strong in dominant lower limb.

A more accurate study of the results of Table 1 in joint moment reveals that the maximum and minimum cor-

relation between center of mass displacement and ankle joint moment in non-dominant lower limb is ( $r=0.98$ ) ( $r=0.16$ ), respectively. This means that the correlation between joint moment and center of mass displacement in non-dominant lower limb has been strong in some cases ( $r=0.98$ ). Generally out of 48 tests only in 6 tests, the correlation was higher from 0.75.

This can be related to manner of weight distribution of subjects on lower limbs. During the test, although weight distribution in most cases was on dominant lower limb, in some cases the subjects put weight on non-dominant lower limb. It should be mentioned that these results correspond to the results of lateral displacement of COP between two feet.

The result of the study of variance analysis shows that (Table 2) although the lower limb factor (dominant or non-dominant) has no effect on correlation between linear displacement of center of mass and angular displacement of ankle joint, it significantly affects correlation of center of mass displacement and ankle joint moment ( $P < 0.001$ ).

**Table 1.** Correlation of linear displacement of center of mass with angular displacement and ankle joint moment (sagittal plane)

Linear displacement of center of mass (Anterior & Posterior)				
	Angular displacement of ankle joint		Ankle joint moment	
	Dominant lower limb	Non-dominant lower limb	Dominant lower limb	Non-dominant lower limb
Mean	0.84	0.80	0.95	0.43
Standard deviation	0.12	0.20	0.05	0.23
Maximum	0.98	0.97	0.93	0.98
Minimum	0.49	0.35	0.73	0.16

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**Table 2.** Results of variance analysis. The effect of dominant lower limb on correlation between center of mass and joint dynamic variables.

		Sum of squares	Mean of squares	Degree of freedom	F	Significance
Joint angular displacement	Intergroup	0.026	0.026	1	0.509	0.477
	In group	4.8	0.051	94		
Joint moment	Intergroup	6.39	6.39	1	172.04	0.000
	In group	3.49	0.037	94		

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On the whole, the above studies revealed that there is a significant relationship between two kinematic and kinetic variables (i.e. angular displacement of ankle joint and ankle joint moment) and center of mass displacement in dominant lower limb. But this correlation is higher for joint moment variable compared to angular displacement. Paired t test was used to determine the significance of this difference in said correlations.

The results indicated that the correlation between joint moment with center of mass displacement in dominant lower limb ( $r=0.95$ ) is significantly higher than the correlation between joint angular displacement and center of mass linear displacement ( $P<0.001$ ).

### Discussion

Since the importance of the ankle joint role for quiet standing balance control has been accepted [7,11-13], the kinematic and kinetics variables have been studied in several researches. The present study attempted to answer two important questions, which have not been dealt with before. First, which variable is more important for predicting movements of center of mass (ankle joint kinematic variable or kinetic variable), and second, whether the ankle joint in dominant and non-dominant leg has a similar role in body balance.

The study of the relationship between angular displacement of ankle joint and center of mass displacement revealed that there is a high correlation between these two variables ( $r=0.82$ ). The study of Gage and Winter also confirms this matter [13] so that according to their assessment, the value of this correlation is 0.88. The study of relationship between ankle joint moment and center of mass displacement indicated that there is a strong correlation between these two variables ( $r=0.95$ ). Cunther et al also reported the value of this correlation ( $r=0.90$ ) [11].

But the important point in the present study was comparison of these relationships between dominant and non-dominant lower limbs. The findings showed that the observed correlation between center of mass displacement and joint angular displacement is the same in dominant and non-dominant lower limbs, however, the strong correlation between center of mass displacement and joint moment was significantly higher in dominant leg than non-dominant lower limb.

The reason for difference in joint performance of non-dominant and dominant lower limbs in joint moment can be due to the manner of weight distribution at quiet standing balance control. The study of COP displacement between two feet revealed that during the test, COP is inclined more toward dominant lower limb. The results of previous studies prove this as well, so that the weight distribution on lower limbs is not parallel at quiet standing balance control [23,24]. The study of Gutnika et al also revealed that during quiet standing balance control, weight distribution was more on one lower limb than the other one [25]. It should also be mentioned that in another study, the difference in dynamic performance of right and left lower limb joints has been reported [11].

The result of the assessment of kinematic relationship of ankle and thigh joints in right and left leg in the said study revealed that [11] there was a significant correlation between dynamic performance of these two joints during posture control, but this correlation has been observed in 24 trials in right leg and in 28 trials in left leg (the total trials in the said study was 60).

The strong point of the said study was that the performance of joints in right and left leg were studied simultaneously (contrary to most researches related to balance, which chose randomly one of the legs for assessment of joints movements), but no attention was paid to the dominant and non-dominant lower limbs of subject and due to this fact, the reason for the observed



difference in the results of right and left leg are not discussed and only reported, while this difference can result from the difference in the performance of dominant and non-dominant lower limbs of subjects.

Another part of the results of the present study showed that in dominant lower limb joint, the correlation between joint moment and center of mass displacement is significantly higher than correlation between joint angular displacement and center of mass displacement ( $P < 0.001$ ). Therefore, it seems that the kinetic variables are more appropriate than joint kinematic variables for predicting center of mass movements.

#### 4. Conclusion

The result of the present study revealed that there is a strong correlation between two variables of angular displacement of ankle joint (in both lower limbs) as well as ankle joint moment (in dominant lower limb) and variable of center of mass linear displacement. However, the correlation obtained from ankle joint moment of dominant lower limb and center of mass displacement is significantly higher than correlation of angular displacement of joint ankle and center of mass displacement.

Thus, for predicting center of mass displacement during postural control, it is important to pay attention to kinetic variables. In addition, according to the results of the present study, it is recommended to take into account the dominant and non-dominant lower limbs of subjects while studying dynamics of lower limb joints during balance control.

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