

**Correlation of Navicular Drop Height and Force Foot Distribution  
Characteristic and Pelvic Drop in Asymptomatic Runners****Andi Fadhilah Tenriwulan<sup>1✉</sup>, Komsak Sinsurin<sup>2</sup>,  
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**Abstract**

To explore the difference of performance between lower limbs and correlation of the navicular drop height and force distribution parameters during running. This study was conducted in the annual running performance test of Physical Therapy Center, Mahidol University. Before running test, navicular drop test was performed. Force distribution parameters were recorded over 7 minutes during running on the Force Distribution Measurement Treadmill (FDM-T) system. Contralateral pelvic drop (CPD) was captured with a video camera. Paired-samples t-test and Pearson or Spearman rank correlation tests were used for statistical analysis. Twenty-nine participants were enrolled in this study. They were asymptomatic runners (novice and recreational). The finding showed that there was no correlation of navicular drop height and force distribution parameters and foot rotation. There were no significant differences of all parameters except with navicular drop height. There was significant difference of navicular drop height between legs in runners. For the pelvic obliquity, the result showed non-significant difference between non-dominant 95% CI (2.5 – 4.5) and dominant 95% CI (3 – 5) ( $p = 0.59$ ) with low effect size ( $d = 0.2$ ). In asymptomatic male and female runners, no significantly side-to-side difference during dynamic running test is an expectation for clinical observation. Typical range of CPD during running might be 3-5 degrees. Based on our finding, navicular drop may not a good predictor for force distribution characteristics during running test.

**How to Cite**

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## INTRODUCTION

The epidemiological study has estimated that up to 70% of runners sustain an overuse running injury each year (Ferber, Hreljac, & Kendall, 2009). Lower extremity was the common injury in runners, about 7.2% - 50.0% for the knee, 9.0% - 32.2% the lower leg, 5.7% - 39.3% the foot, 3.4% - 38.1% upper leg (van Gent et al., 2007).

Biomechanical studies of running have been suggested that excessive repetitive musculoskeletal loads, higher impact, navicular drop (atypical foot pronation), force distribution (center of pressure), poor alignment, peak hip adduction, contralateral pelvic drop (CPD), and high stresses relate to the risk of overuse injury (Bramah, Preece, Gill, & Herrington, 2018; Buist, Bredeleg, Lemmink, van Mechelen, & Diercks, 2010; Creaby et al., 2017; van der Worp et al., 2015). However, in some runners, they are showing injury risks but there is no any symptom who is called as asymptomatic runner (Schueller-Weidekamm, 2010).

Excessive navicular drop and abnormal distribution of foot pressure during running contribute to overuse injuries such as patellofemoral pain syndrome, medial tibial stress syndrome, achilles tendinopathy, tibial stress fractures, gastrocnemius/soleus strains/tears, and plantar fasciitis (Bennett, Reinking, & Rauh, 2012; Condry, Himmerick, & VanHaaften, 2017; Fuller, 1999). Previous study reported that greater than 10 mm of navicular drop height was higher risk of medial leg pain (Neal et al., 2014). If the center of pressure (CoP) distribution in injury runners was changed from normal pattern, it would be lead to seriously well-being in runners (Razak, Zayegh, Begg, & Wahab, 2012). Therefore, navicular drop and CoP usually are examined and assessed in runners in order to detect the possible cause of injury, injury prevention, and observe the progression of physical therapy program (Fuller, 1999; Morrison et al., 2010)

A symmetry between non-dominant and dominant limbs during running requires to reduce the risk factor of injury and may help to keep a longer time of running performance (Carpes, Mota, & Faria, 2010). If there is an asymmetry, a stress on one side of the body will probably occur. However, it does not conclude yet about the relationship between asymmetries and potential risk for injuries. In 2018, Hanley et al (Hanley & Tucker, 2018) studied a symmetry of lower limb movement on gait parameter in 10km treadmill running. They found that asymmetry was the gap between left and right about 1.2% of contact

time, step length, step frequency, flight time, and impact force.

