A prospective biomechanical study of the association between foot pronation and the incidence of anterior knee pain among military recruits

Excessive foot pronation has been considered to be related to anterior knee pain. We undertook a prospective study to test the hypothesis that exertional anterior knee pain is related to the static and dynamic parameters of foot pronation. Two weeks before beginning basic training lasting for 14 weeks, 473 infantry recruits were enrolled into the study and underwent two-dimensional measurement of their subtalar joint displacement angle during walking on a treadmill.

Of the 405 soldiers who finished the training 61 (15%) developed exertional anterior knee pain. No consistent association was found between the incidence of anterior knee pain and any of the parameters of foot pronation. While a statistically significant association was found between anterior knee pain and pronation velocity (left foot, p = 0.05; right foot, p = 0.007), the relationship was contradictory for the right and left foot. Our study does not support the hypothesis that anterior knee pain is related to excessive foot pronation.

A foot with abnormal pronation was first described by Sgarlato$^1$ as either that which functions about an abnormally pronated position or that which moves in the direction of pronation when normally it should be supinating. He stressed that while during static stance abnormal pronation at most results in slight discomfort, during locomotion it may cause pain in the foot and postural symptoms.

James, Bates and Osternig,$^2$ in one of the first studies to analyse the aetiology of injuries in runners, concluded that anterior knee pain was related to abnormal transverse plane rotation, rather than excessive wear of the patellar articular surface. They noted that the transverse plane rotations were associated with the pronation and supination of the subtalar joint which internally rotated with pronation and externally rotated with supination. It was concluded that if internal tibial torsion was increased and prolonged with excessive pronation, more rotation would occur at the knee, with an increased likelihood of anterior knee pain. Duffey et al,$^3$ studying factors related to anterior knee pain in long-distance runners, found that pronation in the first 10% of the stance phase was one risk factor for anterior knee pain. They noted that the participants with anterior knee pain who had this risk factor showed a smaller mean value for pronation than the control group. It was concluded that because pronation reduced the impact shock, runners with less pronation had a greater impact shock and therefore were at a greater risk of anterior knee pain.

There is a widely held view among physiotherapists, athletic trainers and orthopedists that excessive pronation is related to anterior knee pain. For this reason, functional orthotics, which attempt to control subtalar movement, are often prescribed to prevent or to treat anterior knee pain.$^4-8$

We undertook a prospective study among a population known to have a high incidence of exertional anterior knee pain,$^9$ to study the hypothesis that there is a relationship between anterior knee pain and the standing tibio-calcaneal angle and/or dynamic parameters of foot pronation during the stance phase of the gait cycle.

Subjects and Methods
The study group consisted of 473 new infantry recruits who had given their informed consent for participation in the study which was approved by our institutional review board. They were examined two weeks before beginning their four-month basic training course.

In order to measure foot pronation, two-dimensional measurement of the subtalar joint displacement angle was performed. The eversion and inversion angles of the calcaneum were used to designate pronation and supination of the subtalar joint.$^{10-12}$ All the soldiers...
were filmed at 60 Hz, walking barefoot on a treadmill at 5 km/h. Four reflective markers were placed on the posterior aspect of the leg and foot (Fig. 1). The two lower markers, representing the rear foot segment, were placed below the axis of subtalar movement, the lowest being on the calcaneal tubercle and the other 1 cm below the axis of subtalar movement. The upper two markers, representing the leg segment, were placed 2 cm and 8 cm proximal to the axis of subtalar movement, in the midline of tendo Achillis.

Foot pronation was measured both under static and dynamic conditions. The standing tibiocalcaneal angle was measured to evaluate the static stance pronation. Five parameters of dynamic movement were used to measure foot pronation during the gait cycle, namely, the bilateral maximal foot pronation angle during the stance phase, the pronation range of movement, the time to maximum pronation from heel strike, the pronation mean angular velocity and the stance duration. The measurements were made using the computerised Ariel Performance Analysis System (Ariel Dynamics Inc., Trabuco Canyon, California).

The soldiers were examined for the presence of exertional anterior knee pain every two weeks during their training. Those soldiers who had sustained blunt trauma to the patella were excluded from the study. Physical examination of the knee was performed to determine patellofemoral tenderness. The examinations were done by a single orthopaedic surgeon (CM). All the soldiers wore standard infantry boots with bilayer soles (inner layer 45 Shore A and outer layer 90 Shore A polyurethane). Those who withdrew from training for non-orthopaedic reasons were excluded from the study.

**Power and sample size.** On the basis of the evidence available at the time of the design of the study, it was estimated that the incidence of anterior knee pain among the military recruits would approach 15% and it was hypothesised that the mean foot pronation in the group with anterior knee pain would be 7° (SD 4) as opposed to 5° (SD 4) in the group without anterior knee pain. It was determined that a sample size of 63 soldiers in each group would provide power of 80% (α = 0.05) to detect an absolute difference of 2° in foot pronation between the two study groups.

**Statistical analysis.** After the collection of data all the recruits were divided into four equal quartiles. This division was applied separately to the right and the left foot and for each of the foot pronation parameters.

The soldiers with the lowest values of the measured parameter were defined as the lower quartile (Q1) and those with the highest values as the upper 25% quartile (Q4). The remaining 50% of soldiers who had values above the upper end-point for Q1 but below the lower end-point for Q4, were distributed in the second (Q2) and third (Q3) quartiles.

