The Effects of Contralateral Trunk Tilt on Elbow Varus Torque in Baseball Pitchers: A Critically Appraised Topic

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Clinical Scenario: Ulnar collateral ligament injuries are common in baseball pitchers, with excessive elbow varus torque linked to medial elbow injuries. Trunk tilt, or motion in the frontal plane, could be an identifiable and modifiable factor in medial elbow loading. Clinical Question: In high school through professional baseball pitchers, how does increased contralateral trunk tilt compared with no/limited contralateral trunk tilt influence elbow varus torque? Summary of Key Findings: Four studies were included: all were labeled as “controlled” or “descriptive laboratory studies,” representing cross-sectional observational analytic design. One study compared biomechanics of professional pitchers with and without ulnar collateral ligament reconstruction. Two studies measured biomechanics in college pitchers, one of which also included simulations of joint angles. The fourth study measured biomechanics of high school pitchers. All studies measured trunk tilt and its relationship to elbow varus torque, with 3 of the studies linking increased contralateral trunk tilt with increased elbow varus torque. Clinical Bottom Line: Moderate evidence indicated as contralateral trunk tilt increased, so did elbow varus torque, indicating trunk tilt may be a modifiable factor to decrease medial elbow loading during pitching. Strength of Recommendation: Majority consistent findings from the level 3 cross-sectional observational analytic designs suggest grade B evidence in support of trunk tilt as a factor in increasing elbow varus torque.

Keywords: biomechanics, motion analysis, valgus load, ulnar collateral ligament

Clinical Scenario

Throwing athletes frequently experience elbow injuries, with the ulnar collateral ligament (UCL) being involved approximately 84% of the time. Differences in pitching mechanics produce varying forces, torques, and velocities at the elbow and shoulder throughout the pitching motion. Elbow varus torque, or moment, is an internal moment created to stabilize and oppose the external valgus load placed on the medial elbow that is generated during the cocking phase of the pitching motion. Excessive elbow varus torque at shoulder maximum external rotation has been linked to medial elbow injuries. This is likely due to the repetitive valgus torques encountered during throwing that the UCL has to withstand. Improper pitching biomechanics, characterized by various kinematic parameters, have been associated with changes in elbow load and general upper-extremity injury risk. Trunk kinematics during pitching is crucial in transferring forces generated from the lower body to the upper body. Trunk tilt, also called trunk lean, is defined as motion or position in the frontal plane and is associated with elbow varus torque. While it is a newer and less known measure, trunk tilt presents an opportunity for an easily identifiable and modifiable factor to reduce UCL loading and possibly injury. The purpose of this critically appraised topic (CAT) was to examine contralateral trunk tilt in baseball pitchers at the point of maximum external rotation, and to identify its influence on elbow varus torque and potentially its effect on elbow injury.

Focused Clinical Question

In adolescent and adult baseball pitchers, how does increased contralateral trunk tilt compared with no/limited contralateral trunk tilt influence elbow varus torque?

Search Strategy and Criteria

Terms Used to Guide Search Strategy

- Patient/client group: High school, college, or professional baseball pitchers
- Intervention/assessment: Increased trunk tilt, contralateral trunk tilt, lateral trunk tilt, or lateral trunk lean
- Comparison: No/limited trunk tilt, contralateral trunk tilt, lateral trunk tilt, or lateral trunk lean
- Outcomes: Increased elbow varus torque, increased injury risk, or increased UCL injury risk

The search was completed April 2020.

Inclusion and Exclusion Criteria

Inclusion Criteria

- Studies that were peer reviewed
Exclusion Criteria

- Studies that assessed position players rather than, or in addition to, pitchers
- Studies that compared trunk rotation or trunk sequencing, rather than tilt, to elbow mechanics
- Studies that used motion capture other than cameras to assess biomechanics
- Studies that did not include elbow varus torque or UCL injury risk

Evidence Quality Assessment

Each study included in this CAT was reviewed with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist.7 Checklist items were marked either present or absent, with a corresponding page number of where in the study it was found. If at least one subsection of a question was found, it was given credit for that checklist item. Each study was also reviewed with the Downs and Black checklist8 to address quality. Each question was determined either present, absent, or “unable to determine,” with a corresponding page number of where in the study it was found. Two authors completed both checklists independently, then reached agreement about each item for each study.

