EFFECT OF FOREARM POSTURE ON THE ELBOW VARUS TORQUE GENERATED BY THE FLEXOR PRONATOR MUSCLES: IMPLICATIONS FOR THE ULNAR COLLATERAL LIGAMENT

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INTRODUCTION

Overhead throwing is the primary task for athletes who play the position of pitcher in the sport of baseball. While pitching, extreme levels of valgus torque are generated at the elbow and this creates stress on the elbow structures opposing valgus loads, including the ulnar collateral ligament (UCL) [1]. Accordingly, extreme valgus torque has been highly correlated with serious elbow injury [2].

Previous work has demonstrated that the flexor pronator muscles of the arm (Flexor Digitorum Superficialis, Flexor Carpi Radialis, Flexor Carpi Ulnaris, and Pronator Teres) are primary contributors to varus torques that counter applied valgus torques [3, 5]. These muscles originate on the ulnar side of the distal humerus and have been shown to be highly active during pitching [4]. Additionally, experimental work in cadavers has revealed that tension in these muscles relieves stress on the UCL and can protect it from failure [5].

While research studies have effectively established that the flexor pronator muscles are capable of adding stability to the elbow joint, these analyses have focused on a single, neutral, forearm posture [e.g., 3]. This is problematic for understanding the potential for these muscles to reduce injury risk in pitching because baseball players modify forearm posture to throw different pitches [6]. Moreover, pitches that require a supinated forearm, such as the slider, have been associated with a large increase in elbow injury risk [7].

The purpose of this study was to use a biomechanical model to quantify the effect of forearm posture on the capacity of the flexor pronator muscles to generate varus elbow torque. We hypothesized that specific forearm postures would reduce the varus torque capacity, thereby increasing the risk of UCL failure in those postures.

METHODS

To evaluate the effect of forearm posture on the elbow varus torque generated by the flexor pronator muscles, we modified an existing biomechanical model [8] to include a varus axis of rotation at the elbow. Using this model, we calculated the isometric elbow varus torque produced by each muscle as a function of forearm pronation-supination angle. Analyses were completed using the Software for Interactive Musculoskeletal Modeling (SIMM; Musculographics, Inc.; Santa Rosa, CA). We then used a varus-valgus torque balance to examine how different levels of muscle torque would impact the load on the UCL and the risk of ligament failure.

We implemented the axis of rotation for varus-valgus used in the elbow model described by Buchanan et al. (1998) and calculated the isometric elbow varus torques generated by each of the four forearm flexor pronator muscles at (i) its activation level observed during pitching [4], and (ii) maximum activation. Muscle torques were calculated at one degree increments across the full range of motion for pronation-supination while the elbow was positioned at 90° of flexion, the approximate elbow posture adopted while pitching [6]. An individual muscle torque (T_i) was calculated as the product of muscle force (F_i) at the appropriate activation level (α), and moment arm (L_i). That is,

$$(1) \quad T_i(F_i, L_i) = \alpha F_i(l_m(\theta)) * L_i(\theta) ,$$

where the modeled muscle force varies with fiber length (l_m), which varies with forearm rotation angle (θ) [8]. The total, isometric, varus torque produced by the flexor pronator muscles (T_{mus}) was computed as the sum of the individual torques.

We used a torque balance about the varus axis to estimate the torque load imposed on the UCL for both muscle activation patterns evaluated. A preliminary cadaveric study (in which muscles were removed via dissection) reported that external valgus loads (T_{val}) were opposed by the UCL (T_{UCL}), the joint capsule (T_{cap}), and the osseous structures of the joint (T_{oss}) [9]. Thus,

$$(2) \quad T_{UCL} = T_{val} - T_{mus} - T_{cap} - T_{oss} \; ,$$

given the capacity of the flexor pronator muscles to generate a stabilizing varus torque (T_{mus}). The cadaveric study reported that the joint capsule and the osseous structures generated a torque equal to 43% of the applied load [9]. Assuming loading of these structures maintains this proportion across valgus loads, an external valgus load of 100 Nm, and the isometric torque-angle profiles calculated using the biomechanical model, we solved for the resulting T_{UCL}. Valgus loads during pitching have been reported to range from 64 to 120 Nm [1].

To quantify the risk of UCL failure, we calculated a safety factor for the UCL as the ratio of the torque associated with UCL failure (34 Nm) [10] to T_{UCL}. Thus, at a safety factor of 1, the UCL experiences its failure torque.

RESULTS AND DISCUSSION

During pitching, it has been shown that the forearm angle is often between 13° and 25° supination [6], which corresponds to between 23 Nm and 24 Nm of varus muscle torque, assuming the muscle activation levels used during pitching (Fig. 1). For varus muscle torques in this range, the UCL safety factor ranged between 1 and 1.03. Supination beyond 25° further decreased the muscle varus torque, suggesting the UCL would experience loads greater than the reported failure limit. To achieve a UCL safety factor of 8, which is considered typical of ligaments [11], the muscles must exert 53 Nm of torque in a supinated posture. Even at maximum activation, the muscles exerted at most 32 Nm in a pronated position, which would correspond to a UCL safety factor of only 1.4 and a forearm position not typically used during pitching (Fig. 1).

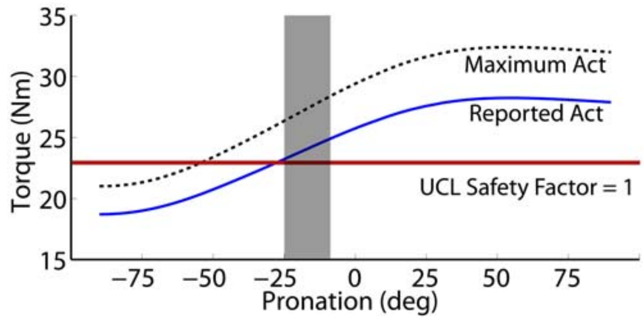

Figure 1. Total isometric varus muscle torque vs. forearm angle at muscle activations reported for pitching (blue curve) and at maximum activations (black dotted curve). Negative angles indicate supination. The shaded gray area represents the range of postures often used when pitching. The red line represents the muscle torque level that results in a UCL safety factor of 1.

A limitation of our study is that pitching is a dynamic task, while our study was a quasi-static analysis. However, changes in the kinematics of the arm would result in changes to the torque capacity regardless of the dynamics of the system.

CONCLUSIONS

Regardless of forearm posture, our biomechanical analysis suggests a 100 Nm valgus load at the elbow is associated with dangerous levels of loading for the UCL. Our results are consistent with a study that reported serious elbow injuries occur to pitchers who experience this loading level [2].

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