Runners With Anterior Knee Pain Use a Greater Percentage of Their Available Pronation Range of Motion

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“Excessive” pronation is often implicated as a risk factor for anterior knee pain (AKP). The amount deemed excessive is typically calculated using the means and standard deviations reported in the literature. However, when using this method, few studies find an association between pronation and AKP. An alternative method of defining excessive pronation is to use the joints’ available range of motion (ROM). The purposes of this study were to (1) evaluate pronation in the context of the joints’ ROM and (2) compare this method to traditional pronation variables in healthy and injured runners. Thirty-six runners (19 healthy, 17 AKP) had their passive pronation ROM measured using a custom-built device and a motion capture system. Dynamic pronation angles during running were captured and compared with the available ROM. In addition, traditional pronation variables were evaluated. No significant differences in traditional pronation variables were noted between healthy and injured runners. In contrast, injured runners used significantly more of their available ROM, maintaining a 4.21° eversion buffer, whereas healthy runners maintained a 7.25° buffer (P = .03, ES = 0.77). Defining excessive pronation in the context of the joints’ available ROM may be a better method of defining excessive pronation and distinguishing those at risk for injury.

Keywords: running, injury, patellofemoral

Running is a popular form of exercise, with some 33.2 million Americans using it regularly as a part of their fitness routine.1 Unfortunately, with all the health benefits that come from a regular running routine also come the increased risk of orthopedic injury. In fact, it has been shown that up to 24% of runners will sustain an injury severe enough to cause them to stop running for seven or more days.2 Of these injuries, the knee is the most frequently injured region of the body, with anterior knee pain (AKP) being a prevalent diagnosis.3–6

As with any overuse injury, several factors contribute to the development of AKP, such as training errors, biomechanical faults, and anatomical abnormalities.7 Two biomechanical factors that are frequently implicated in the development of AKP are “excessive” and/or “prolonged” pronation.8,9 In this injury paradigm, excessive and/or prolonged pronation are thought to keep the tibia internally rotated as the knee begins to extend, thus disrupting the “screw home mechanism.”8,9 To preserve this screw home mechanism, the femur is believed to compensate by internally rotating more than the tibia and therefore achieving the required knee external rotation needed for the knee to extend. However, while this compensation at the femur is thought to preserve the arthrokinematics at the tibiofemoral joint, it disrupts those of the patellofemoral joint, placing increased stress on its articular cartilage and surrounding soft tissue.10

While clinically this injury paradigm is widely accepted, research studies have not supported the association between excessive and/or prolonged pronation and AKP. Prospective and retrospective epidemiology studies have found no association between static and dynamic measures of pronation and the risk of developing AKP in military recruits entering basic training and recreational runners.2,11–14 Similarly, biomechanical studies do not consistently find differences in pronation related variables such as peak eversion, peak tibial internal rotation (TIR), and peak knee internal rotation (KIR) in those with and without AKP.13,15–17 Collectively, these findings bring into question this injury paradigm.

While epidemiological and biomechanical studies have not supported the association between AKP and pronation related variables, orthotic studies have painted a different picture. When specifically focusing on pain and function as outcome measures, these studies consistently find orthotics to reduce pain and improve function.18–20 In fact, Amell et al18 and Saxena et al19 both reported that over 70% of participants with AKP reported amelioration in their symptoms following an orthotic intervention. Therefore, orthotic studies provide some
evidence that foot mechanics have a role in the development of AKP.

While commonly used, the term excessive pronation is not clearly defined or agreed upon in the literature. The word excessive implies the joint has crossed a threshold. In most cases this threshold has been defined using the means and standard deviations reported in the literature.\textsuperscript{21} This technique is limited, however, because (1) a subject-specific threshold is not created and (2) it does not take into account the range of motion (ROM) available at the ankle joint complex (AJC, talocrural + subtalar joint). For instance, two runners presenting with 7° of pronation would likely both be classified as having a “normal” amount of pronation when the threshold is set using the means and standard deviations reported in the literature. However, if one of these runners only had 7° of motion available, one’s interpretation might change because this runner approaches their ROM limits on every step of the run. In contrast, if the other runner had 15° of pronation available, he/she would have an 8° eversion buffer. Using this concept, a more physiological and subject specific threshold could be created to define whether there is a normal or excessive amount of pronation occurring.

