The Association of Foot Arch Posture and Prior History of Shoulder or Elbow Surgery in Elite-Level Baseball Pitchers

In Major League Baseball pitchers, injuries to the shoulder (28%) and elbow (22%) account for more days lost from play than any other anatomic areas, based on time on the disabled list.12,26,35 There have been numerous articles published that investigate the causes of shoulder and elbow pathologies in baseball pitchers.20,34,36,37,56,61

Pathomechanics of the throwing arm have been linked to glenohumeral internal rotation deficits, high maximum pitch velocity, limited trunk and hip rotation, and improper throwing mechanics.1,2,11,21,30,31,53 However, to date, no studies have examined foot arch posture as a potential risk factor for shoulder and elbow injuries in baseball pitchers.

Research suggests that subtle changes in pitching motion may increase stresses on the anatomical structures of the shoulder and elbow, potentially leading to repeated injury and ultimately tissue failure.2,4,41,55,56,59 For example, proper positioning of the lunge limb (contralateral to the throwing arm) at foot plant is required for proper ball positioning, more efficient delivery, and decreased risk of injury.26,26 Although a study by Donatelli et al30 reported that excessive foot arch pronation in baseball players was not significantly associated with lower extremity overuse injuries, it did not differentiate player positions and did not investigate injuries above the hip. To the authors’ knowledge, this is the first study to investigate the association between foot arch posture, as measured through the longitudinal arch angle (LAA), and the odds of having suffered shoulder or elbow surgery.

There exist several methods available to classify and measure foot arch posture.13,20,39,41,44,49 Measurements include the LAA with goniometry, foot mobilization, and platforms for measurement.13,38-40 Several of these methods require the use of a digital gauge, modified digital caliper, videotaping, digital imaging, and platforms for measurement.13,38-40

**STUDY DESIGN:** Case-control.

**OBJECTIVES:** The specific aim of this study was to examine the association between abnormal foot arch postures and a history of shoulder or elbow surgery in baseball pitchers.

**BACKGROUND:** Pitching a baseball generates forces throughout the musculoskeletal structures of the upper and lower limbs. Structures such as the longitudinal arch of the foot are adaptable to stresses over time. Repeated pitching-related stresses may contribute to acquiring abnormal foot arch postures. Inversely, congenitally abnormal foot arch posture may lead to altered stresses of the upper limb during pitching.

**METHODS:** A convenience sample of 77 pitchers was recruited from a Division I university team and a professional baseball franchise. Subjects who had a history of shoulder or elbow surgery to the pitching arm were classified as cases. Subjects who met the criteria for classification of pes planus or pes cavus based on longitudinal arch angle were classified as having abnormal foot arch posture. Odds ratios were calculated to examine the association between abnormal foot arch posture and pitching- or elbow injury requiring surgery.

**RESULTS:** Twenty-three subjects were classified as cases. The odds of being a case were 3.4 (95% confidence interval: 1.2, 9.6; P = .02) times greater for subjects with abnormal foot arch posture and 2.9 (95% confidence interval: 1.0, 8.1; P = .04) times greater for subjects with abnormal foot posture on the lunge leg.

**CONCLUSION:** Abnormal foot arch posture and a surgical history in the pitching shoulder or elbow may be associated. Because the foot and its arches are adaptable and change over time, the pathomechanics of this association should be further explored.

**KEY WORDS:** foot arch posture, pes cavus, pes planus, pitching
The purpose of this study was to examine the association between foot arch postures and shoulder or elbow injuries requiring surgery in elite-level baseball pitchers. We hypothesized that the presence of abnormal foot arch postures would increase the odds of having had a pitching-related shoulder or elbow injury requiring surgery (i.e., labral repair, ulnar collateral ligament repair).

METHODS

Participants

A convenience sample of 77 pitchers was recruited from a Division I university team and a professional baseball franchise over a 2-year period. The exclusion criteria for this study were pitchers with acute lower extremity injury or surgery, or those whose lower extremity was casted or immobilized. This study was approved by the University of Miami Human Subjects Committee, and all subjects signed informed consent prior to testing. All data were considered confidential and were not shared with the players’ coaches or their affiliated organizations.

Procedure

Subjects were interviewed by a licensed health care practitioner (physical therapist or physician) using a standard script. The interview was used to collect information on each subject’s pitching arm and the presence and type of shoulder or elbow surgery related to the act of pitching a baseball. Subjects with a history of shoulder or elbow surgery related to the act of pitching were classified as cases, and those without such a history were classified as controls. The subjects’ height, weight, and age were gathered from official team records.