The mean values and the SD of all the foot pronation parameters (static and dynamic) were calculated separately for each foot (Table I). A frequency distribution procedure was performed, using the Statistical Analysis System (SAS Institute Inc., Cary, North Carolina), to calculate the incidence of anterior knee pain in the quartiles. This analysis was done separately for each foot and for each pronation parameter. The Pearson correlation co-efficient and chi-squared test were computed to see if there was a statistically significant association between exertional anterior knee pain and any of the foot pronation parameters (Table II). Statistical significance was defined as p ≤ 0.05.

**Results**

There were 405 subjects in the final analysis. The overall incidence of exertional anterior knee pain during the four months of training was 15%. The mean value and SD of all the foot pronation parameters of dynamic movement and the standing tibiocalcaneal angle for each foot are presented in Table I.

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**Table I. The mean value (SD) for all the foot pronation parameters**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Foot</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing tibiocalcaneal angle (°)</td>
<td>L</td>
<td>4.46 (3.20)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>5.34 (3.26)</td>
</tr>
<tr>
<td>Maximum foot pronation angle (°)</td>
<td>L</td>
<td>6.9  (4.2)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>8.3  (4.4)</td>
</tr>
<tr>
<td>Pronation range of movement (°)</td>
<td>L</td>
<td>7.8  (2.6)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>7.8  (2.5)</td>
</tr>
<tr>
<td>Time to maximum pronation(s)</td>
<td>L</td>
<td>0.17 (0.06)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.17 (0.06)</td>
</tr>
<tr>
<td>Pronation velocity (°/s)</td>
<td>L</td>
<td>49.7 (21.6)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>49.4 (20.1)</td>
</tr>
<tr>
<td>Stance duration(s)</td>
<td>L</td>
<td>0.58 (0.04)</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.58 (0.04)</td>
</tr>
</tbody>
</table>
The Pearson chi-squared test did not show any significant evidence of an association between anterior knee pain and the standing tibiocalcaneal angle, the maximum foot pronation angle, the range of pronation, the time to maximum pronation and the stance duration. There was a statistically significant association between anterior knee pain and the pronation velocity (Table II), but the association was not consistent between the feet. The incidence of anterior knee pain was greatest in Q1 and Q4 for the left foot. In contrast it was lowest in Q1 and Q4 for the right foot.

**Discussion**

Foot pronation is a complex triplanar movement of the subtalar joint which consists of abduction, dorsiflexion and eversion. Pronation unlocks the transverse tarsal joint, increasing the flexibility of the foot and allowing shock attenuation. During the gait cycle, the foot pronates directly after heel strike and reaches maximum pronation at between 38%, 40% and 50% of the stance phase. The normal range of pronation has been defined as between 4° and 8°. “Overpronators” are considered to have a higher degree of pronation, abnormal timing and abnormal pronation velocity.

The subtalar joint acts as an oblique hinge joint. It has been claimed that abnormal movement of this joint, leading to abnormal tibial rotation, may result in overuse injuries of the lower limb. There seems to be agreement among researchers that pronation of the hindfoot is coupled with internal rotation of the tibia during the first half of stance. Not only the degree of foot pronation, but also the time taken to maximum pronation and the velocity of pronation have been considered to be important factors in determining internal tibial rotation. Abnormality in these parameters is considered to produce abnormal stresses in the lower limb and in the patellofemoral mechanism in particular. Prolonged pronation of the foot and ankle produces excessive internal tibial rotation. This transmits abnormal forces upwards in the kinetic chain and produces abnormal stresses on the whole of the lower limb. Lateral patellofemoral contact pressures increase because the forces of rectus femoris and tensor fascia lata are directed more laterally when the knee has translated medially relative to the foot and pelvis.

In our study, the resting standing tibiocalcaneal angle was not found to be associated with overexertional anterior knee pain. The mean angles found, 5.3° of eversion for the right foot and 4.5° for the left, are slightly greater than the mean value of 3.64° found by McPoil and Cornwall. Some researchers have found an association between the resting tibiocalcaneal angle and anterior knee pain. Lev- inger and Gillear found hindfoot measurements in 13 women with patellofemoral pain with those in 14 asymptomatic women. The resting standing tibiocalcaneal angle was more everted in those with patellofemoral pain. The study of Powers et al failed to show this relationship.

In our investigation, neither the maximum foot pronation angle nor the range of pronation was found to be significantly associated with exertional anterior knee pain. While a statistically significant association was found between overexertional anterior knee pain and pronation velocity, the relationship was contradictory for the right and left foot. Moss et al compared female athletes with and without patellofemoral symptoms. In their study, subjects with patellofemoral symptoms showed a significantly longer time to maximum pronation and a lower mean velocity of pronation from hindfoot contact to maximum pronation. The maximum pronation angle was not found to be significantly related to patellofemoral symptoms.

Orthotic devices have been recommended for the treatment of patellofemoral pain. Johnston and Gross treated 16 patients with this complaint and excessive foot pronation. The study group is large with adequate control group. Our study is prospective and uses a well-established model for exertional anterior knee pain, namely the Israeli infantry recruit. The study group is large with adequate

<table>
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<th>Variable</th>
<th>Incidence of anterior knee pain per % quantile</th>
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<td>Foot</td>
</tr>
<tr>
<td>Standing tibiocalcaneal angle (°)</td>
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statistical power to identify potential differences between the groups. We found no consistent association between any of the static or dynamic parameters of foot pronation and the risk of exertional anterior knee pain. The use of orthotics to treat patellofemoral pain has been advocated by some,\textsuperscript{4-8} based on their potential to control subtalar hyperpronation. Since we found no relationship between pronation and anterior knee pain, the rationale for their use is questionable.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References