Functional Isokinetic Strength Ratios in Baseball Players With Injured Elbows

Yin-Chou Lin, Angela Thompson, Jung-Tang Kung, Liang-Wei Chieh, Shih-Wei Chou, and Jung-Charng Lin

Context: Elbow injuries are widely reported among baseball players. The elbow is susceptible to injury when elbow-flexor and -extensor forces are imbalanced during pitching or throwing. Assessment of muscle-strength ratios may prove useful for diagnosing elbow injury. Objective: The purpose of this study was to assess the relationship between the elbow-flexor and -extensor functional isokinetic ratios and elbow injury in baseball players. Design: Retrospective study. Setting: Biomechanics laboratory. Participants: College baseball players with (n = 9) and without (n = 12) self-reported elbow pain or loss of strength were recruited. Intervention and Main Outcome Measures: Trials were conducted using a dynamometer to assess dominant-arm flexor and extensor concentric and eccentric strength at angular velocities of 60° and 240°/s. Functional isokinetic ratios were calculated and compared between groups. Results: Regression analysis revealed that a ratio of biceps concentric to triceps concentric strength greater than 0.76 (the median value) significantly predicted elbow injury (P = .01, odds ratio of injury = 24). No other ratios or variables (including position played) were predictive of injury status. Conclusions: These findings suggest that the ratio of biceps concentric to triceps concentric functional strength strongly predicts elbow-injury status in baseball players. Assessment of this ratio may prove useful in a practical setting for training purposes and both injury diagnosis and rehabilitation.

Keywords: triceps, biceps, concentric, eccentric

Elbow injuries are a common phenomenon in baseball. Indeed, Lyman et al reported that just over a quarter of youth baseball players experienced elbow pain. The lost playing time, surgery, and rehabilitation associated with these injuries cost millions of dollars every year.

Biomechanical studies have revealed that the elbow moves from flexion to extension during the acceleration phase of throwing at an angular velocity of more than 2000°/s. The medial tensile force produced by elite pitchers has been
estimated to approach and even exceed the maximum tensile strength of the ulnar collateral ligament.\cite{6} As the shoulder approaches maximum external rotation, a simultaneous medial tensile stress and lateral compressive force are transmitted to the elbow and posterior joint capsule.\cite{7} Near the maximum shoulder external rotation and arm cocking, the elbow musculature eccentrically contracts, producing significant elbow varus torque to resist valgus torque.\cite{5,6} As the shoulder moves into the acceleration phase and the elbow rapidly extends, the combination of varus torque (partly from the biceps and triceps compressive forces) and elbow extension leads to the mechanism responsible for valgus extension and potential elbow injury.\cite{6}

Concentric strength is important during the acceleration phase of a pitch, whereas eccentric strength is essential during the follow-through phase. At the moment of release, significant energy and momentum are transferred to the ball and throwing arm. After release, the upper limb muscles contract eccentrically to decelerate the rapidly moving arm, while the muscles controlling the shoulder and elbow produce large compressive forces to resist joint distraction. Both joints are susceptible to injury during this deceleration phase.\cite{3} Indeed, it is generally accepted that many throwing injuries to baseball pitchers occur during the follow-through phase of the pitch, when muscles are contracting eccentrically to facilitate limb deceleration.\cite{8}

When a sporting injury occurs, clinicians treat it by finding the weakest point and strengthening it. However, during throwing (as already noted), there are a number of muscle groups acting in concert. Measuring peak force alone may not identify a weakness, because isolating a muscle group does not imitate actual muscle use. It is our contention that throwing-related elbow injuries may occur because of a relative weakness/strength imbalance and that this should be identifiable by comparing the functional isokinetic ratios\cite{9} of the 2 muscle groups involved in the throwing motion. There has only been 1 report published concerning isokinetic concentric and eccentric strength ratios for elbow extensors and flexors in healthy pitchers,\cite{10} and no study to date has evaluated such ratios in baseball players with injured versus noninjured elbows. Hence the purposes of this study were to assess elbow-flexor and -extensor concentric and eccentric strength, related functional isokinetic ratios, and the relationship of these variables to existing elbow-joint injury in baseball players.