Currently, high technology equipment is getting more popular for assessing running performance such as the machine of force distribution measurement (FDM). However, limitation of high technology tool is expensive and needed high skill of using. This may not applicable in clinical setting. It was an interesting to study an association between clinical and laboratory tests that were navicular drop and running force-distribution measurement.

The contralateral pelvic drop (CPD) has been suggested as an important factor influencing stress tissue injury on lower limb. From the literature review, an increase CPD will increase peak hip adduction about 40 followed by increasing knee abduction moment, increasing bending force on medial tibia, and altering the pressure distribution of foot. Then, the injury comes out to the knee and foot (Dunphy, Casey, Lomond, & Rutherford, 2016; Loudon & Reiman, 2012). Therefore, the purpose of the current study were to explore the difference of performance between lower limbs and correlation of the navicular drop height and force distribution parameters during running.

## METHODS

### Participants

Current study was a cross-sectional study with observational research method. The ethical committee of human rights research of Mahidol University approved the using data from running assessments (MU-CIRB 2018/006.1403). Fifty participants were assessed in an annual assessment for the runners at Physical Therapy Center, Pinkloa Campus. However, twenty-nine runners (17 males and 12 females) were included in this study according to the inclusion criteria which were having no current musculoskeletal symptom within 6 months before testing, no history of lower limb surgery, and forefoot strike pattern during running.

### Protocol

All participants filled out the information sheet of demographic data. The demographic data included general information and history of injury. Before running test on the treadmill, participants were assessed navicular drop height test (Buldt et al., 2018). Procedure of the navicular drop height test was; a) participants sit in the chair with hip ankle and knee 90°, b) palpate and mark navicular tuberosity, c) in sitting position,

mark the paper in the level of navicular tuberosity and the subtalar joint should be in the neutral position, d) then subject standing position, mark in the level of navicular tuberosity, and d) use calliper to measure the differences sitting and standing position.

In this study, researcher did a reliability test for navicular drop test (NDT) and the results showed good reliability for intra-rater (right ICC(3,1) 0.89 and left ICC(3,1) 0.78) with SEM 1.10 and 0.97 respectively. Moreover, comparing NDT skill between young researcher and orthopaedic physical therapist who has 15 years of experiences was performed. An inter-rater reliability was analyzed using agreement and the result showed moderate agreement (left 0.61 and right 0.716).

After the navicular drop height test, researcher explained the procedure of running performance test to runners. Researcher also tested the concurrent validity and reliability of attachment marker in pelvic. For the concurrent validity between 3D as a gold standard and 2D kinematics that use in this current study found a good correlation ( $r_p = 0.8$ ,  $p = 0.006$ ) and excellent intra-rater (ICC 0.92). Runners were asked to perform running on the treadmill machine. The treadmill with sensors, model of Zebris FDM-T Treadmill (Zebris1 Medical GmbH, Germany), was used to detect force distribution during stance phase of running.

Zebris FDM-T Treadmill is an electronic mat of 10,240 miniature force sensors, each approximately  $0.85 \text{ cm} \times 0.85 \text{ cm}$ , over an area of  $150 \times 50 \text{ cm}$ . The speed can be adjusted from 0.2 and 22 km/h with 0.1 km/h interval.

When the participants ran on the treadmill, the ground reaction force was applied to the feet and recorded by the sensor at a sampling rate of 120 Hz. Participants wore their normal training clothes and footwear. Participants were allowed to have 5 mins of warm-up with jogging. Then, they were asked to perform running with speed usual or preferred speed for 2 mins. Data capture was recorded 30 seconds after 2 mins of running with preferred speed.



