# Biomechanical Differences Between Japanese and American Professional Baseball Pitchers

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**Background:** Although baseball injuries are common in both Japan and the United States, the majority of pitching injuries in Japanese players occur at the shoulder, whereas most pitching injuries in American players occur at the elbow. A biomechanical comparison between Japanese and American pitchers may help to identify the different injury mechanisms.

**Hypothesis:** Japanese pitchers produce greater shoulder kinetics whereas American pitchers generate greater elbow kinetics. Also, kinematic differences will be found between the 2 groups, including longer stride and greater lead knee flexion for Japanese pitchers.

**Study Design:** Descriptive laboratory study.

**Methods:** Biomechanical data for 19 Japanese professional baseball pitchers and an age-matched group of 19 American professional baseball pitchers were collected by use of a 3-dimensional, automated, high-speed optical motion capture system. Anthropometric, kinetic, and kinematic data for both groups were compared by use of *t* tests ($P < .05$).

**Results:** American pitchers were taller and heavier and generated greater ball velocity (38.1 ± 1.6 vs 34.7 ± 1.1 m/s; $P < .001$) than their Japanese counterparts. Most elbow and shoulder kinetic parameters, including elbow varus torque (99 ± 17 vs 86 ± 17 N·m; $P = .018$), were greater for American pitchers. However, when normalized by bodyweight and height, shoulder horizontal adduction torque was greater for Japanese pitchers (6.8% ± 1.0% vs 5.8% ± 1.1%; $P = .005$). Japanese pitchers had longer stride (86% ± 5% vs 82% ± 6% of height; $P = .023$), greater shoulder abduction at ball release (101° ± 8° vs 94° ± 9°; $P = .014$), and greater knee flexion after ball release (39° ± 18° vs 28° ± 14°; $P = .039$). Japanese pitchers also demonstrated greater shoulder internal rotation velocity, elbow flexion, and elbow extension velocity.

**Conclusion:** Greater elbow varus torque may predispose American pitchers to greater risk of elbow injury. Japanese pitchers may have increased risk of shoulder injury due to greater normalized horizontal adduction torque and greater abduction angle. Japanese pitchers may be able to reduce their shoulder torque and risk of injury by shortening their stride, reducing their lead knee flexion, and decreasing their throwing arm abduction.

**Clinical Relevance:** Understanding anthropometric, kinetic, and kinematic differences between pitchers from the 2 countries may be of value to clinicians and coaches working to maximize performance of the pitchers while minimizing the risk of injury.

**Keywords:** pitching mechanics; kinematics; kinetics; shoulder; elbow

Baseball at all levels—from youth to professional—has been popular in both the United States and Japan for more than 100 years.[5] The first documented baseball game using rules similar to modern baseball was played in New Jersey in 1846,[22] and by the 1870s, baseball was also being played in Japan.[22,44] Although popularity in both countries has led to more players participating throughout the multiple levels of baseball, this has also led to an increase in athletic exposures and injuries in the sport. In US professional baseball, major and minor league players are unable to play approximately 120,000 days each year,[4] including about 30,000 days on the Major League Baseball (MLB) disabled list.[7] Of particular concern is the number of throwing arm injuries. From 1998 to 2015, the number of shoulder injuries in MLB declined while the number of elbow injuries continued to increase.[3,7] About one-third (34%) of elbow injuries sustained by professional pitchers require surgery.[6] A recent survey documented an alarmingly high prevalence of ulnar collateral ligament surgery among major league pitchers (25%) and minor league pitchers

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(15%).[8] Although elbow injuries have continued to rise and now represent the majority of pitching injuries in professional baseball in the United States, such high rates are not seen among professional pitchers in Japan's Nippon Professional Baseball (NPB).[41] In our clinical experience, Japanese professional pitchers report pain more often in the anterior shoulder rather than the elbow.

Until the 1960s, elite baseball players from Japan played exclusively in NPB, while elite players from the United States played in MLB and its affiliated minor league systems. In 1995, Hideo Nomo "retired" from the Kintetsu Buffaloes in the NPB and then signed with the Los Angeles Dodgers in MLB. Nomo's success opened the door for MLB teams to sign other pitchers from Japan. Since Nomo's debut, more than 50 Japanese-born players have pitched in MLB. Interestingly, a number of prominent Japanese pitchers (eg, Ohtani, Tanaka, Darvish, Matsuzaka, Fujikawa) began to experience serious elbow injuries shortly after joining professional baseball in the United States. Statistical analysis is not possible with these isolated examples, but this trend raises the possibility of injury risk beyond pitching mechanics, such as differences in equipment and fields.