Engsberg\textsuperscript{22} was the first to evaluate dynamic pronation relative to the joints’ available ROM. Using a custom-made ROM device and motion capture system, these authors related the angular excursions seen when running to the available motion at the AJC. They found runners considered to be excessive pronators used more motion than was actively available, exceeding their pronation ROM boundary by an average 8.4°, whereas those with normal amounts of pronation maintained a 1.7° eversion ROM.\textsuperscript{23} This technique is limited, however, because (1) a subject-specific threshold is not created and (2) it does not take into account the range of motion (ROM) available at the ankle joint complex (AJC, talocrural + subtalar joint). For instance, two runners presenting with 7° of pronation would likely both be classified as having a “normal” amount of pronation when the threshold is set using the means and standard deviations reported in the literature. However, if one of these runners only had 7° of motion available, one’s interpretation might change because this runner approaches their ROM limits on every step of the run. In contrast, if the other runner had 15° of pronation available, he/she would have an 8° eversion buffer. Using this concept, a more physiological and subject specific threshold could be created to define whether there is a normal or excessive amount of pronation occurring.

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Therefore, the purposes of this study were to (1) evaluate pronation in the context of the joints’ available passive pronation ROM and (2) compare this method to traditional pronation related variables in runners with and without AKP. It was hypothesized that healthy and injured runners will have similar traditional pronation-related variables; however, injured runners were expected to use a greater percentage of their available pronation ROM.

### Methods

#### Participants

Using data from Engsberg\textsuperscript{22} and McClay et al.\textsuperscript{21} a statistical power analysis found a sample size of 30 to provide 80% power at the \(\alpha = .05\) level. Nineteen healthy runners and seventeen runners with AKP completed this study (Table 1). All runners were required to have been running at least eight miles per week for the prior six months, have a heel-strike footfall pattern and have no history of lower extremity surgery. Those experiencing AKP were evaluated by a licensed physical therapist to (1) rule out any ligamentous laxity, meniscal pathology, tendonitis and iliotibial band syndrome, and (2) to confirm that signs and symptoms were consistent with pain originating from the patellofemoral joint. Before participating, subjects filled out a physical activity readiness questionnaire and signed the informed consent approved by the Institutional Review Board at the University of Massachusetts.

### Table 1 Subject information and anthropometrics

<table>
<thead>
<tr>
<th></th>
<th>Healthy</th>
<th>Injured</th>
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</thead>
<tbody>
<tr>
<td>n</td>
<td>19</td>
<td>17</td>
</tr>
<tr>
<td>Male</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Female</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>Age</td>
<td>34 (10)</td>
<td>29.8 (7)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>65.2 (12)</td>
<td>60.2 (8)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.72 (0.09)</td>
<td>1.63 (0.08)</td>
</tr>
</tbody>
</table>

Note. mean (standard deviation).

#### Passive Eversion ROM Protocol

To ensure that the AJC’s full ROM was captured, runners were required to first warm up on the treadmill for 10 to 15 minutes and complete three sets of gastrocnemius and soleus stretches followed by ankle circles. Runners were then positioned in the custom-made ROM device inspired by that of Allinger and Engsberg.\textsuperscript{25} This device was designed to passively evert the AJC in multiple sagittal plane positions while still allowing translation in all three planes (Figure 1). Once in the device, the runner’s foot was positioned such that the heel and second metatarsal head bisected the foot platform and the sagittal plane...
axis bisected the medial and lateral malleoli. With the aid of a laser level, the platform carriage was moved to align the tibia vertically in both the frontal and sagittal plane. The foot and tibia were then secured and a compressive load (100 N) was applied to the long axis of the tibia.