Figure 1. Zebris FDM-T Treadmill

### Data Acquisition

The navicular drop was collected for all of the participants. The data from the FDM-T system was exported. The foot rotation and force distribution parameters were chosen for analysis. Foot rotation describes the angle between the running direction the longitudinal axis of the foot. Negative score means inward rotation, positive score means outward rotation. The first peak vertical force and second peak vertical force is a value of the average vertical ground reaction force. Maximum force elevation and its localization in relation to gait cycles are given for the heel and forefoot for the left and right sides, respectively. The vertical line is the separator of the stance and swing phase. Peak pressure at midfoot which is the average maximum score in  $\text{N/cm}^2$  for mid-foot. Single leg stance time is the time change from heel to forefoot. The single support line is the average length of the line showing CoP development from one side of the body, when all ground contact is considered.

### Statistical Analysis

All statistical analyses were performed using SPSS software (IBM SPSS Statistics for Windows, Version 23.0 Armonk, NY, USA). The statistical significance level set at 0.05 for all analyses. Normality test was performed using the Shapiro-Wilk test. Demographic data reported with a descriptive statistic. The association of the navicular drop height and force distribution parameters using Pearson correlation and Spearman correlation. Side to side difference between dominant and non-dominant legs, the asymmetry between legs was determined using paired-samples t-tests and provided the ES (effect size).

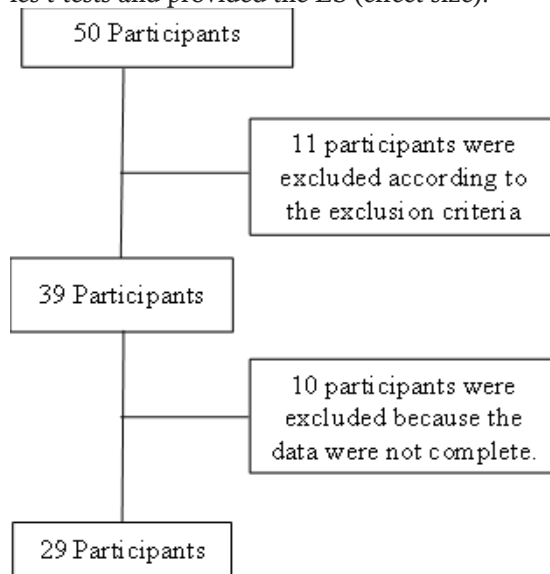


Figure 2. Flow chart of the study

**RESULTS AND DISCUSSION**

Fifty runners enrolled in this study. There were eleven participants excluded because they were not suitable with the inclusion criteria. In data processing, we found that there were incomplete data of ten participants because of the software problem. Data of twenty-nine participants were processed and analysed. The characteristics of twenty-nine participants are shown in the **Table 1**.

**Table 1.** Characteristics of the runners (n = 29)

Characteristics	Mean ± SD
Age (years)	39.5 ± 8.6
Body weight (kg)	65.6 ± 8.5
Height (cm)	168.9 ± 7.8
BMI (kg/m <sup>2</sup> )	22.9 ± 1.4
Running speed (km/hr)	8.1 ± 1.8
Running distance (km)	21.2 ± 13.8
Running experience (years)	3.24 ± 2.12
Freq of running (times/week)	3.17 ± 1.1

Runners are in the middle age, normal BMI, three years of running experience in average and three times per week of running exercise.

**Table 2.** The correlation coefficient between navicular drop height and force distribution in asymptomatic runners (N= 29)

Parameters	Limbs		p-value	
	Non-dominant	Dominant	Non-dominant	Dominant
Peak GRF (N/kg)	0.2	-0.1	0.4	0.6
Midfoot pressure (N/cm <sup>2</sup> )	0.02	-0.15	0.9	0.4
Single support line (mm)	0.2	0.1	0.3	0.6
Single-leg stance time (sec)	0.3	0.27	0.2	0.27
Foot external rotation (deg)	-0.1	0.15	0.7	0.4

In asymptomatic runners, the correlations are shown in **Table 2**. There was no significant correlation between navicular drop height and force distribution parameters during running test in both dominant and non-dominant legs.