In both countries, the baseball used is a spherical ball formed by yarn wound around a small core of cork or rubber. The wound balls are then covered with 2 strips of white horsehide or cowhide, which are tightly stitched together with red cotton thread.[29,36] The baseballs in both countries are regulated to a circumference between 22.9 and 23.5 cm and a mass between 142 and 149 g.[29,36] Although Japanese baseballs previously tended to be at the low end of the regulation ranges, in 2011 the NPB commissioner ordered the baseballs to be manufactured in line with baseballs in the United States.[25] Furthermore, NPB has added target values for the baseball coefficient of restitution along with specifications for stitch width (0.8 cm), stitch height (0.9 mm), and number of stitches (108).[36] An additional difference reported between Japanese and American baseballs is their "stickiness." The consensus of many scouts and players who have played in both leagues is that the Japanese ball is stickier than the baseballs used in the United States.[23]

In addition to the differences in the baseballs used, differences are found with respect to the pitching mounds. Although the mounds are constructed to the same specifications (mound height, slope, etc) in both countries, the materials used for construction are different. In the United States, mounds are made with hard red/brown soil and clay, but in Japan they are made of softer, more powdery dirt, which allows pitchers to dig in more easily and provides less resistance when pitchers drag their back foot during delivery.[42] The differences in materials is primarily due to the soil makeup on the island of Japan. The soil used to build the mounds is soft and dark due to the volcanogenic sediment or volcanic ash.[27]

Although the effects of mound construction and baseball specifications on injury rates are unknown, the primary risk factor in both countries is the quantity of pitching. Several studies have correlated the amount of pitching with arm pain and injury risk in amateur baseball, specifically in the United States.[13,28,46] In the United States, some amateur pitchers participate on multiple teams, play baseball year-round, throw more than they should, and neglect to take the recommended rest. In response to these risk factors, many youth leagues across the United States are beginning to limit how much a pitcher throws, abiding by recommendations made by Pitch Smart.[30] In addition to these recommendations, a common practice in the United States (in both amateur and professional baseball) is for a team to have a pitching rotation where pitchers will have off-days and light bullpen sessions between competitive starts.

Other potential risk factors that may differ between Japan and the United States include body size, ball velocity, and pitching mechanics. Pitchers in MLB are overall taller, have greater mass, and pitch with more velocity than their NPB counterparts[35]; these differences themselves may increase the injury risk for MLB pitchers. Regarding mechanics, Japanese and American pitching instructors emphasize different motions for the lower body. American pitchers are taught that after lifting the lead knee, they should stride forward and land in a "strong position" and then extend their lead knee to use the lead leg as a stable base to rotate the trunk.[31] A study of 127 American professional and collegiate pitchers showed that those who pitched with greater lead knee extension velocity achieved greater ball velocity.[31] Japanese pitchers are taught that after lifting the lead knee, they should lower their center of mass and stride out, moving the trunk forward toward the lead foot.[9] Japanese pitchers are taught to keep their front knee flexed during ball release.[26]

Almost 20 years ago, Escamilla et al[10,12] published a pair of studies comparing the biomechanics of American pitchers versus elite Asian pitchers. Their study[12] of data manually digitized from the 1996 Olympics revealed a trend for a longer stride in Asian pitchers (85% height, n = 12) than American or Cuban pitchers (80%, n = 14), but the trend was not statistically significant ($P = .089$) with these small groups. The Olympics study showed no difference in lead knee flexion between the groups,[12] but a laboratory study of automated motion capture found significantly more ($P < .01$) lead knee flexion at ball release for Korean professional

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pitchers (48°, n = 8) than American professional pitchers (32°, n = 11).[10]

Although these previous studies provide some insight, differences between elite pitchers from the United States and Japan have not been investigated. Therefore, the purpose of this study was to compare pitching biomechanics between Japanese and American professional baseball pitchers. We hypothesized that kinematic differences would be found between the two groups as follows: (1) Japanese pitchers would have a longer stride and greater lead knee flexion than their American counterparts and (2) American pitchers would generate greater elbow kinetics, whereas Japanese pitchers would generate greater kinetics at the shoulder.