**Materials and Methods**

**Participants**

All male baseball players on a university team were approached to take part in the study, which was conducted during preseason training. The inclusion criteria were subjective complaints of elbow pain or discomfort or loss of strength. Players who experienced excessive pain during testing and were unable to complete the procedure were excluded from analysis. A total of 23 subjects ultimately took part in the study. All subjects provided written informed consent before taking part in the study.
Procedures

Peak torque of concentric and eccentric elbow extensors and flexors was assessed for both arms of each subject at angular velocities of 60° and 240°/s. These angular velocities represent explosive muscle power and endurance, respectively. A Cybex Norm dynamometer (Cybex International, Inc, Ronkonkoma, NY) was used for these measurements. The dominant hand was defined as that preferentially used for pitching and throwing.

After a 15-minute general warm-up of jogging on a treadmill at a comfortable speed and stretching the major muscle groups, all subjects were given a brief explanation of testing procedures and the possible side effects. They then performed a submaximal trial to become familiar with the isokinetic device and testing conditions (see Figure 1). Calibration during testing was checked using the dynamometer’s calibration program. All measurements were gravity compensated for limb weight. During elbow-flexion and -extension testing, the subjects were tested in a supine position with restraining straps placed across their shoulders and waists. The arm

Figure 1 — Experimental setup. Subjects were tested in a supine position with restraining straps placed across their shoulders and waists. The arm was positioned next to the torso at 0° to 10° of abduction. The forearm was pronated 90° such that the hand was in a neutral position.
was positioned next to the torso at 0° to 10° of abduction. The forearm was pro-
nated 90° such that the hand was in a neutral position. Pads were placed behind
and lateral to the elbow to eliminate extraneous movement. The concentric and
eccentric strength of the dominant arm were tested in the following order: elbow
flexion, elbow extension. Subjects performed 3 sets of 5 repetitions of maximum
contraction at a speed of 60°/s and 20 repetitions of maximum contraction at a speed
of 240°/s. The rest interval between maximum contractions was 30 seconds. The
rest interval between test-speed changes and muscle groups was 5 minutes. The
concentric and eccentric torque curves demonstrating the greatest torques were
chosen to represent a subject’s maximal strength at that speed.

The following ratios were computed for both arms of each subject: biceps
congentric:biceps eccentric, triceps concentric:triceps eccentric, biceps con-
centric:triceps concentric, biceps eccentric:triceps eccentric, triceps concentric:
biceps concentric, and biceps concentric:triceps eccentric. These ratios were previously
reported by Mikesky et al.10

Statistical Analysis
Continuous variables are presented as mean ± SD, and categorical variables are
given as the frequency (percentage). Epidemiological data were compared using
either a Student t test or a chi-square test. Logistic (univariate and multivariate)
regression analysis was performed for each angular velocity (including the variables
pertaining to muscle torque and strength ratios) to establish a predictive model for
elbow injury. Some continuous variables (namely, the ratios of biceps eccentric
to biceps concentric, biceps concentric to triceps concentric, triceps eccentric to
triceps concentric, and biceps concentric to triceps concentric) were nonnormally
distributed and transformed to categorical variables for analysis. For these vari-
ables, median values were used as cutoff points for analysis. All statistical analysis
was performed using SAS software version 9.1.3 (SAS Inc, Cary, NC), and the
“proc logistic” procedure was performed. The best predicted model was selected
by stepwise extraction. All tests were 2-sided, and differences were considered
significant when P < .05.

Results
The study population included 11 pitchers, 5 of whom complained of elbow pain or
discomfort, and 14 nonpitchers, 4 of whom complained of elbow pain or discomfort.
Of the 5 injured pitchers, 1 had undergone previous surgical reconstruction of the
ulnar collateral ligament. Other injured pitchers complained of medial elbow pain
and loss of strength.

The epidemiological characteristics of the 21 subjects included for analysis are
presented in Table 1. There were no significant differences between the injured and
noninjured groups for any of these variables. Data from 2 of the initial 23 subjects
were excluded from analysis because their eccentric to concentric strength ratios
were extremely high (5.44 and 7.43, respectively, vs values ranging from 1.20 to
3.35 in the other subjects). These high ratios were most likely the result of inap-
propriate equipment use.