**Table 2** exhibits the findings of correlation of NDT and force distribution parameters, and foot rotation. The study of Nakhaee et al (Nak-

haee, Rahimi, Abaee, Rezasoltani, & Kalantari, 2008) found moderate correlation of navicular drop value and peak pressure arch index in dynamic condition in professional runners. The finding of the current study did not support Nakhaee's study. We found no significant correlation of navicular drop height and FDM-T parameters. However, it could be that the different types of runner might show different result. Nakhaee's study examined in professional runners but we investigated in novice and recreational runners.

In 2012, Lee and Hertel found that during running, navicular drop height had no correlation with the plantar pressure. Only rear-foot alignment showed significantly correlation with the maximum plantar pressure in the region of the medial rear-foot and midfoot (Lee & Hertel, 2012). The findings of our study supported the study of Lee and Hertel that navicular drop height was not a predictor of maximum plantar pressure during running. To confirm about this, rearfoot kinematic should be detected in the further study.

The small spectrum of navicular drop height range (~4 mm) might be the reason why there was no significant correlation of force distribution parameters and navicular drop height. In further study, participants with normal and hyper-pronation foot would be recruited in the study. In addition, foot rotation found no significant correlation with navicular height. Valenzuela et al (Valenzuela, Lynn, Noffal, & Brown, 2016), found that the external rotation foot effected to the decrease in knee abduction moment during running. However, navicular drop effected to increased knee abduction moment during running (Luz et al., 2018; Powell, Andrews, Stickley, & Williams, 2016). This contradictive mechanism might be the reason the foot rotation had no correlation with navicular drop. Moreover, external rotation of foot causes tibial external rotation (Button, 2015). The tibial internal rotation occurs in navicular drop. It might be the other reason of no correlation was found between foot rotation and navicular drop height.

In 2012, Eslami et al (Eslami, Damavandi, & Ferber, 2014) reported that navicular drop height has a significant correlation with tibial internal rotation excursion where excessive tibial internal rotation causes timing and velocity of rearfoot pronation abnormal. Moreover, they found navicular drop height associated with maximum ankle inversion moment and knee adduction moments in the stance phase of running. Peak plantar pressure was changed due to change in peak ankle inversion moment and knee adduction



**Table 3.** Statistical comparisons of NDT, force distribution parameters, and foot rotation between limbs in asymptomatic runners (mean ± SD)

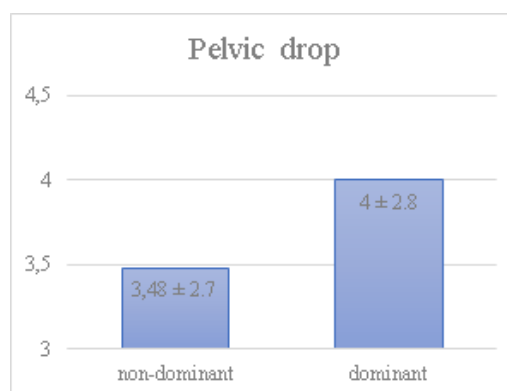
Parameters	Limbs		95% CI (Lower – Upper)		p-value
	Non-dominant	Dominant	Non-dominant	Dominant	
NDT (mm)	8.0 ± 2.2	7.0 ± 1.9	7.1 – 9	6.1 – 7.5	<0.001
Peak GRF (N/kg)	19.0 ± 2.8	19.1 ± 2.9	18 – 20	18 – 20.1	0.7
Midfoot pressure (N/cm2)	19.4 ± 6.3	19.5 ± 6.2	17 – 21.8	17.1 – 21.9	0.7
Single support line (mm)	138.7 ± 48.8	141.9 ± 48.2	120.1 – 157.2	123.5 – 160.2	0.19
Single-leg stance time (sec)	0.06 ± 0.04	0.06 ± 0.04	0.04 – 0.07	0.04 – 0.07	0.9
Foot external rotation (deg)	8.1 ± 4.6	9.5 ± 4.8	6.4 – 9.9	7.6 – 11.3	0.06

moments (De Ridder, Willems, & Roosen, 2012; Ferrigno, Thorp, Shakoor, & Wimmer, 2014).

