Foot Placement Angle and Arch Type: Effect on Rearfoot Motion

Thomas W. Kernozek, MS, Mark D. Ricard, PhD


The purpose of the study was to describe the relationship between foot placement angle, arch type, and rearfoot motion during running. Twenty women were filmed in the frontal plane at 100 fps. Subjects displaying a variety of foot placement angles were chosen. Before data collection, arch indices were calculated. Each subject ran five trials at a pace of 3.5m/sec. All subjects wore the same type of shoe. All trials were digitized to determine rearfoot angles throughout foot contact. The following mean values were obtained: total rearfoot was 10.09°, maximum pronation was -9.63°, foot placement angle was 7.58° and arch index (AI) was 0.23cm^2. Non-linear regression was used to predict the relationship between maximum pronation and total rearfoot motion using foot placement angle and AI. Foot placement angle was the best single predictor of total rearfoot motion. When using both foot placement angle and arch type as predictors of total rearfoot motion, r^2 was .35. Less abduction was associated with more total rearfoot motion. Arch type exhibited a quadratic relationship with total rearfoot motion. Normal-arched individuals (AI > .26cm^2) exhibited less total rearfoot motion than high-arched (AI > .26cm^2) and flat-arched (AI < .21 cm^2) individuals. For maximum pronation, foot placement angle was the only significant predictor (r^2 = .13). Greater foot placement angles (more abduction) were associated with less maximum pronation.

KEY WORDS: Arch; Foot; Running

Since the early 1970s, with the increase in recreational running, there has been a corresponding increase in running-related injuries to the lower extremity. Many of these injuries have been linked to excessive pronation.1-4 Previous research has indicated that the foot tends to be placed in a more abducted position as running speed increases.5 As shown in figure 1, this angular deviation of the foot is defined as foot placement angle.6 In an evaluation of 14 elite women runners, running at a five-minute per mile pace, Williams and colleagues7 reported a negative correlation (r = -.55) between foot placement angle and maximum pronation, and a positive correlation (r = .83) between total amount of pronation and foot placement angle. Therefore, foot placement angles may influence the amount of pronation exhibited by the runner.

Clark8 found significant differences in the amount of pronation in an easy standing stance between high-arched and low-arched groups. Runners with flat feet tend to spend a greater amount of time in pronation during the support phase.9,10 The repetitive loading caused by running, combined with excessive subtalar joint motion, can be attributed to injury of the lower extremity.9 Therefore, flatter arches may tend to predispose an individual to greater rearfoot motion and a greater chance of injury.

Lapidus11 stated that individuals with pronated foot placement angles and flat feet tend to pronate more. The purpose of this study was to describe the relationship between foot placement angle, arch type, and rearfoot motion in running.

METHODS

Subjects

Twenty healthy women, aged 18 to 30 were selected from university fitness classes. Before participation in the project,
Rearfoot angle measurement is determined by monitoring the inversion-eversion of the calcaneous relative to the shank throughout ground contact. (a) At heel strike, the subtalar joint is supinated, defined as a positive rearfoot angle. (b) After heel strike, the subtalar joint passes through neutral position, defined as a 0° rearfoot angle. (c) The subtalar joint then progresses into pronation, a negative rearfoot angle. As the foot strikes the ground, rearfoot motion progresses from supination to pronation and back to supination at toe off.

The subjects gave consent in accordance with university policy. The mean mass for the entire sample was 56.95 ± 3.08 kg.

The subjects were selected based on foot placement angle so that a broad range of abduction during running was obtained for the sample. Nine subjects were selected who exhibited excessive foot placement angles during gait (>7° of abduction). Eleven other subjects were selected who exhibited foot placement angles within the normal range (≤7° but >0° of abduction).

Testing Procedures

The data were collected during a single session of approximately 20 to 30 minutes. Initially, each subject was required to complete a dynamic arch index (AI). To facilitate the film analysis, 1-cm reference markers were placed on the gastrocnemius, Achilles tendon, top of the shoe, and bottom of the shoe on the right leg of each subject, as mentioned by Clarke and associates (fig 2). These reference markers were used to determine the inversion-eversion of the calcaneus relative to the shank throughout foot contact. Eversion was used to describe the amount of pronation that occurred during running.

Heel angles were normalized by taking a calibration shot of each subject in stance. Each subject was positioned with the foot externally rotated 7° and the heels 5cm apart and filmed, as described by Clarke and associates. The difference between the heel angles derived from the calibration measure and the vertical were subtracted from all rearfoot measurements.

Before data collection, each subject was familiarized with the equipment and testing environment. A warm-up period was then provided to allow the subject to become accustomed to pacing and foot placement within the filming area. Only trials in which the subject maintained velocity within the required pace (3.5 m/sec ± 5%) and exhibited foot placement within the filming area were analyzed. Two photo-electric cells were used to ensure 3.5 m/sec pacing. All subjects wore the same shoe type.

After the subject was comfortable with the former testing conditions, powder was sprinkled on a portion of the runway so an imprint could be measured within the filming area. After each trial, the location and orientation of the chalk imprint was measured to obtain foot placement angle data relative to the direction of travel (fig 1).