Findings from the univariate analysis examining predictors of elbow injury
with regard to the trials conducted at 60°/s are presented in Table 2. None of the
Table 1  Epidemiological Characteristics of the Subjects (N = 21)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total</th>
<th>Noninjured</th>
<th>Injured</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age^a</td>
<td>19.90 ± 1.22</td>
<td>20.17 ± 1.34</td>
<td>19.56 ± 1.01</td>
<td>.27</td>
</tr>
<tr>
<td>Height^a</td>
<td>177.3 ± 5.38</td>
<td>177.75 ± 4.75</td>
<td>176.78 ± 6.38</td>
<td>.18</td>
</tr>
<tr>
<td>Weight^a</td>
<td>76.59 ± 9.05</td>
<td>74.28 ± 7.49</td>
<td>79.67 ± 10.43</td>
<td>.69</td>
</tr>
<tr>
<td>Position^b</td>
<td></td>
<td></td>
<td></td>
<td>.79</td>
</tr>
<tr>
<td>pitcher</td>
<td>10 (47.62)</td>
<td>5 (41.67)</td>
<td>5 (55.56)</td>
<td></td>
</tr>
<tr>
<td>outfielder</td>
<td>4 (19.05)</td>
<td>2 (16.67)</td>
<td>2 (22.22)</td>
<td></td>
</tr>
<tr>
<td>infielder</td>
<td>5 (23.81)</td>
<td>4 (33.33)</td>
<td>1 (11.11)</td>
<td></td>
</tr>
<tr>
<td>catcher</td>
<td>2 (9.52)</td>
<td>1 (8.33)</td>
<td>1 (11.11)</td>
<td></td>
</tr>
<tr>
<td>Dominant arm^b</td>
<td></td>
<td></td>
<td></td>
<td>.40</td>
</tr>
<tr>
<td>left</td>
<td>7 (33.33)</td>
<td>3 (25.00)</td>
<td>4 (44.44)</td>
<td></td>
</tr>
<tr>
<td>right</td>
<td>14 (66.67)</td>
<td>9 (75.00)</td>
<td>5 (55.56)</td>
<td></td>
</tr>
</tbody>
</table>

Values are mean ± SD or frequency (percentage).
^a Analyzed by Student t test.
^b Analyzed by chi-square test.

Table 2  Results of the Univariate Regression Analysis for Predictors of Elbow Injury as Indicated by Trials at 60°/s

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds ratio</th>
<th>95% confidence interval</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque measurement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>biceps concentric</td>
<td>0.91</td>
<td>(0.81, 1.03)</td>
<td>.14</td>
</tr>
<tr>
<td>biceps eccentric</td>
<td>0.94</td>
<td>(0.86, 1.03)</td>
<td>.20</td>
</tr>
<tr>
<td>triceps concentric^a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤1.33</td>
<td>1.00</td>
<td>reference</td>
<td>—</td>
</tr>
<tr>
<td>&gt;1.33</td>
<td>0.57</td>
<td>(0.10, 3.27)</td>
<td>.53</td>
</tr>
<tr>
<td>triceps eccentric</td>
<td>0.96</td>
<td>(0.88, 1.04)</td>
<td>.29</td>
</tr>
<tr>
<td>Strength ratio</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>biceps eccentric to biceps concentric</td>
<td>1.71</td>
<td>(0.01, 224.45)</td>
<td>.83</td>
</tr>
<tr>
<td>triceps eccentric to triceps concentric</td>
<td>0.94</td>
<td>(0.85, 1.05)</td>
<td>.30</td>
</tr>
<tr>
<td>biceps concentric to triceps concentric^a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤0.81</td>
<td>1.00</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>&gt;0.81</td>
<td>1.25</td>
<td>(0.22, 7.08)</td>
<td>.80</td>
</tr>
<tr>
<td>biceps eccentric to triceps eccentric</td>
<td>0.35</td>
<td>(0.01, 56.87)</td>
<td>.69</td>
</tr>
<tr>
<td>biceps eccentric to triceps concentric</td>
<td>0.73</td>
<td>(0.01, 97.52)</td>
<td>.90</td>
</tr>
<tr>
<td>triceps eccentric to biceps concentric</td>
<td>3.53</td>
<td>(0.09, 136.46)</td>
<td>.50</td>
</tr>
</tbody>
</table>

^a Nonnormally distributed data.
torque measures or strength ratios significantly predicted injury at this speed. The multivariate-regression findings were identical to the univariate (data not shown).

Findings from the univariate analysis examining predictors of elbow injury with regard to the trials conducted at 240°/s are presented in Table 3. At this speed, a biceps concentric to triceps concentric ratio of greater than 0.76 (the group median) was found to be significantly associated with an increased risk of elbow injury ($P = .01$). The biceps eccentric to triceps concentric ratio was a borderline ($P = .07$) predictor of elbow injury. No other measures were predictive of elbow injury at this speed. The multivariate-regression findings were identical to the univariate (data not shown).