## METHODS

### Participants

This study was approved by the institutional review board at Nobuhara Hospital and Institute of Biomechanics (NHIB; Tatsuno Hyogo, Japan) and determined as exempt by the institutional review board at St Vincent's Health System (Birmingham, Alabama, USA). This study involved a retrospective review of data previously collected by the NHIB and the American Sports Medicine Institute (ASMI). For their data to be included in the present study, pitchers must have had no significant injury (ie, one that required them to miss playing time) in the 12 months prior to testing. Biomechanical data from 19 Japanese professional and semiprofessional pitchers (16 right-handed, 3 left-handed) were provided by NHIB. An age-matched set of 19 American minor league pitchers (16 right-handed, 3 left-handed) were selected from the ASMI database.

### Data Collection

At the time of testing, each participant wore tight-fitting spandex shorts, socks, and athletic shoes. A set of 24 retroreflective markers were attached to the participant.[15,39] Markers were placed bilaterally on the acromion process, elbow epicondyles (lateral and medial), styloid processes (ulnar and radial), greater trochanter, femoral epicondyles (lateral and medial), malleoli (lateral and medial), and third distal metatarsal. Additionally, a marker was placed between the second and third distal metacarpals on the throwing hand and another on the heel of the left foot. Prior to the start of data collection, each participant conducted his typical pregame warm-up routine, which generally consisted of stretching, nonthrowing drills, and throwing drills. Each participant was then allowed to throw an unspecified number of warm-up pitches until he felt ready to pitch with full effort. Participants threw pitches (both warm-up pitches and subsequent full-effort pitches) off a mound toward a strike zone target positioned 18.44 m from the pitching rubber. This setup conformed with both NPB and MLB regulations.[29,36] After concluding their warm-up, study participants threw a minimum of 3 full-effort fastballs at a self-selected pace, during which ball velocity and pitcher kinematic data were collected. If the pitcher threw more than 3 fastballs, only data from the first 3 fastballs were included for analysis.

TABLE 1
Participant Characteristics[a]

| | Japanese Pitchers (n = 19) | American Pitchers (n = 19) | $P$ |
|---|---|---|---|
| Age, y | 24.1 ± 3.6 | 24.1 ± 1.6 | >.99 |
| Height, cm | 180 ± 7 | 188 ± 7 | **<.001** |
| Mass, kg | 79 ± 9 | 96 ± 12 | **<.001** |
| Ball velocity, m/s | 34.7 ± 1.1 | 38.1 ± 1.6 | **<.001** |

[a]Data are reported as mean ± SD. Bolded $P$ values indicate statistically significant between-group differences ($P < .05$).

For all pitchers, 3-dimensional motion data were quantified by use of an automated motion capture system. Data from the Japanese pitchers were collected with 7 cameras (ProReflex MCU-500+; Qualisys) at 500 Hz, while data from the American pitchers were collected with 12 cameras (Raptor-12HS system; Motion Analysis Corp) at 240 Hz.

Ball velocity was recorded by use of a radar gun (Japanese, SpeedMax2; American, Stalker Sports Radar). Characteristics of the Japanese and American pitchers are compared in Table 1.

### Data Processing

Japanese motion data were converted to a 240-Hz sample rate by use of cubic spline interpolation. Japanese and American data were then processed via BioPitch software (ASMI). Marker position data were filtered by use of a fourth-order, Butterworth, low-pass filter with a cutoff frequency of 13.4 Hz.[17] The joint centers of the elbows, wrists, knees, and ankles were defined as the midpoints between their respective medial and lateral markers, while the shoulder and hip joint centers were calculated through use of techniques previously described.[11,16,17] The pitching motion was broken into 6 phases: wind-up (initial movement to maximum knee height), stride (maximum knee height to foot contact), arm cocking (foot contact to maximum shoulder external rotation), arm acceleration (maximum shoulder external rotation to ball release), arm deceleration (ball release to maximum shoulder internal rotation), and follow-through (maximum internal rotation to end of motion).[47] For each pitch, kinematic and kinetic parameters[16] were calculated by use of the marker data; the estimated mass properties of the upper arm, forearm, hand, and ball[17,47]; and the standard kinematics and inverse dynamics calculations.[47]