Summary of Search and Key Findings

- The search aimed to identify biomechanical motion analysis studies in a variety of pitching skill levels that examined relationships among trunk tilt and elbow varus torque. Studies used reasonably similar methods and variables to allow for comparison.
- Figure 1 illustrates the search process and results. Of 40 studies identified, 4 studies qualified1-6 and were included for appraisal as shown in Table 1. It is relevant to note that 2 of the studies come from the same research group.3,4 All studies were labeled as “controlled” or “descriptive laboratory studies,” representing cross-sectional observational analytic design.3-6
- One study compared pitching biomechanics, and trunk tilt specifically, between professional pitchers who did and did not have a history of UCL reconstruction.4 The second study used computer simulations and regression analysis to determine effects of lateral trunk tilt angles on shoulder abduction angles and peak elbow varus torque.3 Another study compared pitching biomechanics in high school pitchers who did or did not meet criteria for excessive contralateral trunk tilt.5 The fourth study assessed the association between contralateral trunk position between professional pitchers with and without UCL reconstruction.4 The second study reported that as contralateral trunk tilt increased, the shoulder abduction angle minimizing peak elbow varus torque decreased, with different combinations of trunk tilt and shoulder abduction influencing peak elbow varus torque.3 The third study indicated pitchers with excessive contralateral trunk tilt demonstrated higher ball speed and greater elbow varus moment.5 The last study found increased contralateral trunk lean was associated with increases in elbow varus moment and ball speed.6

Results of Quality Assessment From Best Available Evidence

Studies included 16 to 20 of 22 possible items listed in the STROBE. For Downs and Black, studies included 13 to 20 of 27 possible (Table 1). In the case of controlled laboratory studies that did not include an intervention or control group, many of the questions on the Downs and Black checklist were labeled “unable to determine” because the question did not apply to this kind of study, thus yielding a score of zero for that question.

Clinical Bottom Line

Strength of Recommendation

The 4 studies described in Table 1 represent the best evidence available based on assessing the relationship between contralateral trunk tilt and elbow varus torque. The 4 articles were determined to represent level 3 evidence applying the 2011 Oxford Centre for Evidence-Based Medicine levels of evidence. Though the studies were of lower quality, they were consistent in findings. Collectively, the body of evidence included to answer the clinical question aligns with the strength of recommendation of B.

