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BIOMECHANICAL MARKERS OF PROLONGED PRONATION IN RUNNERS

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SUMMARY
This study examines the idea that the duration of foot pronation may be an important variable to consider in the development of common running injuries. The results show individuals with prolonged pronation do not necessarily have excessive amounts or velocities of pronation, however, they do show movement patterns which have been prospectively implicated in the development of running injuries. The results further suggest prolonged pronators can identified using a set of three biomechanical parameters, two of which can be easily measured in clinical settings.

INTRODUCTION
Excessive amounts or velocities of foot pronation are among the most commonly cited biomechanical factors for development of overuse injuries [1]. However, support for this concept in the literature is inconclusive. While several studies suggest there is a relationship between the amount or velocity of pronation and injuries, an equal amount of authors report no such relationship exists [1,2]. These inconclusive results suggest alternative theories on how abnormal pronation may be related to injury should be considered. Given the structural changes in the foot which occur during pronation, it may be that the duration the foot remains in a pronated position throughout stance, not necessarily the amount or velocity of pronation, is the more important variable for injury development [3].

However, before relationships between pronation duration and injury can be examined, biomechanical variables quantifying pronation duration, and specifically prolonged pronation, must be identified. Therefore, the purpose of this study was to identify biomechanical markers of clinically determined prolonged pronation. It was hypothesized that individuals who demonstrate prolonged pronation would not necessarily demonstrate excessive amounts or velocities of pronation but that they would demonstrate different kinematic patterns compared to non-prolonged pronators.

METHODS
Twenty competitive runners (sex: 14M, 6F, age: 22 ± 4.7 years, weekly mileage: 59.3 ± 16.2 miles) participated in this study. Subjects underwent a clinical exam measuring 10 variables documenting general lower limb alignment, flexibility, and mobility [3]. Subjects then participated in an observational gait analysis where they ran on a treadmill at speed approximating their easy training pace while their running gait was filmed with a high speed video camera sampling at 300 Hz (GC-PX10, JVC Corp.). Two clinicians independently reviewed the video and classified each subject as a non-prolonged (NPP) or prolonged (PP) pronator based on the relative alignment between the vertical axis of the shoe counter and the long axis of the tibia at the frame showing heel off.

Subjects then completed a 3D motion analysis where they ran continuous laps in the laboratory. Their whole body motion was recorded by a 10-camera motion capture system (Motion Analysis Corp.) sampling at 200 Hz. Ground reaction forces were recorded with three force plates (AMTI) sampling at 1000 Hz. For every subject, their foot strike pattern was characterized as rearfoot strike (RFS) or mid/forefoot strike (M/FFS). Filtered marker trajectories were used to calculate 17 variables describing orientations and movement of the leg segments. Implications of prolonged pronation for lower limb loading were assessed by examining center of pressure (COP) trajectories. At each frame during stance the COP was transformed from the lab coordinate system and expressed relative to the anatomic structures of the foot.

Inter-rater agreement between clinicians was evaluated with a kappa statistic. Discrepancies in classification were resolved by both clinicians viewing the video together. Differences between NPP and PP groups on clinical exam and kinematic variables were evaluated using a 2x2 (pronation group x foot strike pattern) analysis of variance, with arch height and running speed entered as covariates. To examine odds of being in the PP group, variables with main effects of pronation group at $p < .2$ were entered into a binary forward logistic regression equation. The influence of each individual predictor variable was then assessed by sequentially evaluating the regression equation with variables entered at “low risk” and “high risk” values [4]. A 2x2 ANOVA was also used to compare COP trajectories between NPP and PP groups. Comparisons were made in increments of 10% stance from foot contact to toe off, in both the anterior-posterior (A/P) and medio-lateral (M/L) directions.

RESULTS AND DISCUSSION

The kappa statistic for agreement between the two clinicians was 0.73. After resolving discrepancies, 21 limbs were classified in the NPP group (12 RFS, 9 M/FFS) and 19 limbs were classified in the PP group (13 RFS, 6 M/FFS).

Neither the amount of pronation (NPP: 11.8 ± 4.1°, PP: 12.4 ± 4.7°, p = .544) nor the maximal velocity of pronation (NPP: 315.7 ± 120.4 °/s, PP: 370.8 ± 154.4 °/s, p = .224) were different between groups. From the 10 clinical exam measures and 17 kinematic variables, only 4 were significantly different between groups (Table 1).

Table 1. Variables which were significantly different between NPP and PP groups. All significant at $p < .01$.