Once positioned, the runner’s AJC was passively everted in seven sagittal plane positions ranging from 40° of plantar flexion to maximum dorsiflexion. In each of these sagittal plane positions a predetermined torque was applied to evert the AJC using a torque wrench. The torque applied was calculated by summing the torque required to move the platform to a given position and an additional 10 N·m was used to load the AJC (Applied torque = 10 N·m + Resistance of foot carriage). Once the desired torque was reached, the position of the AJC was captured with an eight camera motion capture system (Qualisys, Gothenburg, Sweden). A total of three repetitions were captured in each sagittal plane position.

Figure 1 — Device used to passively move the ankle joint complex through its range of motion. This device allowed for a passive torque to be applied along the frontal and sagittal plane axes, while allowing for translation in all three planes.

Running Protocol

Subjects ran in a neutral running shoe (New Balance 415) with a modified heel counter to allow the calcaneal tracking cluster to remain fixed during both passive ROM trials and dynamic trials. This eliminated the error associated with multiple calibrations and marker replacement. Subjects then ran for five minutes at 2.9 m/s and kinematic data were collected at 200 Hz over the final 30 s.

Data Analysis

Marker trajectories from the ROM and running trials were processed and analyzed in Visual 3D (C-Motion, Germantown, MD). Raw marker trajectories were first smoothed using a 12 Hz dual-pass, fourth-order, low-pass Butterworth filter. Segment and joint angles were calculated using Cardan angles with an x-y-z rotation sequence. Variables of interest were analyzed during stance, with touchdown defined as the minimum vertical position of a marker placed on the posterior lateral aspect of the midsole and push-off at peak knee extension.

Passive eversion ROM values were averaged over the three repetitions in each sagittal plane position. An eversion boundary was then created by interpolating between the measured sagittal plane positions. The eversion buffer was then determined by subtracting the angular distance between the dynamic joint angles and the passive eversion boundary (Figure 2). The minimum distance recorded was deemed their eversion buffer.

Traditional pronation related variables were also recorded. These variables include the AJC’s eversion angle at touchdown, peak eversion, time to peak eversion, total AJC frontal plane ROM, peak eversion velocity, peak TIR, time to peak TIR, TIR ROM, peak KIR and time to peak KIR. All variables were recorded and averaged over ten footfalls. Differences between healthy and injured runners were evaluated using a one-way analysis of variance. All statistical tests were deemed significant at \( \alpha = 0.05 \).

Results

Healthy and injured runners demonstrated no statistically significant differences across any traditional pronation related variables (Table 2). However, peak eversion velocity approached statistical significance, with injured runners having faster pronation velocities (\( P = 0.06, \text{ES} = 0.62 \)). In contrast to the traditional pronation related variables, injured runners demonstrated significantly smaller eversion buffers compared with healthy runners (Table 2; \( P = 0.03, \text{ES} = 0.77 \)). This smaller eversion buffer was in large part due to injured runners having less passive eversion ROM at 10 and 20 degrees of dorsiflexion (Table 3; \( P = 0.14 \) and 0.13, \( \text{ES} = 0.55 \) and 0.77). While these results were statistically significant, a post hoc power analysis found the eversion buffer variable to have a power of 61% for this study. The discrepancy between the a priori and post hoc power analyses was a result
Figure 2 — Passive eversion range of motion measurements were taken in seven sagittal plane positions. The range of motion boundary was then defined by interpolating between these sagittal plane measurements. The ankle joint complex’s position during the stance phase of running was plotted relative this boundary. The angular distance between the boundary and the joints’ angle during stance were calculated. The minimum distance for each step was deemed the eversion buffer.