Answer to Clinical Question

There is moderate, consistent evidence to suggest that trunk motion in the frontal plane is linked to elbow varus torque in pitchers of different skill levels. Specifically, 3 out of the 4 studies found that as contralateral trunk tilt increased, so did elbow varus torque. The fourth study indicated that following UCL reconstruction and rehabilitation, at least in a select group of professional pitchers, trunk tilt and elbow varus torque were not significantly different from uninjured controls. Taken together, there appears to be a relationship between trunk tilt and elbow loading. Trunk tilt may be easily identifiable and...
<table>
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<th>Citation</th>
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<th>Solomito et al&lt;sup&gt;6&lt;/sup&gt;</th>
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<tr>
<td><strong>Study design</strong></td>
<td>Controlled (descriptive) laboratory study</td>
<td>Descriptive laboratory study with computer simulation</td>
<td>Descriptive laboratory study</td>
<td>Descriptive laboratory study</td>
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<td><strong>Participants</strong></td>
<td>80 professional baseball pitchers consented; 77 were tested: 39 UCLr and 38 control.</td>
<td>33 healthy college aged pitchers</td>
<td>73 high school aged pitchers consented, 72 analyzed</td>
<td>99 college pitchers from D1 and D3 NCAA institutions</td>
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<td><strong>Inclusion/ exclusion criteria</strong></td>
<td>During spring training, active pitchers who were competing for a roster position were included. UCLr group limited to 4-y postop, while control group had no history of elbow or shoulder surgery in the throwing arm and were healthy for 12 mo before participating in the study.</td>
<td>Had to be overhand or ¾ hand pitcher.</td>
<td>Ages 13–19, with at least 2 y as a starting or relief pitcher. Accustomed to pitching off a high school regulation mound. Submarine and sidearm pitchers were excluded, as were any pitchers with pain/injury/muscle soreness that prevented them from pitching normally.</td>
<td>At least 2 y of experience, with no serious injury to the pitching arm—defined as missing at least one game or practice within 6 mo of analysis and no history of surgery on the pitching arm.</td>
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<td><strong>Intervention investigated</strong></td>
<td>Twenty-three reflective markers were placed on anatomical landmarks. Participants warmed-up with a teammate in the open field. Participants pitched off a mound at their outdoor training facility. Participants threw 10 fastballs 18.4 m from the mound to a catcher at home plate, similar to a game environment. They were instructed to throw with full effort down the middle of the strike zone. Trials were analyzed without regard to accuracy or velocity.</td>
<td>Twelve reflective markers were placed on anatomical landmarks. Participants were allowed unlimited warm-up. Testing occurred in an indoor laboratory. Participants threw 5–8 fastball pitches toward a strike zone 18.4 m from the pitching rubber. The strike zone was delineated by ribbon on a net over home plate. Participants rested for 30–60 s between pitches. A radar gun measured ball speed.</td>
<td>Forty reflective markers were placed on anatomical landmarks. Participants were allowed unlimited warm-up. Testing occurred in an indoor laboratory, off a custom-built high school regulation pitching mound. Participants completed 5–10 submaximal throws for accommodation. Participants pitched fastballs to a backstop with a strike zone 18.4 m from the pitching rubber. From a wind up, they pitched as fast and accurately as possible to an “X” in the strike zone. Five qualifying pitches were captured, with a minimum of 3 pitches for strikes, indicated by hitting the strike zone. Participants rested 30–60 s between pitches.</td>
<td>Thirty-eight reflective markers were placed on anatomic landmarks. Participants were allowed unlimited warm-up. Testing occurred in an indoor laboratory, from a 10-in high mound to a pitching target with strike zone. Participants threw different pitch types in a random order to simulate a game. Seven fastball pitch trials were collected, with participants throwing from the mound to the strike zone 18.4 m away. The first 3 trials in which all markers were present were analyzed for each participant.</td>
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<td><strong>Outcome measures</strong></td>
<td>Kinematics and kinetics were calculated, including trunk lateral tilt. A calibrated radar gun measured ball speed. Mean values were calculated for each dependent variable across 10 trials for each participant, regardless of velocity or accuracy of the pitch. T tests were applied to test for differences among the groups.</td>
<td>Kinematics and kinetics were calculated, including shoulder abduction angle and lateral trunk tilt. Using the fastest fastball trial, 42 different pitching simulations were created for each participant by varying lateral trunk tilt and shoulder abduction. Angular velocities were kept constant during the motions in order to isolate the effects of the variables on elbow varus torque. Shoulder and elbow forces and torques were calculated for trials and simulations. A series of ANOVAs were performed to assess the effects of shoulder abduction and lateral trunk tilt on elbow varus torque. Peak elbow varus torque was normalized in the simulations to the peak elbow varus torque during motion trials for each participant for qualitative comparison. Correlation coefficients were calculated for the regression models.</td>
<td>Kinematic and kinetic data were calculated. Raters used video to determine instant of maximum shoulder external rotation, then trunk tilt was evaluated at that frame in the frontal plane. Raters determined if the pitcher demonstrated excessive contralateral trunk tilt by examining “whether the side of the pitcher’s head ipsilateral to the throwing limb was deviated from a vertical line passing through the pitchers stride foot ankle by more than a head width.” Those that met this criterion were deemed to have contralateral trunk-flexion angles greater than 25°. Groups with and without excessive contralateral trunk tilt were compared with t tests.</td>
<td>Kinematics and kinetics were calculated, including ball velocity, lateral trunk lean, shoulder internal rotation moment, and elbow varus moment. A random intercept mixed-effects regression model was used.</td>
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### Table 1 (continued)