Instrumentation

A 16-mm Locam camera fitted with a Canon 18-108mm zoom lens was used to record each running trial. The camera was operating at a speed of 100 frames/second with a shutter factor of 1/3. Perspective error was minimized by locating the camera 15m behind the center of the film area. To maximize image size, the camera field of view included only the subject’s lower extremity. Kodak 4X (7277) Reversal film with a 320 ASA rating was used to record the subject’s motion in the frontal plane.

Kinematic Data

The X-Y coordinate points of the gastrocnemius, Achilles tendon, top of the shoe, and bottom of the shoe were obtained using a Numonics 1224 digitizer interfaced with a Zenith 248 microcomputer. Digitizing began a minimum of five frames before right foot contact and terminated two frames after toe off. The raw film coordinates were smoothed with a Blackman low-pass filter at a 20 Hz cutoff.

The data were processed using laboratory software to generate rearfoot angles and rearfoot angular velocities. The corresponding foot placement angle data were also calculated by computer program and stored.

Statistical Treatment of Data

Mean values for each subject were calculated for foot placement angle and maximum pronation. A stepwise non-linear multiple regression was used to predict the amount of maximum pronation and total rearfoot motion from foot placement angle and AI.

RESULTS

Descriptive

Table 1 presents the sample means, standard deviations, and ranges for touchdown angle, maximum pronation, time to maximum pronation, maximum pronation velocity, time to maximum pronation velocity, foot placement angle and AI. The mean for foot placement angle was 7.58° ± 4.37°. The mean for AI was 0.23 cm² ± 0.05 cm². This mean value indicated the presence of a normal arch type across all subjects analyzed. Maximum pronation ranged from -2.54° to 18.50°. The mean for total rearfoot motion was 10.09° ± 3.89°.
Table 1: Descriptive Statistics for Rearfoot, Arch, and Foot Placement Angle Variables*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Touchdown angle (degrees)</td>
<td>0.47</td>
<td>3.52</td>
<td>-6.73 to 9.14</td>
</tr>
<tr>
<td>Maximum pronation (degrees)</td>
<td>-9.63</td>
<td>3.79</td>
<td>-2.54 to -18.50</td>
</tr>
<tr>
<td>Time to maximum pronation (msec)</td>
<td>87.10</td>
<td>27.60</td>
<td>40.00 to 170.00</td>
</tr>
<tr>
<td>Total rearfoot motion (degrees)</td>
<td>10.09</td>
<td>3.89</td>
<td>1.60 to 18.61</td>
</tr>
<tr>
<td>Maximum pronation velocity (degrees/msec)</td>
<td>-219.58</td>
<td>70.94</td>
<td>-47.55 to -426.45</td>
</tr>
<tr>
<td>Time to maximum pronation velocity (msec)</td>
<td>12.50</td>
<td>7.83</td>
<td>-10.00 to 30.00</td>
</tr>
<tr>
<td>Foot placement angle (degrees)</td>
<td>7.58</td>
<td>4.37</td>
<td>-0.12 to 17.40</td>
</tr>
<tr>
<td>Arch index (cm²)</td>
<td>0.23</td>
<td>0.49</td>
<td>0.12 to 0.32</td>
</tr>
</tbody>
</table>

*100 observations

Multiple Regression

A stepwise non-linear multiple regression equation was used to calculate a prediction equation for maximum pronation and total rearfoot motion from foot placement angle and AI across all subjects (table 2). The single best predictor for total rearfoot motion was foot placement angle, which accounted for 6.5% of the total rearfoot motion variance. The coefficient for foot placement angle indicated a negative relationship with total rearfoot motion. The second predictor which entered into the equation was AI cubed. Arch index cubed was a positive predictor of total rearfoot motion. The addition of AI cubed to the equation increased the $r^2$ to 13%. The third predictor which entered into the equation was AI squared. Arch index squared was a negative predictor of total rearfoot motion. These three variables in combination enhanced the predictive model explaining 35% of the total rearfoot motion variance. All other variables failed to increase the predictive power of the model to predict total rearfoot motion. The graphic representation of this relationship is depicted in figure 3. A quadratic relationship was found between arch type and total rearfoot motion. Normal-arched individuals exhibited the least total rearfoot motion; high-arched and flat-arched individuals exhibited the most. Foot placement angle had a small negative effect on total rearfoot motion.

Table 3 depicts the relationship between foot placement angle and arch type on maximum pronation. The single best predictor for maximum pronation was foot placement angle, which accounted for 13% of the maximum pronation variance. Foot placement angle cubed was a positive predictor of maximum pronation. All other variables failed to increase the predictive power of the model to predict total rearfoot motion. This relationship is depicted in figure 4. Foot placement angle had the greatest influence on maximum pronation. Greater abduction of the foot was associated with less maximum pronation. Arch type was not a significant predictor of maximum pronation values.