Variable	NPP	PP
Period of pronation (%, Per_P)	67.5 (±15.2)	90.1 (±12.6)
Eversion at heel off (°, EHO)	-0.9 (±3.6)	-5.5 (±4.4)
Standing tibia varus angle relative to floor (°, SVA)	7.3 (±1.5)	9.2 (±1.7)
Static prone hip internal rotation ROM (°, $SHIR_{ROM}$)	35.9 (±12.1)	26.7 (±7.1)

Results for dorsiflexion excursion (DFE) demonstrated a significant pronation group x foot strike interaction. For runners using a RFS, individuals in the NPP group demonstrated less DFE than those in the PP group (NPP: 14.4° ± 2.3°, PP: 19.6 ± 4.9°, p = .019). However, for runners using a M/FFS, individuals in the NPP group demonstrated more DFE than those in the PP group (NPP: 29.6° ± 5.3°, PP: 23.5 ± 5.7°, p = .019).

Following an analysis for multi-colinearity, the following variables were entered into the logistic regression model: SVA, $SHIR_{ROM}$, hip internal rotation excursion during stance phase (HIR_{excur}), and static prone hip external rotation range of motion ($SHER_{ROM}$). The final model describing odds of being a prolonged pronator was:

$$Odds = -9.386 + 1.632*HIR_{ROM} + 3.425*SVA + 0.868*SHIR_{ROM}$$

The final model was significant (χ^2 = 29.215, df = 3, $p < .001$), able to correctly classify 94.9% of the limbs, and explained 80% of the variance between NPP and PP groups (Nagelkerke R^2 = .80).

Assuming the mean values for the NPP group represented a "low risk" condition and 1.5 standard deviations above or below these values represented "high risk" conditions [4], sequentially evaluating the regression equation resulted in the following combinations. With all variables entered at "low risk" values (HIR_{excur} = 5.5°, SVA = 7.3°, and $SHIR_{ROM}$ = 35.9°) the odds of being in the PP group were 0.06. With only HIR_{excur} entered at a "high risk" value (HIR_{excur} = 8.1) the odds of being in the PP group increased to 0.21. With both HIR_{excur} and SVA entered at "high risk" values (HIR_{excur} = 8.1°, SVA = 8.8°) odds of being in the PP group increased again to 1.29. Finally, with all three variables were entered at "high risk" values (HIR_{excur} = 8.1°, STV = 8.9°, and $SHIR_{ROM}$ = 23.8°), the odds of being in the PP group rose to 7.2

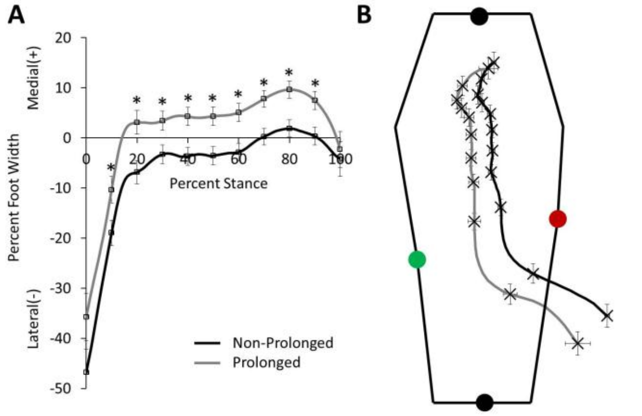

Figure 1. M/L location of the COP (A), and trajectory of the COP plotted in an outline of the foot based on marker locations (B).

Analysis of the COP trajectories revealed the point of force application differed between NPP and PP groups. The COP was located significantly more medial at each time point from 10% through 90% of stance in the PP group compared to the NPP group (Figure 1). In the A/P direction, there were no main effects of pronation group at any time point. However, for both NPP and PP groups the COP was located significantly more anteriorly at initial contact, 10%, and 20% of stance in subjects who used a M/FFS compared to those who used a RFS.

CONCLUSIONS

The results of this study support the idea that pronation duration should be considered as a unique variable in future studies on running injuries. Individuals with prolonged pronation do not necessarily demonstrate excessive amounts or velocities of pronation. However, compared to non-prolonged pronators they demonstrate kinematic patterns marked by foot strike type dependent differences in DFE and a more medial location of the COP across stance, both of which have prospectively been linked to the development of overuse running injuries [5]. While additional work is required to clarify the clinical implications of prolonged pronation, it currently appears that prolonged pronators can be identified using three simple biomechanical parameters, two of which are easy to measure in clinical settings.

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