To classify subjects as exposed to an abnormal foot arch posture, we measured the LAA with an 8-inch goniometer. A study by McPoil and Cornwall found that static measurements of the LAA strongly predicted dynamic foot arch postures at mid support in running and midstance in walking. In their study, the static LAA was determined from a digital image of the medial aspect of each of the subject’s feet, obtained in a relaxed standing posture, as well as with the leg maximally internally rotated. For the dynamic phase, subjects were asked to walk across a 12-m walkway, then to run across a 25-m runway, while the medial aspect of each foot was videotaped. The LAA was digitized from the video images at midstance in walking and at mid support while running for 5 trials per extremity. Jonson and Gross reported that measurement of the LAA with an 8-inch goniometer was a highly reliable static measure, with an intrarater reliability of 0.90 and interrater reliability of 0.81.

To remove tester bias, the individual performing the physical examination was blinded to the results of the interview. During the physical examination, the LAAs of both the stance and lunge feet were measured once (FIGURE 1). Each subject was asked to stand on an elevated platform for ease of measurement. The midpoint of the medial malleolus, navicular tuberosity, and the medial aspect of the first metatarsal head were identified by palpation and marked on each foot. Subjects were instructed to place the foot not being measured 15 cm away and posteriorly, so that it would not obstruct data collection. Subjects were then asked to stand comfortably and relaxed, with equal weight bearing. The goniometer axis was placed over the navicular tuberosity, with one arm fixed at the midpoint of the medial malleolus and the other at the midpoint of the medial aspect of the first metatarsal head. Measurement information was recorded on a data-collection sheet.

Each foot was then categorized as pes planus, typical, or pes cavus, based on the measurements taken of the LAA. As described by McPoil and Cornwall, typical arch posture was defined as having an LAA between 130° and 150° (FIGURE 2), pes planus as having an arch posture of less than 130° (FIGURE 3), and pes cavus as having an arch posture of greater than 150° (FIGURE 4).

Statistical Analysis

Statistical analyses were performed using SAS for Microsoft Windows 9.2 (SAS Institute Inc, Cary, NC). Statistical significance was set at P<.05. The characteristics of cases and controls were compared using Student t tests and chi-square statistics. Odds ratios with 95% confidence intervals were calculated using the PROC LOGISTIC procedure in SAS.
This relationship allows

The mechanisms underlying these findings may involve an association between foot arch posture and the throwing arm.

Although this study did not directly measure the biomechanics of the arch as it relates to the shoulder or elbow during the act of pitching, our findings suggest an association that can be interpreted in the context of what is known about human biomechanics. The arch of the foot should provide for an elastic, springy connection between the regions of the foot. The relationship allows for normalized weight bearing and the dissipation of ground reaction forces before they are transmitted to the leg and thigh.

It is also known that foot arch posture changes over time because of factors such as growth, aging, and disease-dependent degenerative processes during life. Redmond et al discovered that a U-shaped relationship existed for age, with minors and older adults exhibiting higher foot posture index scores than the general adult population. Because the foot and its arches are adaptable and provide for both stability and flexibility, this implies that the posture of the foot is not necessarily fixed, but can change over time.

Performance athletes, such as baseball
players, begin intensive training at an early age. Training at such an early age, when the musculoskeletal system is still in development, may result in adaptive changes to the body. Because the repetitive act of pitching requires constant unilateral overload of the upper and lower limbs from the wind-up phase through follow-through, there is an inherent chance of developing asymmetries of the upper and lower limbs as compared to the nonthrowing side. Aydog et al studied foot morphology across different sports and found that the arch index differed among sports that involved leg dominance (soccer and handball) compared to sports that did not involve leg dominance (wrestling) and nonathletic controls.

It could be further argued that perhaps those pitchers with a shoulder or elbow injury may alter their pitching mechanics, which may lead to abnormal stresses that cause changes to foot posture. Pathomechanically, it is plausible that an injured shoulder could lead to reduced capacities of the upper and lower limbs, altered patterns of muscle coordination, instability and/or hypermobility in one direction with reduced motion and translation in others, or muscle weakness and imbalance, which could then lead to the collapsing of the arch of the foot as a means of compensation in order to generate the forces required in the pitching action.

Conversely, the presence of abnormal foot arch postures has been associated with musculoskeletal problems of the muscles and joints of the ankle, knee, hip, and low back. Levy et al reported that an increase in plantar surface pressure associated with pes planus foot type had significantly greater numbers of lower extremity overuse injuries. Cote et al found that postural stability was affected by foot type (pronated, neutral, or supinated) under both static and dynamic conditions. Foot arch posture classified with the foot posture index has also been associated with the development of various overuse injuries of the lower extremities and osteoarthritis of the knee. However, because these studies are not longitudinal from childhood to adulthood, it is not known whether the abnormalities of foot arch posture are congenital or acquired.