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<td>Results</td>
<td>Neither shoulder and elbow PROM, nor shoulder and elbow biomechanics were statistically significantly different between the 2 groups. The UCLr group did not appear to be “holding back,” because stride length, horizontal adduction, and forward trunk tilt were not statistically significantly different. The UCLr group did not demonstrate late shoulder rotation or altered trunk and arm position in the frontal plane.</td>
<td>In the simulations, significant interactions were found between shoulder abduction and lateral trunk tilt. As contralateral trunk tilt increased, the shoulder abduction angle minimizing peak elbow varus torque decreased. In simulated motions, 10° of contralateral trunk tilt and 100° of shoulder abduction created the minimum peak varus torque. The combination of 120° of shoulder abduction and 40° of contralateral trunk tilt produced the largest value of peak elbow varus torque.</td>
<td>Excessive contralateral trunk tilt was found in 31 (43%) of pitchers. Pitchers with excessive contralateral trunk tilt had higher ball speed, and experienced a greater elbow varus moment. Pitchers with excessive contralateral trunk tilt demonstrated “greater upper torso contralateral flexion at maximum shoulder external rotation and ball release.”</td>
<td>Total average trunk lean ROM was 24° (10°). When maximum external rotation was reached, pitchers were near maximum lean at 18° (10°). Maximum lean was 19° (10°), around the same time as maximum elbow varus moment. Contralateral trunk lean influenced joint moments more than ball velocity, suggesting “that for every 10° increase over the median contralateral trunk lean at maximum external rotation, the elbow varus moment increased by 3.7 N·m . . . .” At ball release, every 10° increase in lateral trunk lean over the median resulted in a ball velocity increase of 0.4 m/s and elbow varus moment increase of 3.5 N·m.</td>
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<td>Level of evidence</td>
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<td>Downs and Black</td>
<td>20/27</td>
<td>15/27</td>
<td>20/27</td>
<td>13/27</td>
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<td>Contribution to CAT question and conclusion</td>
<td>3—Inconclusive Professional pitchers with UCL reconstruction did not demonstrate any significant differences to a control group in elbow, shoulder, or trunk biomechanics.</td>
<td>4—Moderately conclusive Shoulder abduction between 90° and 100°, and contralateral trunk tilt of 10° and 30° resulted in lower peak elbow varus torque.</td>
<td>4—Moderately conclusive While excessive contralateral trunk tilt was associated with improvements in some aspects of pitch performance, it was also associated with increased elbow varus moment.</td>
<td>4—Moderately conclusive Increased contralateral trunk lean may increase ball velocity, but it also increased elbow varus moment.</td>
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Abbreviations: ANOVAs, analysis of variances; CAT, critically appraised topic; NCAA, National Collegiate Athletic Association; PROM, passive ROM; ROM, range of motion; STROBE, Strengthening the Reporting of Observational Studies in Epidemiology; UCL, ulnar collateral ligament; UCLr, UCL—reconstructed.
modifiable with intervention, providing a mechanism to decrease elbow varus torque and hopefully protect the elbow.

**Implications for Practice, Education, and Future Research**

Injuries to the throwing arm, specifically the shoulder and elbow, are common in pitching. Medial elbow injuries are most likely to occur in pitchers when high forces and/or torques are applied repeatedly to vulnerable tissues, such as the UCL, when moving through arm cocking and acceleration phases. At the point of maximum shoulder external rotation in pitching, the medial elbow is at risk of injury due to the maximum elbow varus torque that is produced to counteract the external valgus force experienced by the UCL. Specifically, of the 90 N·m of elbow varus torque produced during pitching, about 50 N·m is created through tension in the UCL.