Table 2 A comparison of traditional pronation-related variables and the eversion buffer of injured and healthy runners

<table>
<thead>
<tr>
<th>Variables</th>
<th>Healthy</th>
<th>Injured</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>New Approach</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eversion Buffer</td>
<td>7.25 (4.3)</td>
<td>4.21 (3.6)</td>
<td>.03</td>
</tr>
<tr>
<td><strong>Traditional Approach</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AJC Touchdown Angle</td>
<td>3.15 (2.7)</td>
<td>2.79 (3.8)</td>
<td>.65</td>
</tr>
<tr>
<td>AJC Peak Eversion</td>
<td>−7.57 (5.9)</td>
<td>−7.70 (3.2)</td>
<td>.73</td>
</tr>
<tr>
<td>AJC Time to Peak Eversion</td>
<td>41.20 (11.2)</td>
<td>39.70 (8.3)</td>
<td>.70</td>
</tr>
<tr>
<td>AJC ROM</td>
<td>10.72 (4.6)</td>
<td>10.50 (2.9)</td>
<td>.99</td>
</tr>
<tr>
<td>AJC Peak Eversion Velocity</td>
<td>−236.10 (82.0)</td>
<td>−279.0 (34.0)</td>
<td>.06</td>
</tr>
<tr>
<td>Peak TIR</td>
<td>−8.95 (6.1)</td>
<td>−7.79 (5.5)</td>
<td>.86</td>
</tr>
<tr>
<td>Time to Peak TIR</td>
<td>40.95 (15.2)</td>
<td>43.7 (15.3)</td>
<td>.85</td>
</tr>
<tr>
<td>TIR ROM</td>
<td>8.89 (4.5)</td>
<td>7.49 (2.96)</td>
<td>.45</td>
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<tr>
<td>Peak KIR</td>
<td>−10.92 (5.9)</td>
<td>−10.36 (6.0)</td>
<td>.98</td>
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<tr>
<td>Time to Peak KIR</td>
<td>42.35 (12.3)</td>
<td>39.40 (12.1)</td>
<td>.45</td>
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<tr>
<td>KIR ROM</td>
<td>9.78 (4.4)</td>
<td>8.46 (4.5)</td>
<td>.60</td>
</tr>
</tbody>
</table>

*Note.* mean (standard deviation).

Table 3 Passive eversion range of motion values in different sagittal plane positions

<table>
<thead>
<tr>
<th>Variables</th>
<th>PF 30</th>
<th>PF 20</th>
<th>PF 10</th>
<th>0</th>
<th>DF 10</th>
<th>DF 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy</td>
<td>−7.6 (7.1)</td>
<td>−9.8 (6.6)</td>
<td>−11.0 (6.7)</td>
<td>−13.0 (6.7)</td>
<td>−14.8 (6.9)</td>
<td>−17.0 (6.4)</td>
</tr>
<tr>
<td>Injured</td>
<td>−7.5 (5.3)</td>
<td>−9.5 (4.2)</td>
<td>−10.4 (4.0)</td>
<td>−11.5 (3.6)</td>
<td>−11.8 (3.9)</td>
<td>−13.0 (3.9)</td>
</tr>
</tbody>
</table>

*P*-value

|       | .57 | .89 | .73 | .43 | .14 | .13 |

*Note.* mean (standard deviation), PF = plantar flexion, DF = dorsiflexion.
of the magnitude of difference between groups used in each analyses. Engsberg reported approximately a ten degree eversion buffer difference between runners with a normal and excessive amount of pronation, whereas this study found a three degree difference in buffer between healthy and injured runners.

Discussion

The purposes of this study were to (1) evaluate pronation in the context of the joints’ available pronation ROM and (2) compare this method to traditional pronation related variables in runners with and without AKP. It was hypothesized that injured runners would use a greater percentage of their available passive pronation ROM, while demonstrating no differences in the traditional pronation related variables. As hypothesized, injured runners were found to use a significantly greater percentage of their available pronation ROM. In contrast, healthy and injured runners did not demonstrate any differences in the quantity and/or timing of peak pronation and tibial internal rotation. If excessive pronation is believed to be a risk factor for AKP, these findings suggest that the amount deemed excessive should be based on where the joint functions relative to its available ROM and not based on peak eversion alone. The eversion buffer is a product of both the quantity of motion available at the AJC and its excursion during running. While both can have an influence on this value, it was the reduction in passive eversion ROM that differentiated healthy and injured runners (Figure 2). Although these passive ROM differences were not statistically significant they had moderate effect sizes, with injured runners having less passive eversion ROM at both 10° and 20° of dorsiflexion (Table 3; P = .14 and 0.13, ES = 0.55 and 0.77), while demonstrating no differences in dynamic peak eversion (P = .73, ES = 0.02). This reduction in passive eversion ROM is likely a combination of differences in soft tissue and bony anatomy. While the contribution of each of these could not be determined with this study design, it could be theorized that individuals with soft tissue limitations could benefit from stretching exercises to increase their eversion ROM. In contrast, those with bony limitations would benefit from orthotic and footwear interventions that would reduce the amount of peak eversion.