DISCUSSION

The purpose of this study was to describe the relationship of foot placement angle and arch type on rearfoot motion. Total rearfoot motion, which is the total relative motion of the rearfoot throughout ground contact, was found to be a function of both arch type and foot placement angle. Using equation 3 in table 2 for predicting total rearfoot motion, an individual with a normal arch type (AI = 0.23cm²) and 7° of abduction would exhibit 6.19° of total rearfoot motion. Arch types on the extremes, namely flat (AI = 0.29m²) and high (AI = 0.19cm²), with 7° of abduction, exhibited total rearfoot motion...

Table 2: Stepwise Multiple Regression Analysis of Sample for Total Rearfoot Motion

<table>
<thead>
<tr>
<th>Step</th>
<th>$r$</th>
<th>$r^2$</th>
<th>$f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.25</td>
<td>0.06</td>
<td>6.81</td>
</tr>
<tr>
<td>Equation 1</td>
<td>$Y = (-.23) FPA + (11.82)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>.36</td>
<td>.13</td>
<td>7.38</td>
</tr>
<tr>
<td>Equation 2</td>
<td>$Y = (-.28) FPA + (131.13) AI^3 + 10.37$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>.59</td>
<td>.35</td>
<td>17.31</td>
</tr>
<tr>
<td>Equation 3</td>
<td>$Y = (-.22) FPA + (2049.41) AI^3 + (-691.96) AI^2 + 21.81$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$Y = $ Total rearfoot motion
FPA = Foot placement angle
AI = Arch index

Table 3: Stepwise Multiple Regression Analysis of Sample for Maximum Pronation

<table>
<thead>
<tr>
<th>Step</th>
<th>$r$</th>
<th>$r^2$</th>
<th>$f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.36</td>
<td>0.13</td>
<td>15.36</td>
</tr>
<tr>
<td>Equation 1</td>
<td>$Y = (0.01) FPA^3 + (-10.58)$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| $Y = $ Maximum pronation.
FPA = Foot placement angle
AI = Arch index
Fig 4--The relationship between foot placement angle and arch type on maximum pronation is shown. Foot placement angle had the greatest influence on maximum pronation. Increased abduction of the foot resulted in less maximum pronation. Arch type was not a significant predictor of maximum pronation values.

Values of 11.33° and 9.35°, respectively. Clarke8 found a positive relationship between arch type and pronation. Flat-arched individuals pronated significantly more in stance than high-arched individuals (-11.8° and -2.7° respectively). Lapidus11 added that an individual with a flattened arch tended to exhibit more pronation. In our study, a quadratic relationship between arch type and rearfoot motion was observed. Flat-arched individuals exhibited the greatest rearfoot motion, followed by high-arched and then normal-arched individuals.

Foot placement angle showed a slight negative relationship with total rearfoot motion. This result was contrary to Lapidus10 statement that individuals with abducted feet tend to pronate more. However, we found that greater foot placement angles (more abduction) were associated with less total rearfoot motion. When analyzing maximum pronation, which was the maximum eversion angle throughout foot contact, foot placement angle was the single best predictor. Using equation 1 in table 3, individuals with 4.5° of foot abduction would exhibit -10.3° of pronation. Using the same equation, an individual with 11.4° of foot abduction would exhibit -8.8° of maximum pronation. Thus, greater abduction was associated with less maximum pronation. These results are contrary to the results of Williams and colleagues.14 They found that greater abduction was negatively correlated (-.55) with maximum pronation. These differences may have been caused by the methods used to calculate foot placement angle. In our study, it was assumed that the direction of travel was linear. Chodera and Levell14 found that the instantaneous direction of running is not always a straight line. Oscillations occur about the direction of travel, confounding foot placement angle measures. Thus foot placement angle, as calculated in this study, may not be reliable due to subject variability and the actual methodology used.

Excessive motion of the lower extremity has been linked to various running injuries.1-4 Thus rearfoot variables are useful in the prediction and prevention of running injury. Maximum pronation is the rearfoot variable which is most often linked to injury.5 Based on this study, if maximum pronation was used to predict running injury, individuals with little or no foot abduction would be most susceptible regardless of which arch type they possessed. If total rearfoot motion was used to predict lower extremity injury, individuals with flattened arches and little or no abduction of the foot would be most susceptible to injury.

The results of this study raise concerns about reporting maximum pronation values. Unreliable marker placement and soft-tissue movement can influence maximum pronation values. If marker reliability was low, maximum pronation values could have been affected. Due to this concern, total rearfoot motion may be a better measure in that it describes the relative motion about the subtalar joint. Thus, excessive rearfoot motion may be a better measure to predict lower extremity injury than maximum pronation.

CONCLUSIONS

The results of this study suggest that arch type was a better predictor of total rearfoot motion than foot placement angle. Normal-arched individuals exhibited less total rearfoot motion than either flat-arched or high-arched individuals. Foot placement angle had a negative relationship with total rearfoot motion. As foot placement angles increased, total rearfoot motion tended to decrease.

Foot placement angle was found to be a better predictor of maximum pronation than arch type. As foot placement angles increased, maximum pronation decreased. Individuals with foot placement angles ≤7° exhibited more maximum pronation than individuals who exhibited foot placement angles ≥7°. Arch type was not a significant predictor of maximum pronation.

References