In biomechanical and cadaveric studies, the UCL reached tissue failure around 32 to 34 N·m of tensile force, yet, during pitching elbow varus moments can exceed 60 N·m. To throw successfully, a pitcher must perform a coordinated sequence of movements in consecutive body segments that transfer forces from the legs up the kinetic chain to the distal segments of the upper extremity. In previous biomechanical studies, poor pitching mechanics increased loads and torques experienced at the shoulder and elbow, which was interpreted as increasing upper-extremity injury risk. A number of kinematic factors have been linked to increased upper-extremity injury risk including foot position on contact, pelvic rotation timing, trunk rotation timing, arm slot, shoulder range of motion, and arm speed, but one factor that has not been studied as much is trunk movement in the frontal plane. Lateral trunk tilt away from the pitching arm (ie, contralateral trunk tilt) shifts the trunk axis of rotation away from the pitching arm, thus increasing the lever arm and the torques experienced at the elbow. If biomechanical factors, such as trunk position in the frontal plane, place the elbow at higher risk of injury by increasing valgus loading and the varus torque response, coaching and training methods designed to correct these mechanics may decrease risk of UCL injury.

Articles in this CAT were all level 3 evidence and had moderate to high scores for both STROBE and Downs and Black. Items that were missing from the checklists were mainly due to the type of studies that we included. Oyama et al, Solomito et al, and Matsuo and Fleisig all generally found that as contralateral trunk tilt increased, the amount of elbow varus torque increased. In addition, Matsuo and Fleisig assessed shoulder abduction and trunk tilt and their interactions. Using captured pitching trials, they simulated the elbow varus torque when pitching with combinations of shoulder abduction angle (70°, 80°, 90°, 100°, 110°, and 120°) and trunk tilt angle (−20°, −10°, 0°, 10°, 20°, 30°, and 40°). From simulations, there was a significant interaction between lateral trunk tilt and shoulder abduction. Based on the analysis, the lowest peak varus torque was found at 100° of shoulder abduction and 10° of contralateral trunk tilt, while the greatest torque was at 120° of shoulder abduction and 40° of contralateral trunk tilt. Overall, when shoulder abduction was between 90° and 100°, and contralateral trunk tilt was 10° to 30°, peak elbow varus torque was low.

Oyama et al built off of Matsuo’s research to determine biomechanical implications of excessive contralateral trunk tilt, defined as exceeding 25° of tilt. Pitchers who demonstrated excessive contralateral trunk tilt produced a higher ball speed, but also experienced approximately 10% greater elbow joint loading. A similar relationship was found in Solomito et al that for every 10° increase in contralateral trunk tilt, elbow varus torque increased by 3.7 N·m, and ball velocity increased by 0.4 m·s⁻¹. While increased ball velocity may be viewed as a desirable outcome, the authors indicated the trade-off of greater injury risk from the increased elbow varus torque would not be preferred. All 3 articles showed a positive relationship between increased contralateral trunk tilt and increased elbow varus torque; however, there were some differences. Each study used a different pitching population (professionals with/without UCL injury, college, or high school); marker sets; testing protocol (location, mound type, pitch type, and number of pitches collected); and variables of interest (contralateral trunk tilt, shoulder and elbow biomechanics, ball speed, elbow varus moment, etc), making it somewhat difficult to compare results directly. Results reported in the studies may not be applied to broader populations or settings, but trunk tilt does seem relevant to pitching mechanics. Based on clinical studies indicating that up to 33% of professional pitchers do not return to their preinjury level following UCL reconstruction, Fleisig et al compared the biomechanical profiles of professional pitchers who had undergone UCL reconstruction compared with those who had not. For the purpose of this study, only pitchers who were no longer in rehabilitation and were competing for an active spot on the roster were included. The authors did not find any statistically significant differences in elbow varus torque or trunk tilt among the groups, which they interpreted as the UCL reconstructed group being fully recovered or “not holding back.” However, pitching biomechanics were not collected from the UCL reconstruction group before injury, so no baseline comparisons could be drawn, and the authors did not directly compare the relationship between trunk tilt and elbow varus. While it is encouraging that professional pitchers who successfully returned to play after reconstruction and rehabilitation had similar biomechanical profiles to their otherwise healthy counterparts, it remains unclear what is occurring with contralateral trunk tilt in the 33% of pitchers who do not return to play.