In asymptomatic runners, average of navicular drop height, force distribution parameters, and foot rotation are shown in **Table 3**. There were no significant differences of all parameters except with NDT. There was significant difference of NDT between legs in runners.

Non-dominant side of navicular drop height was significantly greater than dominant side. When determining the magnitude of NDT, non-dominant side showed greater 1 mm than dominant side. The different value was very small and might not be meaningful in the clinical field as well.

In this study, peak GRF, midfoot pressure, single support line, single-leg stance time, and foot rotation showed no significant difference between limbs in asymptomatic runners. These parameters were measured in dynamic running test with FDM-T machine. In 2018, Robadey et al (Robadey et al., 2018) reported that contact and step time during running in treadmill were more symmetry. Whereas, in the injury runners, one side of the limb had higher stress because external force from ground reaction force (Zifchock, Davis, & Hamill, 2006). In 2013, Bredeweg et al (Bredeweg, Kluitenberg, Bessem, Buist, & Sport, 2013) found high asymmetry for kinetic variable (impact peak and contact time) in injury runners. Zifchock et al (Zifchock, Davis, Higginson, McCaw, & Royer, 2008) investigated running performance between limbs with 3D motion analysis and stated that injury and un-injury runners showed the same level of asymmetry. However, the hip and tibial rotations were more elevate on one side in injury runners. Foot external rotation during running showed no significant difference between dominant and non-dominant during running. The study of Stefanyshyn (Stefanyshyn & Engsborg, 1994), found that foot abduction (foot external rotation) between left and right legs showed no significant difference in un-injury ankle. It indicated both limbs were equal during running (Hamill, van Emmerik, Heiderscheit, & Li, 1999).



**Figure 3.** Comparison contralateral pelvic drop between non-dominant and dominant leg in asymptomatic runners

For the pelvic obliquity, the result showed non-significant difference between non-dominant 95% CI (2.5 – 4.5) and dominant 95% CI (3 – 5) (p = 0.59) with low effect size (d = 0.2).

After statistical analysis, we found that there was no significant difference of any correlation of the navicular drop and force distribution parameters and any side-to-side difference on force distribution and foot rotation parameters during running test. In the present study, contralateral pelvic drop showed no significant difference between dominant and non-dominant sides in asymptomatic runners. The range of CPD in asymptomatic runners was 3 – 4 degrees. This may assume that symmetry of hip abductor strength and neuromuscular control would be expected in asymptomatic runners. However, in the present study, the strength and muscle activity of the hip abductor muscle was not measured. Therefore, hip abductor muscle strength and EMG muscle activity should be included in the further study.

When determine the magnitude of contralateral pelvic drop in the current study, we found 95% CI of 3 – 5 degrees. So, it is possible that typical range of contralateral pelvic drop may be for 3 – 5 degrees in asymptomatic runners. However, to confirm our state, we plan to include more participants in the further study.

## CONCLUSION

In asymptomatic runners, side-to-side difference of lower limb during running test found non-significant difference. Therefore, very small side-to-side difference between limbs should be expected in asymptomatic runners. Besides, contralateral pelvic drop should be in range of 3 to 5 degrees in both male and female asymptomatic runners.

All runners in this study ran with forefoot style which might not affect to correlation of mid-foot pressure and navicular drop height. Runners with forefoot strike typically contact with more plantarflexed compared to rearfoot style, meanwhile navicular drop occurs in dorsiflexed. This might be the reason why there was no correlation. Besides, the small spectrum of navicular drop height range in this study would be another reason. It is interesting to recruit participants with normal and hyper-pronation foot in further study.

For the further study, we suggest that all kinetic parameters should be normalized by body weight. To determine a magnitude of contralateral pelvic drop in asymptomatic runners, more participants should be recruited. More parameters such as rearfoot angle, and hip abductor muscle strength and EMG activity would be interesting to investigate in further study.

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