**Pes Planus Condition**

In our study, pes planus in the stance foot had the highest odds ratio (3.7) of all conditions and was statistically significant. No statistical significance was found for pes planus in the lunge foot, a condition with the lowest odds ratio (2.4) among all other conditions. This finding suggests that pes planus on the stance foot may alter loading during the wind-up phase of the pitching motion more than any other condition.

Pes planus can create a foot that is flexible and unstable, and necessitates more compensatory muscle action than a typical arch to support and propel the weight of the body. Pes planus has also

### TABLE 3

<table>
<thead>
<tr>
<th>Foot Posture Status</th>
<th>Frequency, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical bilateral</td>
<td>43 (55.8)</td>
</tr>
<tr>
<td>Pes planus</td>
<td></td>
</tr>
<tr>
<td>Both legs</td>
<td>6 (78)</td>
</tr>
<tr>
<td>Stance leg only</td>
<td>6 (78)</td>
</tr>
<tr>
<td>Lunge leg only</td>
<td>6 (78)</td>
</tr>
<tr>
<td>Pes cavus</td>
<td></td>
</tr>
<tr>
<td>Both legs</td>
<td>9 (117)</td>
</tr>
<tr>
<td>Stance leg only</td>
<td>4 (52)</td>
</tr>
<tr>
<td>Lunge leg only</td>
<td>3 (39)</td>
</tr>
</tbody>
</table>

**Chi-square statistic.**

### TABLE 4

<table>
<thead>
<tr>
<th>Foot/Posture</th>
<th>Pitching Arm (Surgery), n (%)</th>
<th>Pitching Arm (No Surgery), n (%)</th>
<th>P Value*</th>
<th>Odds Ratio†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stance foot</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pes planus</td>
<td>6 (50.0)</td>
<td>6 (50.0)</td>
<td>.05</td>
<td>3.7 (1.0, 13.8)</td>
</tr>
<tr>
<td>Typical</td>
<td>11 (21.2)</td>
<td>41 (78.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pes cavus</td>
<td>6 (46.2)</td>
<td>7 (53.8)</td>
<td>.07</td>
<td>3.2 (0.9, 11.5)</td>
</tr>
<tr>
<td>Typical</td>
<td>11 (21.2)</td>
<td>41 (78.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abnormal</td>
<td>12 (48.0)</td>
<td>13 (52.0)</td>
<td>.02</td>
<td>3.4 (1.2, 9.6)</td>
</tr>
<tr>
<td>Typical</td>
<td>11 (21.2)</td>
<td>41 (78.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lunge foot</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pes planus</td>
<td>5 (41.7)</td>
<td>7 (58.3)</td>
<td>.18</td>
<td>2.4 (0.7, 9.1)</td>
</tr>
<tr>
<td>Typical</td>
<td>12 (22.6)</td>
<td>41 (77.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pes cavus</td>
<td>6 (50.0)</td>
<td>6 (50.0)</td>
<td>.06</td>
<td>3.4 (0.9, 12.6)</td>
</tr>
<tr>
<td>Typical</td>
<td>12 (22.6)</td>
<td>41 (77.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abnormal</td>
<td>11 (45.8)</td>
<td>13 (54.2)</td>
<td>.04</td>
<td>2.9 (1.0, 8.1)</td>
</tr>
<tr>
<td>Typical</td>
<td>12 (22.6)</td>
<td>41 (77.4)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Chi-square statistic.

†Values in parentheses are 95% confidence interval.

‡Abnormal posture is a reference to the sum of pes planus and pes cavus for that specific condition.
been shown to lead to subsequent malalignments in the spine, specifically increases in lumbar lordosis.\textsuperscript{22} Increases in lumbar lordosis have been shown to cause hyperabduction and hyper-external rotation of the shoulder during the pitching motion, creating increases in forces at the shoulder and elbow.\textsuperscript{1,2,56} This abnormal increase in lordosis, specifically during the acceleration phase of the pitching motion, places the shoulder and elbow at risk of injury because of the higher forces.

**Pes Cavus Condition**

In our study, the odds ratios associated with pes cavus on either the stance foot (3.2) or the lunge foot (3.4) near statistical significance. However, it should be noted that the odds ratio for lunge-foot pes cavus was higher than that for the stance foot. Because the lunge foot is in contact with the ground during the deceleration phases of the throwing motion, further investigation of the stresses on the upper and lower limbs due to this condition is warranted.