Elbow varus torque appears to be influenced by the interaction of contralateral trunk tilt, arm slot, and shoulder abduction angle. Arm slot is defined as the position of the arm in the frontal plane at the time of ball release and is typically categorically classified as overhand, 3-quarter, and sidearm. Using collected data and simulations, elbow varus torque was altered based on changing or holding constant contralateral trunk tilt and shoulder abduction angle. However, their relationship with arm slot is not clear or well defined in the literature. In a study by Escamilla et al, higher arm slot (ie, the arm angle relative to vertical) was correlated to an increase in elbow varus torque. If the higher arm slot is reflective of the greater contralateral trunk tilt angle, their finding supports the results from the studies discussed in this CAT. However, the authors did not measure trunk tilt directly; thus the Escamilla study was not included in this paper. Alternately, Aguinaldo and Chambers reported that the lower shoulder abduction angle (ie, angle of the arm relative to trunk) was correlated with higher elbow external valgus torque. To date, studies have not separated or consistently identified contralateral trunk tilt, arm slot, and shoulder abduction angle. Knowing this interaction exists, suggests future research may need to better clarify the role of contralateral trunk tilt, arm slot, and shoulder abduction angle, to determine comprehensive factors influencing or related to peak elbow varus torque.
Based on the 4 studies included, there are realistic and easily applicable strategies athletic trainers, coaches, and strength and conditioning personnel can adopt to reduce joint loading at the elbow and potentially injury risk for the UCL. Pitchers may adopt excessive contralateral trunk tilt as a compensatory mechanism secondary to previous injuries or weakness of hip and abdominal musculature, or limitations in hip or trunk range of motion.\textsuperscript{5} Shifting the trunk axis of rotation away from the pitching arm (increasing contralateral trunk tilt) effectively creates a longer radius that increases the moment at both the shoulder and elbow. This allows for the pitcher to increase their forward velocity by increasing the radius between the ball and the axis of rotation, which can increase ball velocity.\textsuperscript{6} A preseason or in-season assessment of hip and spine mobility and strength, with appropriate strengthening drills and/or mobility work to address deficits, may minimize the need for compensatory trunk tilt.\textsuperscript{1,5} Identifying excessive trunk tilt may be possible with easily accessible video equipment, rather than research-grade cameras. As an example, Oyama et al\textsuperscript{5} rerated the videos from the first 30 pitchers tested in their study from a research-grade camera frame rate (300 frames per second) to an off-the-shelf commercially available camera rate (60 frames per second) and found strong agreement between calculated values of trunk tilt. If excessive trunk tilt is identified, verbal or visual cues may improve trunk mechanics during pitching. Maintaining a more upright posture, keeping the upper torso slightly flexed at stride foot contact, emphasizing the need to rotate the upper torso toward the target, or bringing the focus to trunk movement in the transverse, not frontal, plane may help.\textsuperscript{5} It is important to note, however, that the efficacy of these strategies at reducing joint loading or injury risk has not been demonstrated. In addition, if these strategies were implemented, the effects on ball velocity are unknown at this time. Future research should identify other strength or functional factors that may contribute to adoption of excessive contralateral trunk tilt, so that targeted interventions may be developed.

Overall, understanding what modifiable risk factors influence medial elbow loads, such as contralateral trunk tilt, will help drive the development of clinical interventions used to reduce injury risk. Contralateral trunk tilt is one potentially easily identifiable and modifiable factor that an athletic trainer or pitching coach can address to reduce the elbow moments and, theoretically, UCL injury risk. This CAT should be reviewed in 2 years to determine if there are additional studies providing evidence that would alter the clinical bottom line.

Acknowledgment

The authors have no conflicts of interest to declare.

References