The kinematic parameters measured at the instant of lead foot contact included stride length, lead foot position, lead foot angle, lead knee flexion, pelvic rotation, trunk axial rotation, upper trunk lateral tilt, shoulder abduction, shoulder horizontal abduction, shoulder external rotation, and elbow flexion. Stride length was the distance from the back ankle's position at the time of maximum lead knee height to the lead ankle's position at the time of foot contact, divided by the pitcher's height. Lead foot position was the distance in the "closed" direction (from first base toward third base for a right-handed pitcher, from third base toward first base for a left-handed pitcher) of the lead ankle's position at the time of foot contact relative to the back ankle's position at maximum lead knee height. Lead foot angle was the angle between the anterior direction of the foot and the "pitch direction" (from the pitching rubber to home plate), where a positive value indicated internal rotation of the foot. Pelvic rotation was the angle between a line connecting the two hips and the pitch direction, where a positive value indicated the anterior direction of the pelvis rotated toward home plate. Trunk axial rotation was positive when the anterior direction of the pelvis was rotated more than the anterior direction of the upper trunk toward the pitch direction. Upper trunk lateral tilt was the angle between the horizontal plane and a line through the two shoulders; a positive value indicated that the lead shoulder was higher than the back shoulder.

The kinematic parameters measured during the arm cocking phase included maximum pelvic rotation velocity as well as maximum upper trunk rotation velocity. Three kinematic parameters (maximum shoulder external rotation, maximum shoulder horizontal adduction, and maximum elbow flexion) were measured near the instant of maximum shoulder external rotation. Two kinematic parameters (maximum angular velocities of shoulder internal rotation and elbow extension) were measured during the arm acceleration phase.

The parameters measured at the instant of ball release included lead knee flexion, trunk forward tilt, trunk side tilt, shoulder abduction, and elbow flexion. Trunk forward tilt was the angle between the superior direction of the trunk and the vertical direction, in the global plane defined by the vertical direction and pitch direction. Trunk side tilt was the angle between the superior direction of the trunk and the vertical direction, in the global plane perpendicular to pitch direction; trunk side tilt was positive when the trunk was tilted toward the glove arm side. Finally, lead knee flexion and trunk forward tilt were measured at the instant of maximum shoulder internal rotation.

Elbow kinetic parameters were expressed as the forces and torques applied to the forearm at the elbow joint. Shoulder kinetic parameters were expressed as the forces and torques applied to the upper arm at the shoulder joint. Half of the kinetic parameters (maximum values of elbow varus torque, shoulder internal rotation torque, and shoulder horizontal adduction torque) occurred near the instant of maximum shoulder external rotation, while the other half (maximum values of elbow flexion torque, elbow proximal force, and shoulder proximal force) occurred near the instant of ball release. Kinetic parameters were expressed in both raw magnitudes (force in N, torque in N·m) and normalized values (force divided by weight, torque divided by weight × height).

TABLE 2
Kinematic Parameters[a]

| Parameter | Japanese Pitchers | American Pitchers | *P* |
|---|---|---|---|
| *Instant of lead foot contact* | | | |
| Stride, % height | 86 ± 5 | 82 ± 6 | **.023** |
| Lead foot position, cm | 8 ± 11 | 26 ± 11 | **<.001** |
| Lead foot angle, deg | 5 ± 7 | 14 ± 7 | **<.001** |
| Lead knee flexion, deg | 48 ± 9 | 45 ± 10 | .440 |
| Pelvic rotation, deg | 47 ± 9 | 31 ± 13 | **<.001** |
| Trunk axial rotation, deg | 48 ± 11 | 41 ± 10 | .058 |
| Upper trunk lateral tilt, deg | 5 ± 6 | 9 ± 6 | **.044** |
| Shoulder abduction, deg | 92 ± 11 | 91 ± 8 | .718 |
| Shoulder horizontal abduction, deg | 14 ± 10 | 18 ± 17 | .453 |
| Shoulder external rotation, deg | 76 ± 31 | 61 ± 28 | .141 |
| Elbow flexion, deg | 105 ± 14 | 94 ± 15 | **.030** |
| *Arm cocking phase* | | | |
| Maximum pelvic rotation velocity, deg/s | 553 ± 67 | 559 ± 51 | .747 |
| Maximum upper trunk rotation velocity, deg/s | 1197 ± 120 | 1131 ± 105 | .082 |
| *Instant of maximum shoulder external rotation* | | | |
| Maximum shoulder external rotation, deg | 178 ± 12 | 172 ± 9 | .081 |
| Maximum shoulder horizontal adduction, deg | 18 ± 5 | 19 ± 7 | .558 |
| Maximum elbow flexion, deg | 114 ± 8 | 107 ± 8 | **.012** |
| *Arm acceleration phase* | | | |
| Maximum shoulder internal rotation angular velocity, deg/s | 8476 ± 1953 | 6842 ± 935 | **.002** |
| Maximum elbow extension angular velocity, deg/s | 3030 ± 498 | 2651 ± 269 | **.006** |
| *Instant of ball release* | | | |
| Lead knee flexion, deg | 45 ± 16 | 38 ± 13 | .156 |
| Trunk forward tilt, deg | 34 ± 7 | 31 ± 6 | .151 |
| Trunk side tilt, deg | 24 ± 9 | 19 ± 7 | .074 |
| Shoulder abduction, deg | 101 ± 8 | 94 ± 9 | **.014** |
| Elbow flexion, deg | 20 ± 6 | 25 ± 5 | **.016** |
| *Instant of maximum shoulder internal rotation* | | | |
| Lead knee flexion, deg | 39 ± 18 | 28 ± 14 | **.039** |
| Trunk forward tilt, deg | 45 ± 8 | 41 ± 8 | .121 |