Pes cavus, compared to pes planus, is typically considered to create a more rigid system in the lower extremity across multiple conditions.\textsuperscript{2,50} Williams et al\textsuperscript{50} studied runners to determine if structural deviations of the medial longitudinal arch were associated with differences in lower extremity kinematics. The study\textsuperscript{50} found that the high-arch (pes cavus) condition demonstrated differences in lower extremity kinematics, specifically, a decrease in knee flexion excursion during stance and differences in leg stiffness and vertical loading rates. The mechanical parameter of leg stiffness, which was defined as the ability of the lower extremity to attenuate the excessive forces generated during stance during the act of running, was higher in high-arch runners.\textsuperscript{50} A result of increased leg stiffness is a decrease in sagittal plane excursion at the knee, reduced center of mass, larger vertical loading rates, and different muscle activity.\textsuperscript{50} The findings of this study support the hypothesis that a pes cavus foot may have difficulty with shock absorption due to a smaller weight-bearing area.\textsuperscript{22} We hypothesize that the decreased ability to attenuate shock through the foot may limit the ability to decelerate the upper and lower limbs during follow-through. Additionally, a smaller weight-bearing surface on the lunge foot could lead to a loss of balance at follow-through and potentially hinder the act of deceleration. Finally, the pes cavus condition may also lead to the need to compensate by creating hypermobility in joints proximal to the foot.

**Epidemiology of Injuries**

Because of the high incidence of shoulder and elbow injuries in professional and collegiate-level baseball pitchers, these athletes provided the optimal population for this study.\textsuperscript{15,55} The frequency of superolabral-complex injuries was found to correlate well with that of a study by Han et al.\textsuperscript{24} that reported superolabral lesions to be the most commonly observed shoulder injury in pitchers. Superolabral lesions accounted for 19.8% of total injuries in pitchers from junior high school through college.\textsuperscript{24} In collegiate baseball, the percentage of superolabral lesions rose to 26.5%.\textsuperscript{24} Han et al.\textsuperscript{24} also reported that ulnar collateral ligament injuries were the most common lesions in their study, accounting for 32.5% of all injuries. Additionally, successful pitchers with longer careers are exposed to an ever-increasing volume of pitches thrown and, therefore, risk of potential injury.

**Clinical Implications**

There are several important clinical implications of this research. First, these findings should alert health care professionals who work with baseball pitchers to assess foot arch posture. Second, preventative interventions through treatments for abnormal foot arch postures may prove to be of benefit. Examples of possible interventions could be participation screenings, movement screenings, balance training, orthotics, taping, and stretching.\textsuperscript{32,53,54,57} Vicenzino et al\textsuperscript{57} reported augmented taping as effective in controlling pronation during both static and dynamic activity, as it was able to induce changes in static foot arch posture that paralleled those seen during walking and jogging.

**Limitations of the Current Study**

There are several potential limitations of this study that should be noted. A major limitation was the low number of subjects in the case and control groups, which affected the chi-square analysis results and the 95% CIs. Although the odds ratios were significant, the 95% CIs were very wide, which limited interpretation of the results of the study and increased the risk of both type I and type II errors. However, the CIs do provide the information required to interpret these findings in light of both the small sample size and the multiple comparisons. The participant history of shoulder or elbow surgery was taken by subjective report rather than medical-record review, introducing possible recall error. The study relied solely on the LAA to classify foot arch posture. The authors acknowledge that there are more accurate measures of foot arch posture than the LAA; however, the decision to use the LAA was based on data-collection time constraints and a lack of instrumentation. Tester reliability for the LAA was not measured prior to data collection. The tester was educated by the primary investigator in how to measure the LAA, with additional practice sessions to confirm consistency in measurement. Data collection was conducted on the day of the multidisciplinary preseason physical examinations for pitchers of all levels in the professional franchise at their spring training complex. Additionally, data collection for the pitchers at the university level faced similar challenges.

**Future Investigations**

There are many potential directions that future studies can take to further substantiate the association, establish causal...
direction, evaluate possible mechanisms by which foot posture may influence the pitching motion, and develop effective interventions to potentially decrease the risk of injury.

CONCLUSION

The influence of the musculoskeletal structures on throwing is well established and often cited. There are numerous investigations in the literature that detail how musculoskeletal impairments and structural abnormalities can result in lower extremity injuries. However, to the authors’ knowledge, this is the first study that examined the association between foot arch postures and a history of shoulder or elbow surgery related to the pitching motion. The current study demonstrated increased odds for a throwing-related injury to the shoulder or elbow in pitchers with an abnormal foot arch posture in either the lunge or stance foot. However, further investigations are needed to examine what specific changes to the throwing motion an abnormal foot posture may cause.

KEY POINTS

- FINDINGS: The current study demonstrates increased odds for a throwing-related injury to the shoulder or elbow in pitchers with an abnormal foot arch posture in either the lunge or stance foot.
- IMPLICATIONS: Identification of an abnormal foot posture in a baseball pitcher may help in decision making when creating an injury-prevention intervention for throwing-related injury to the shoulder or elbow in pitchers. Future investigations are needed to examine what specific changes to the throwing motion an abnormal foot posture may cause.
- CAUTION: This was a case-control study that used only the LAA for classification of foot type.

REFERENCES


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