Our findings are contradictory to those reported by Engsberg, who found pronators and neutral runners to have similar eversion ROM boundaries. In contrast, they found pronators to have greater amounts of dynamic eversion and as a result exceeded their eversion boundary by an average of 8.4°, while neutral runners maintained a 1.7° buffer. In contrast, our study found a majority of subjects stayed within their available passive ROM boundary while running, with only three (8%) of subjects exceeding their available motion. In addition, those who did exceed their eversion boundary did so by less than one degree. These differences are most likely a result of Engsberg using active ROM to define their eversion boundary where we used passive motion to define this boundary. It is plausible that the subjects were unable to actively reach end range and therefore their eversion boundary was underestimated. Therefore, future work should use a passive motion to fully capture the eversion ROM.

Evaluating pronation in this context helps explain the discrepancies seen between clinical orthotic studies and biomechanical studies. Orthotics designed to limit pronation have generally been shown to decrease pain and improve function. However, biomechanical studies on pronation do not consistently show differences between healthy and injured runners. If limiting pronation is the reason for improved function in orthotic studies, one would expect injured runners to have greater pronation than healthy runners in biomechanical studies. This discrepancy could be a result of evaluating excessive pronation in the wrong context. Traditionally, biomechanical studies have attempted to find a link between excessive pronation and injury without evaluating the quantity of motion available at the AJC. Therefore, these studies would not have captured the eversion buffer of these runners, which based on the findings of this study may be a more effective method of distinguishing those at risk for injury. In contrast, clinical orthotic studies have typically evaluated injured runner, with feasibly small eversion buffers. While not measured, the clinical outcomes seen in these studies may be due to the orthotics ability to increase the eversion buffer. Utilizing the eversion buffer as a variable, might not only explain these discrepancies but better target those at risk for AKP and those who would benefit from some eversion control leading to an even greater number of successful clinical outcomes.

A smaller eversion buffer could increase a runner’s risk of injury for several reasons. First, as a joint approaches end range, greater stress and strain will be placed on the joints’ soft tissue. Secondly, the joint may have a reduced ability to attenuate the impact forces via joint rotation in early stance. Thirdly, the AJC may have less flexibility to accommodate for change in the running terrain. Lastly, because of the reasons listed above, the AJC will have fewer coordinative solutions. This would require the body to seek out new coordinative solutions that would likely include more proximal joints. For example, a runner displaying a small buffer while running on a flat treadmill would likely exhaust their remaining eversion ROM when running on a cambered road, trail, or when stepping on an unexpected object such as a rock. As a result, a more proximal joint such as the knee would have to compensate to accommodate for the lack of frontal plane motion at the AJC. Unfortunately the knee primarily moves in the sagittal plane and compared with the AJC, is less suited to move in the frontal plane. On average, the subtalar joint axis lies 42° in the sagittal plane and 16° in the transverse plane, and therefore designed to move and accommodate for perturbations in the frontal plane. In contrast the knee axis lies primarily in the frontal plane and therefore designed to move primarily in the sagittal plane. As a result, the knee is less capable of adapting to these frontal plane perturbations.
and therefore could be prone to injury when it is required to make such accommodations.

In conclusion, runners with AKP had significantly smaller eversion buffers while showing no differences in peak eversion. These findings suggest that using a joints’ passive ROM to define excessive pronation may be more effective at distinguishing those at risk for injury. Future studies should evaluate the ability of the eversion buffer to prospectively identify these at risk for injury and explore the minimal buffer size that should be considered healthy.

**References**