[a]Data are reported as mean ± SD. Bolded *P* values indicate statistically significant between-group differences ($P < .05$).

## Statistical Analyses

To determine whether biomechanical differences existed between Japanese and American pitchers, statistical analyses were performed with SAS 9.4 (SAS Institute). For each individual pitcher, the mean value of his 3 fastballs was computed for each biomechanical parameter. Two-sample *t* tests were then performed to compare the two groups. The threshold for statistical significance was set at $\alpha = .05$.

## RESULTS

Kinematic results are shown in Table 2. At the instant of foot contact, Japanese pitchers demonstrated a longer normalized stride with a less closed lead foot position and angle (ie, for a right-handed pitcher, less to the third base side and less internally rotated toward the third base line). The Japanese pitchers had more pelvic rotation at the instant of

TABLE 3
Kinetic Parameters[a]

| Parameter | Japanese Pitchers | American Pitchers | P |
|---|---|---|---|
| *Instant of maximum external rotation* | | | |
| Maximum elbow varus torque | | | |
| Torque, N·m | 86 ± 17 | 99 ± 17 | **.018** |
| Normalized torque | 6.1 ± 0.9 | 5.6 ± 0.8 | .075 |
| Maximum shoulder internal rotation torque | | | |
| Torque, N·m | 85 ± 16 | 100 ± 16 | **.006** |
| Normalized torque | 6.1 ± 0.8 | 5.7 ± 0.8 | .136 |
| Maximum shoulder horizontal adduction torque | | | |
| Torque, N·m | 94 ± 14 | 101 ± 17 | .148 |
| Normalized torque | 6.8 ± 1.0 | 5.8 ± 1.1 | **.005** |
| *Instant of ball release* | | | |
| Maximum elbow flexion torque | | | |
| Torque, N·m | 50 ± 6 | 68 ± 12 | **<.001** |
| Normalized torque | 3.6 ± 0.6 | 3.9 ± 0.5 | .163 |
| Maximum elbow proximal force | | | |
| Force, N | 957 ± 109 | 1151 ± 161 | **<.001** |
| Normalized force | 124 ± 16 | 122 ± 12 | .688 |
| Maximum shoulder proximal force | | | |
| Force, N | 960 ± 111 | 1176 ± 182 | **<.001** |
| Normalized force | 125 ± 18 | 125 ± 16 | .970 |

[a]Data are reported as mean ± SD. Normalized torque = % weight × height; normalized force = % weight. Bolded *P* values indicate statistically significant between-group differences ($P < .05$).

foot contact, consistent with the fact that maximum pelvic rotational velocity occurred earlier for Japanese pitchers. Additionally, Japanese pitchers obtained less upper trunk lateral tilt than their American counterparts.

Maximum velocities for shoulder internal rotation and elbow extension were significantly greater for Japanese pitchers. Japanese pitchers also had greater shoulder abduction at ball release. After ball release, Japanese pitchers maintained more lead knee flexion than their American counterparts.

Kinetic results are shown in Table 3. Near the instant of maximum shoulder external rotation, American pitchers generated greater shoulder internal rotation torque and elbow varus torque. When results were normalized by height and weight, Japanese pitchers produced greater shoulder horizontal adduction torque to accelerate the arm forward with the rotating upper trunk. American pitchers produced greater shoulder proximal force, elbow proximal force, and elbow flexion torque to decelerate the arm motion near the time of ball release.