### Discussion

The primary aim of the current study was to examine the relationship between elbow-flexor and -extensor functional isokinetic strength ratios and elbow injury in a cohort of injured and uninjured baseball players. We determined that a biceps
concentric to triceps concentric strength ratio of more than 0.76 was strongly predictive of elbow injury.

Electromyographic studies of baseball pitchers have revealed that the antagonist muscles fire eccentrically to decelerate motion of the agonists and play a critical role in facilitating dynamic stabilization and optimal function.\textsuperscript{8,11–13} It would seem that assessment of the functional ratio may provide a more accurate means to evaluate realistic dynamic joint stability. In the current study, we noted that increased dominant-arm flexor concentric to extensor concentric ratios (>0.76) were highly predictive of elbow injury at an angular velocity of 240°/s but not 60°/s. This finding was independent of field position and hand dominance and indicates that the injured subjects had relatively weaker triceps than biceps concentric muscle strength at higher angular velocities. Presumably, the lack of an effect at 60°/s is a result of the fact that this angular velocity is too low and less reflective of a realistic throwing motion.

The elbow joint is most vulnerable to injury at the time of maximum external shoulder rotation and the follow-through phase after the ball has been released.\textsuperscript{3,8} The higher ratios of flexor concentric to extensor concentric associated with elbow injury indicate relatively weaker extensor concentric strength. It is unclear how the ratio of elbow-flexor to -extensor concentric strength correlates with the prevention of elbow injuries during the acceleration–deceleration phase of throwing in which the biceps acts eccentrically and the triceps remains relatively quiet. However, it remains clinically important for injury prevention and rehabilitation to optimize a proper strength balance before a return to throwing.

We found that neither elbow-flexion nor -extension peak torque values were predictive of elbow injury, regardless of the speed at which the trials were performed. This finding indicates that injured baseball players cannot be differentiated from their uninjured peers by measuring peak force only. We suggest that peak torque, the most widely assessed isokinetic strength parameter, does not provide an adequate measure of functionality in baseball players.

The ratios of biceps concentric to biceps eccentric strength and biceps eccentric to triceps eccentric strength were not significantly predictive of elbow injury at 240°/s. These ratios compare 2 opposing motions that cannot be performed simultaneously. Our findings indicate that there was not an imbalance between these 2 ratios and that these ratios are therefore not related to elbow injury. These results agree with those reported by Mikesky et al.\textsuperscript{10}

We further noted that the ratio of biceps concentric to triceps eccentric strength assessed at 240°/s was not a significant predictor of elbow injury. This finding is not unexpected considering that the biceps works mostly eccentrically during the act of throwing.

The ratio of biceps eccentric to triceps concentric strength was a borderline significant predictor of elbow injury in this study ($P = .07$). This finding may be related to the fact that during the follow-through phase of throwing the biceps acts in an eccentric manner to decelerate the concentric force generated by the triceps.

It has been postulated that explosive power in a pitch is more related to low speed, and endurance is related to high speed.\textsuperscript{14} Hence a player may have satisfactory explosive power but lack endurance and consequently be exposed to an increased risk of injury from the repetitive act of throwing. It would be of significant value if functional ratio assessment could be used to distinguish precisely what is wrong
with the elbow before resorting to more expensive or invasive diagnostic means. Future studies are warranted to determine whether strengthening the extensor and flexor muscles at a high angular speed prevents elbow injury or facilitates recovery in baseball players.

This study has several limitations. First, the assessment exercise used does not result in muscle contraction identical to that associated with throwing, per se. However, currently this is one of the most accurate ways to measure muscle strength. Second, in reality pitchers throw at speeds much greater than $240^\circ/s$. Hence the relevance of our findings could be strengthened by creating conditions more comparable to the real pitching motion. Third, our testing of the elbow at $0^\circ$ of abduction may not allow for accurate generalizations of performance during the early and late cocking phases of the pitching process, when the elbow is flexed and the wrist pronated, both of which may influence biceps strength because of changes in the muscle length–tension relationship. A further limitation is the relatively small and nonrandomly selected population sample. Finally, the elbow injuries were self-reported, nonhomogeneous, and not clinically diagnosed.

Conclusions

In summary, our findings suggest that the ratio of biceps concentric to triceps concentric functional strength strongly predicts elbow injury (or lack thereof) in baseball players. Although larger-scale trials are warranted to confirm this finding, assessment of this ratio may prove useful in a practical setting for training purposes and both injury diagnosis and rehabilitation.

References