## DISCUSSION

As hypothesized, Japanese pitchers had a longer stride (scaled by height). The longer stride was accompanied by a less closed lead foot position, a less closed lead foot angle, and earlier pelvic rotation. We believe that the less closed foot position was a natural result of the longer stride. For example, Figure 1 shows the overhead view of the motion of the lead ankle for one of the Japanese right-handed pitchers. Had his lead foot landed earlier, at a typical stride length for an American pitcher, the lead foot would have been more closed (ie, toward third base). The longer stride for Japanese pitchers may also explain the greater pelvic rotation at foot contact. That is, the extra time needed for the longer stride gave Japanese pitchers more time to rotate the pelvis. The hypothesis that Japanese pitchers used greater lead knee flexion was partially supported. No significant difference was found in knee flexion at the instant of foot contact. However, after ball release, knee flexion was greater for the Japanese pitchers.

The greater upper extremity angular velocities for Japanese pitchers may be attributable to greater range of motion. On average, a Japanese pitcher extended his elbow 94° (from 114° to 20°), whereas an American pitcher extended his elbow 82° (from 107° to 25°). The Japanese pitchers also had 6° more shoulder external rotation (178° vs 172°), which would be clinically relevant but was not statistically significant. In hindsight, it would have been interesting to see whether the Japanese pitchers had greater flexibility (shoulder and elbow passive range of motion) than their American counterparts.

The fact that the American professional pitchers were bigger (greater bodyweight and height) than the Japanese professional pitchers complicates the comparison of kinetics. It is unknown whether raw magnitudes of joint forces (N) and torques (N·m) should be compared between the two groups or whether it is more clinically relevant to compare kinetics normalized by body size. More to the point, it is unknown whether the size and strength of joint ligaments and tendons are similar between Japanese and American pitchers or whether tissue size and strength are proportional to body size. In the absence of this knowledge, the current study analyzed both magnitudes and normalized magnitudes for the two groups of pitchers.

The hypothesis that Americans would have greater elbow kinetics was partially supported. The magnitude of elbow varus torque was significantly greater in American pitchers. This is clinically important, as the ulnar collateral ligament is a primary contributor to varus torque in pitching.[14,18,24] Excessive varus torque[1,2,32] and repetition[13,21,33,40] may increase the risk of ulnar collateral ligament injury. The higher varus torque (and elbow injury rate) in American pitchers may be related to their higher pitch velocities. A recent study of 64 professional pitchers in the United States analyzed the relationships between ball velocity and elbow varus torque both within and across pitchers.[43] Although the association between velocity and torque was weak across players, a very strong correlation ($R^2 = 0.96$) was found within players. That is, a pitcher had significantly less elbow varus torque when his fastball velocity was decreased. The authors of that study concluded that pitchers may be able to reduce their risk of elbow injury by varying fastball velocities instead of throwing all pitches with maximal effort.[43]

Results from this study only partially supported the hypothesis that Japanese pitchers produce greater

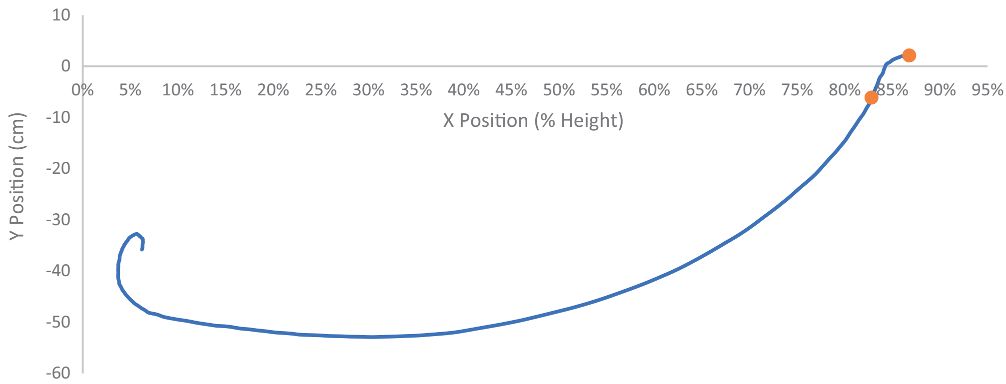


**Figure 1.** Overhead view of the motion of the lead (ie left) ankle for a right-handed Japanese pitcher, from the instant of maximum knee height to the instant of lead foot contact. The origin (0,0) is the position of the back (ie, right) ankle at the instant of maximum knee height. The *X* position is motion of the left ankle toward home plate, and the *Y* position represents the motion toward first base (+Y) or third base (–Y). This Japanese pitcher was selected because his stride length (87% height) was close to the group average. The circle marker at the end of the line represents his ankle at the instant of foot contact, whereas the other circle marker represents a point with a typical American stride length (ie, 4% less than the Japanese stride).

shoulder torques and forces. The normalized value of shoulder horizontal adduction torque was significantly greater for the Japanese pitchers. For all pitchers, maximum shoulder horizontal adduction torque occurred near the end of the arm cocking phase. As the upper trunk rotates to face the target, force and torque are needed to accelerate the upper extremity forward with the trunk and maintain shoulder stability. That is, ligaments and tendons about the anterior aspect of the glenohumeral joint resist posterior translation and horizontal abduction of the upper arm. Tension about the anterior shoulder may lead to a rotator interval lesion.[34,37,38] The greater shoulder abduction angle at ball release for Japanese pitchers may further increase the risk of shoulder injury, including superior impingement, subacromial bursitis, rotator interval lesion, rotator cuff tear, subscapularis tendinitis, or superior labral anterior-posterior (SLAP) lesion.[14,19,20] Yanagisawa et al[45] reported high signal on T2-weighted images in the subscapularis of Japanese pitchers up to 48 hours after pitching. In our clinical experience with Japanese professional pitchers, T2-weighted magnetic resonance imaging has revealed high intensity in the subscapularis or rotator interval.

In contrast to the hypothesis about greater shoulder kinetics in Japanese pitchers, shoulder internal rotation torque and proximal force were significantly greater for the American pitchers. The greater shoulder proximal force for the American pitchers may be related to their extension of the lead knee from foot contact to ball release, decelerating the forward motion of their body.

The greater kinetic values for the American pitchers may also be due to their greater size (height and weight). Although not examined in the current study, the bigger athletes might have stronger, more powerful muscles to generate more joint force and torque. The greater ball velocity for American pitchers may also be related to their greater shoulder and elbow kinetics. Recent studies have shown relationships between ball velocity, elbow torque, and elbow injuries in American professional baseball.[43] Furthermore, within an individual pitcher, reduction in fastball velocity is strongly related to reduced elbow varus torque.[43]

As with all studies, this investigation had limitations. Data were captured in laboratory settings instead of during competition. Although all participants were encouraged to pitch with full effort, the recorded ball velocities were less than game velocities, suggesting that full effort was not achieved. However, reduced ball velocities were noted for both groups tested and compared. Motion analysis has inherent limitations, including marker motion, joint center computation, mass property estimation, and rigid body assumption. Another limitation was the sample size. Although several statistically significant (and clinically relevant) differences were found, some values only approached significance, and testing larger groups may have revealed additional statistically significant differences. Another statistical issue was the chance of type I error due to the number of *t* tests performed, particularly for significant differences with *P* values slightly less than .05. Given our clinical experience and knowledge of pitching biomechanics, we are confident in our interpretation and conclusions of this study; adding more participants in the future may lead to lower *P* values and less concern for false differences. Finally, the Japanese and American pitchers were tested in different facilities, with different equipment and different investigators. Although data were collected with two different motion capture systems, all data were analyzed by the same biomechanical software, minimizing the effect of the different systems.

## CONCLUSION

American pitchers were taller and heavier and generated greater torques, forces, and ball velocities than their Japanese counterparts. Of particular concern was the greater elbow varus torque produced by American pitchers, which may increase the risk of ulnar collateral ligament tear and other elbow injuries. When values were normalized by height and weight, Japanese pitchers generated greater shoulder horizontal adduction torque. In addition, Japanese pitchers displayed greater abduction at the time of ball release. Greater normalized torque coupled with greater abduction angle may imply an increased the risk of shoulder injury. Differences in kinetics between the two groups may be due to variations in pitching kinematics. Further study is needed to determine whether Japanese pitchers may be able to reduce their shoulder torque and risk of injury by shortening their stride, reducing their lead knee flexion, and decreasing their throwing arm abduction.

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